The Role of Local Community Institutions in the Adaptation of Rural and Urban Communities to the Impacts of Climate Change on Water Access and Use

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by

Renias Dube, Beatrice Maphosa and Judy Scott-Goldman
Hydrosoft Institute

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Obtainable from

Water Research Commission
Private Bag X03
Gezina
0031

orders@wrc.org.za or download from www.wrc.org.za

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Executive summary

Background

There is indisputable evidence that the global climate is changing (IPCC, 2012). While climate change is global, the nature of impacts is specific to each location. The implications of these impacts depend on the circumstances of those who are exposed. In South Africa, as in most of Africa, the communities are more exposed to climate change impacts than their counterparts in developed countries. The majority of the population in developing countries is not equipped to deal with commonly encountered adverse climate impacts. This situation is worsened by the less predictable convoluted climate, whose changes continue to be poorly understood and interpreted. As our climate continues to take on new characteristics due to both natural and anthropogenic factors, the implications of these changes or rather the feedback mechanisms are even further away from being understood. The latest IPCC report, (IPCC, 2012), describes a system of complex climatic feedbacks, clustered and compound climatic events whose implications are said to be a grey area that is characterised by inadequate information and knowledge.

The task of meeting water access targets for all communities in South Africa is complicated by the general lack of services which continue to dominate the current planning and development agenda. Responsible authorities and institutions are slow and hesitant to include climate change, mitigation and adaptation in their agendas as they battle to deal with the current water access crisis as just one of many other immediate challenges. It is against this background that the study sought to investigate the circumstances which surround water access in communities before dealing with issues of climate change and climate change adaptation in water access.

Rationale

Southern Africa is home to a large segment of population relying on climate-sensitive economic activities such as rain-fed subsistence agriculture (Connor et al., 2009). Like many other developing countries, South Africa is struggling to cope with the burdens associated with disease, conflict and mismanagement of natural resources. These factors, combined with limited human, economic and infrastructural capacity, exacerbate the impacts of climate variability and change.

The vulnerabilities of both rural and urban communities to climate change impacts are widely varied and still poorly understood. The existing local institutions are under-capacitated and not ready to take on the additional burden of supporting climate change adaptation measures. Institutional support for community adaptation to climate change could be delivered with little need for additional resources if the adaptation initiatives were built into ongoing programmes. The development of mechanisms for ensuring that relevant institutions can support communities in adapting to climate change challenges is already overdue. The need to develop a generic framework of institutional support for communities as they adapt to climate change has been identified in past WRC engagements with relevant stakeholders. The development of a framework for adaptation can only be successfully accomplished, when all constraining variables are researched and understood. The development of a climate change adaptation framework focusing on local communities can only be undertaken when all the key building blocks have been identified. These building blocks include the following:

- Comprehensive maps of climate change vulnerability at community level;
- Knowledge base of climate change as an additional stressor that must be considered as part of several complex stressors in water access and use;
- Long-term goals for community water access and use. This could entail integrating the 'bottom-up' approach, where the goals, as set out by community members, are central, and the top-down approach based on how water access is articulated by the institutions expected to serve communities;
- Capacities of communities and institutions. Communities that are exposed to specific climate change impacts have some ability to adapt; in addition, institutions have the capacity to provide some level of support in the process of adaptation. Ideally, if these capacities are correctly coupled, they will generate the much-needed synergy;
- Toolboxes of possible adaptation measures. These include an inventory of possible adaptation measures, outlining the roles and responsibilities of various institutions, as well as identifying the gaps in the provision of community support;
- Policy and legal frameworks for supporting climate change adaptation; and
- Community reception mechanisms for adaptation measures and community buy-in. An understanding of the dynamics of ownership and empowerment through direct community and institutional involvement is needed to ensure sustainability of developed solutions.

Objectives

The overall goal in the study is to develop methods that could be used by relevant water sector institutions to support local communities in adapting to climate change impacts on water access and use. The methodology was expected to take the form of an adaptation framework for climate change impacts. The project goal was divided into study objectives, as follows:

1. To identify water use-related climate change responses by local communities and define the role of institutions in ensuring adaptive capacity of those communities;

2. Baseline investigation into the degree and level of vulnerability imposed on communities due to climate change impacts and their responses;

3. Baseline investigation into the role of institutions in supporting communities' livelihoods;

4. Conduct needs analysis on community livelihoods and rural institutions;

5. Develop appropriate analytical tool(s) on environmental risks, reductions in livelihood opportunities and stresses on existing resources and social institutions;

6. Identify and develop policy framework for communities' adaptation practices, including migration, diversification and other adaptation options, in response to climate change impacts; and

7. Undertake piloting in a rural setting and at urban community level to clarify roles of local institutions in the adaptation actions of communities dealing with climate change impacts on water supply.

Case studies and field work

In the study a 'bottom-up' approach was used as the starting point. The aim was to understand the nature of water access and use, climate change impacts, adaptation capacity and community sensitivity to exposure and vulnerability of communities within their own environment, before investigating current and future roles of institutions in supporting water access and use. The investigations led to the development of a climate change adaptation framework. This framework is set to become the platform whereby institutions can holistically access community needs and provide suitable support mechanisms, especially in dealing with climate change impacts. Case study areas were selected to develop the envisaged solution.

A workshop was held a few months after the project was started during which researchers and participants discussed the various factors which were to be considered in selecting case study areas. It was noted that the case studies had to be representative of the different types of water access opportunities available to local communities in both rural and urban settings in different parts of the country. In addition to being representative, other factors considered in the study area selection criteria included the following:

- areas in different climatic regions of the country;
- area delineation according to national planning;
- the need to work in areas with different settlement patterns;
- areas with varied livelihoods;
- communities with varied population densities;
- communities in both urban and rural settings;
- areas where similar studies have not been done;
- areas supplied by largely different river systems and dams;
- the need to represent a large population group in the country.

Consideration of the above factors for selecting case study areas, along with early project work, revealed the need to focus on local municipalities as the main local institution for communities, an important factor in the study. Assessments of water access revealed that more than 90% of the community member population relied on district and local municipalities in accessing water. The following local municipalities (LM) were selected for use as case studies, and were also used in pilot studies for the adaptation framework:

Thulamela LM;

Msunduzi LM;

Madibeng LM;

Letsemeng LM.

The study areas include rural communities in Thulamela and Madibeng, although Madibeng also has a large community of people who reside there but travel daily to work in Gauteng Province, thus making it a dormitory municipality. Msunduzi is mostly urbanised with a dense population in the City of Pietermaritzburg. A large proportion of the population living in Edendale, a township in Msunduzi, can be described as poorly resourced in terms of per capita income. Water service provision for the future, however, looks very promising due to a large number of planned water programmes. Letsemeng represents a very sparsely populated area which is mostly commercial farm land. Out of the total of 10 180.71 km^2 of land in Letsemeng, 9 730.22 km^2 (95.6%) is farmland owned by less than 1% of the population in the area (Letsemeng, 2011). Further descriptions of study areas are provided in Tables i and ii below.

Table i: Pilot study areas: Data obtained from Stats SA (2011)

	Thulamela LM	**Msunduzi LM**	**Madibeng LM**	**Letsemeng LM**
Area in Km^2	2 966	649	3 839	10 180
Households	156 594	163 990	160 724	38 626
Population	618 462	618 536	477 381	38 628
Change in population between 2001 and 2011	Increase of 0.6%	Increase of 1%	Increase of 3%	Decrease of 1%
Population density (per km^2)	208	953	124.4	3.7
Population size for largest town	Thohoyandou 69 000	Pietermaritzburg 500 000	Brits 123 000	Koffiefontein 9 000
Unemployment rate	43.8%	33.0%	30.4%	22.3%
Piped water inside dwelling	15.2%	47.91%	22.2%	49.8%
District Municipality	Vhembe	uMmgungundlovu	Bojanala	Xhariep

Table ii: Information for districts where study areas are located (Stats SA, 2011)

District Municipality	Bojanala	uMgungundlovu	Vhembe	Xhariep
Population	1 268 618	988 837	1 240 035	127 627
Province	North West	KwaZulu-Natal	Limpopo	Free State
Households	911 120	217 876	137 852	37 245
Area (Km^2)	18 332	8942	21 407	34 249
Capital	Rustenburg	Pietermaritzburg	Thohoyandou	Trompsburg
Unemployment rate	30.7%	30.4%	38.7%	26.8%
Piped water inside dwelling	26.0%	42.7%	15.4%	42.7%

Study data and information

Data and information were obtained from the communities and institutions using several techniques. Questionnaires were mostly used, while desktop investigations, literature studies, consultations and telephone interviews were also used. In administering questionnaires, approximately four households per settlement were interviewed to obtain an overall picture of the water access circumstances in a particular ward and its settlements. Several settlements made up each ward. Settlements were considered to be areas with a group of households within the same geographical setting, such as a village, suburb, informal settlement or a residential township. The ward and municipal boundaries used were in accordance with the municipal boundaries provision (Department of Provincial and Local Government, 2009).

Twenty-four research assistants and four researchers participated in the development and administering of the questionnaires in the four case study areas. The administration of questionnaires was completed in two phases. The first phase in August 2011 involved all four areas and a total of 312 respondents provided answers to the first questionnaire. The questionnaire comprised 51 questions, covering the following subject areas: nature of housing and settlement, livelihood information, water access and use, role of water service institution, and knowledge on climate change and adaptation. The second phase of questionnaire administration was completed in November 2011. This data collection initiative was aimed at obtaining data on community needs, institutional capacity and adaptation options. In this second phase, 488 households and 31 farmers were interviewed in the same study areas.

Institutional leaders in water sector institutions in the study areas were consulted to obtain information about the areas, as understood or documented by the water sector institutions.

Information on climate change was obtained through the CSIR. The CCAM-CSIRO Mk3.5 data (CSIR, 2010) was used to determine the nature of impacts due to climate change. For purposes of study area assessments, average temperature and rainfall data were considered. In assessing the changes, the climate data from the period 1961 to 1990 were compared with projected climate data for the period 2071 to 2100. The climate change data used in the study showed that temperatures in the country will generally increase by about 2°C. The climate data for the study also showed increasing rainfall over most of South Africa with the exception of the south and south-west coastal areas, where a decrease was predicted.

Important impact factors included the fact that the increased rainfall in the Drakensberg Mountain peaks will generate more runoff in the Vaal and Orange systems. These river systems, which originate in the Drakensberg highlands, will generate even more water and supplement current usage in the provinces of Gauteng, Free Sate, North West, Mpumalanga, Northern Cape, Eastern Cape and KwaZulu-Natal. It is noted that there are other climate change data sets which show other trends.

The CCAM-CSIRO Mk3.5 used in the study was one of six data sets available from the CSIR. The trends in the data set selected are corroborated in the predictions obtained and used in the most recent DWA study entitled: Status Quo Analysis: Climate Change Impacts on Water Resources (DWA, 2013b). In the DWA Status Quo study, the four GCMs used for four case study areas showed rainfall increases ranging from 5% to 36%, with the exception of one scenario in De Aar, where rainfall is set to decrease for one of the four GCMs. The nature of rainfall increases for the data set used in this study is presented in Figure i, where the percentage increase in rainfall for the two periods considered is shown. The increase in temperature for the period projected is shown in Figure ii.

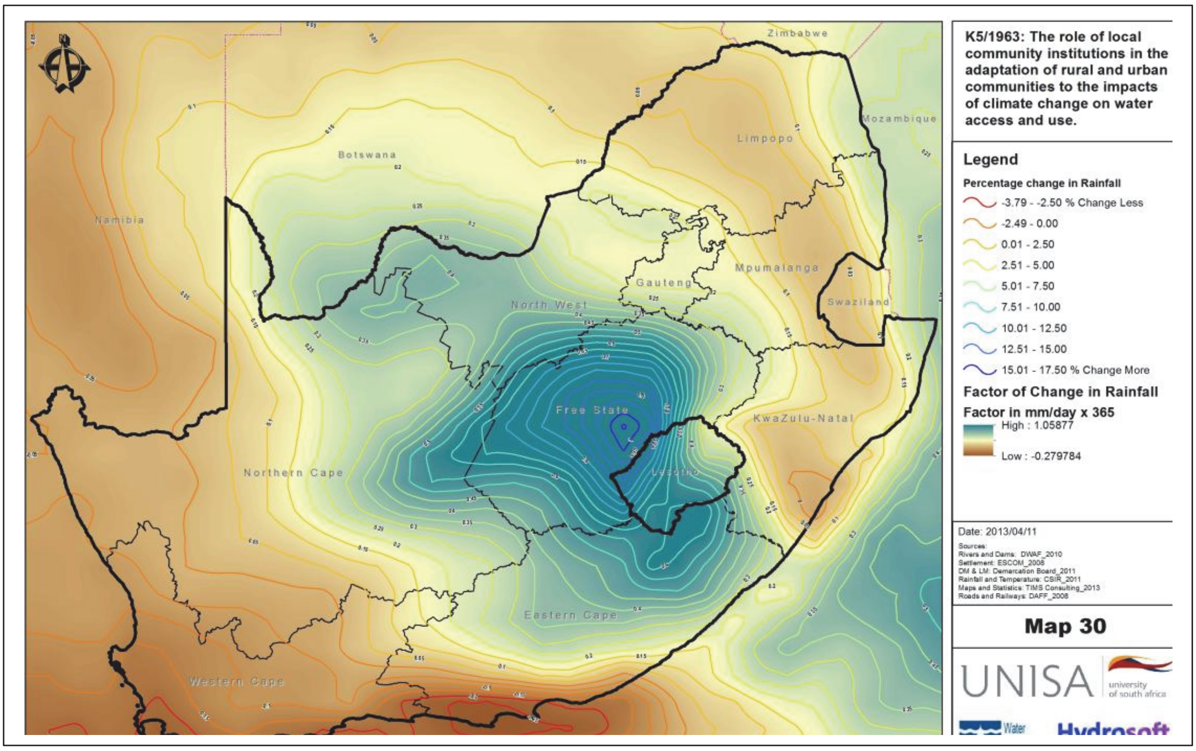

Figure i: Percentage change in Rainfall between 1961-1990 and 2070-2100 over South Africa

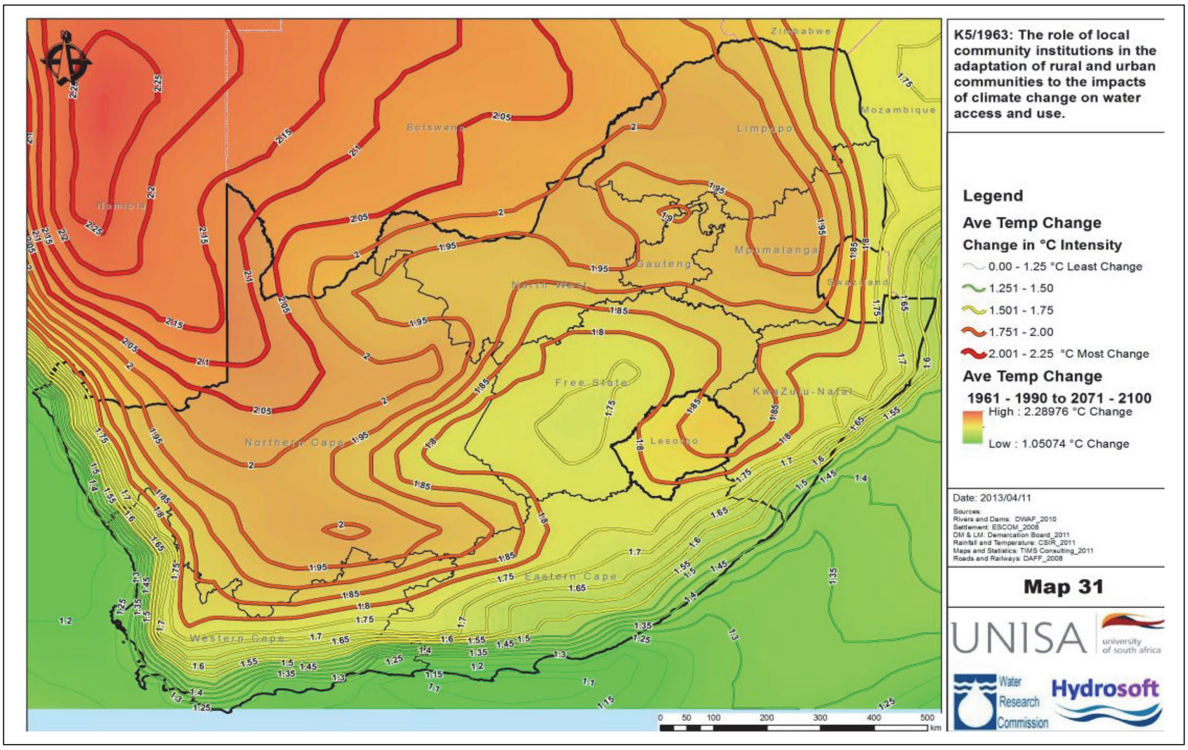

Figure ii: Average temperature increase in Degrees Celsius for the period 1961-1990 to 2071-2100

Development of the adaptation framework

Conceptualization and development

Communities facing increasing water access challenges due to a number of stressing factors, including climate change, need institutional support with well-founded plans. Ideally, these plans have to be based on community needs, vulnerability, nature of challenges, and capacity to deliver, along with many other variables, whose relevance differ for each community. Implemented water access programmes and activities must be prioritised and address appropriate problems in each community. Quantification of community vulnerability provides the basis for decisions to be made in providing water access support.

Community vulnerability quantification involves identifying the exposure and sensitivities causing vulnerability to climate change impacts, and then converting those stressors to figures which are in turn used to map out the ranges of vulnerability by stressor, per community. Vulnerability mapping encourages improved communication of risks as well as the knowledge of what is being threatened by climate change. The maps also provide improved visual presentations, thereby improving understanding of the risks and vulnerabilities so that decision-makers and other stakeholders can identify where resources are needed for adaptation. Corrective action can be taken before the impacts escalate into disastrous scenarios.

Communities were central to the study in obtaining information on vulnerability. Whilst several similar studies tend to suggest vulnerabilities within communities, this study targeted the communities to establish the description and quantification of vulnerability. In the study, vulnerability quantification was achieved through a method involving several stages of evaluating the elements of vulnerability.

Vulnerability was calculated as being a function of the three main variables: Exposure, Sensitivity and Adaptive Capacity. The three variables were considered to be composed of indicators that could be evaluated on the basis of the information obtained from the study areas. The equations to connect the input data to generate the main variables, and hence the vulnerability, were written In the Adaptation Framework Software. The framework was conceptualised on the basis of the flow diagram illustrated in Figure iii below.

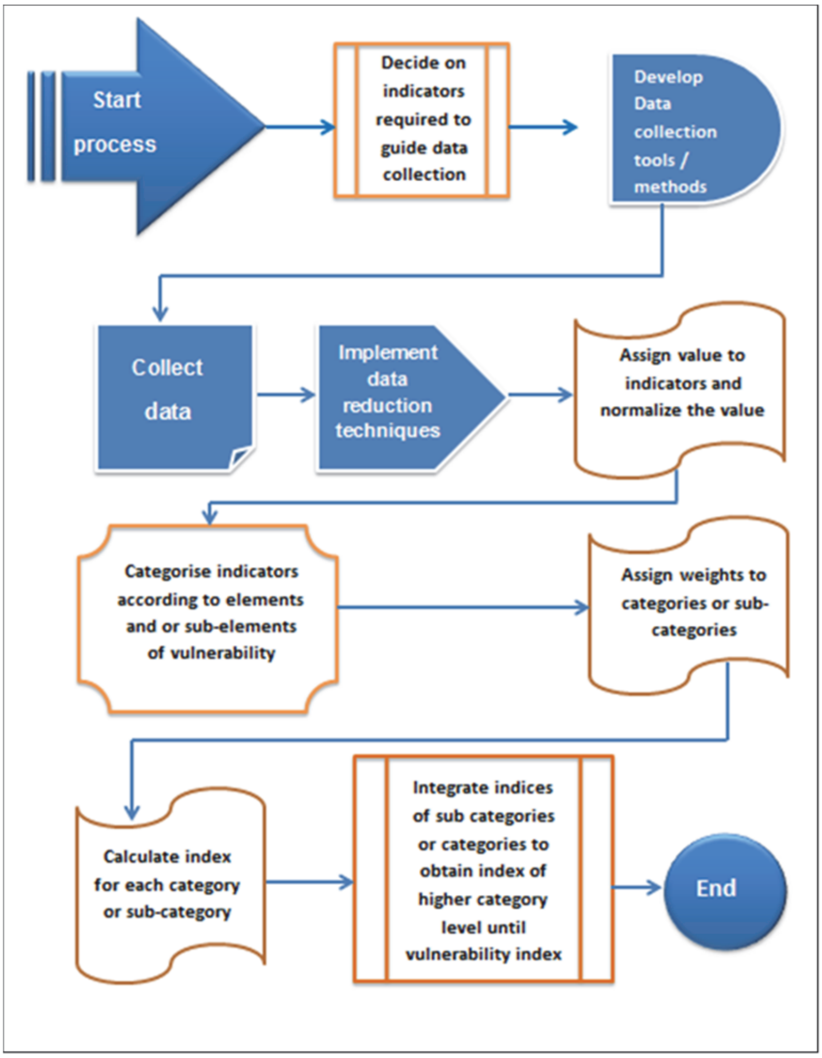

Figure iii: Adaptation framework flow diagram (Source: Authors)

Hydrosoft Climate Change Adaptation Framework Software

The Hydrosoft Climate Change Adaptation Framework (HCCAF) was developed as a GIS-based tool where the state of water affairs of several communities within an environment of climate change is analysed as a single integrated scenario. In each scenario, the objective is to determine the community vulnerabilities and the nature of adaptation responses which are suitable for each community. The current state of water affairs, as well as planned water-related developments, is used to measure the vulnerability of each community to climate change impacts with respect to community water access and use. The quantification of vulnerability is derived from the relationship between the following variables:

Exposure to climate change impacts;

Sensitivity to climate change impacts;

Adaptive capacity to climate change impacts.

Determination of exposure in the framework is based on three measures of impact. These are changes in temperature, changes in average rainfall and a measure of extreme events due to climate change. The exposure measurement is based on the CCAM-CISRO climate change data obtained from the CSIR's environmental group in 2010. Since there are many climate change data models giving varied outputs, the framework allows for the user to change the climate change dataset from which the exposure indicators are derived to generate other scenarios.

The quantification of sensitivity in the framework is based on 19 sensitivity indicators derived from various sources, especially the communities targeted in the case studies and the municipalities where they reside. The framework, which already captures the case study scenario, allows the user to extend the use to other local municipalities.

Adaptive capacity is described in the HCCAF using 10 indicators. Adaptive capacity measurement took into account the capacity of the communities and that of the municipalities responsible for their water access.

In the formulation of vulnerability, adaptive capacity is the only positive, while exposure and sensitivity are negative. The calculation in the framework is such that some communities have zero vulnerability, which occurs when the calculated contribution of both exposure and sensitivity is equal to the contribution of adaptive capacity indicators. The quantified values of vulnerability, exposure, sensitivity and adaptive capacity are set to be used as the basis to plan and implement adaptation responses for impacts of climate change on water access. The framework, illustrated in Figure iv below, allows the user to evaluate exposure, sensitivity and adaptive capacity to climate change impacts. This tool also provides the platform for defining the appropriate adaptation measures for each community.

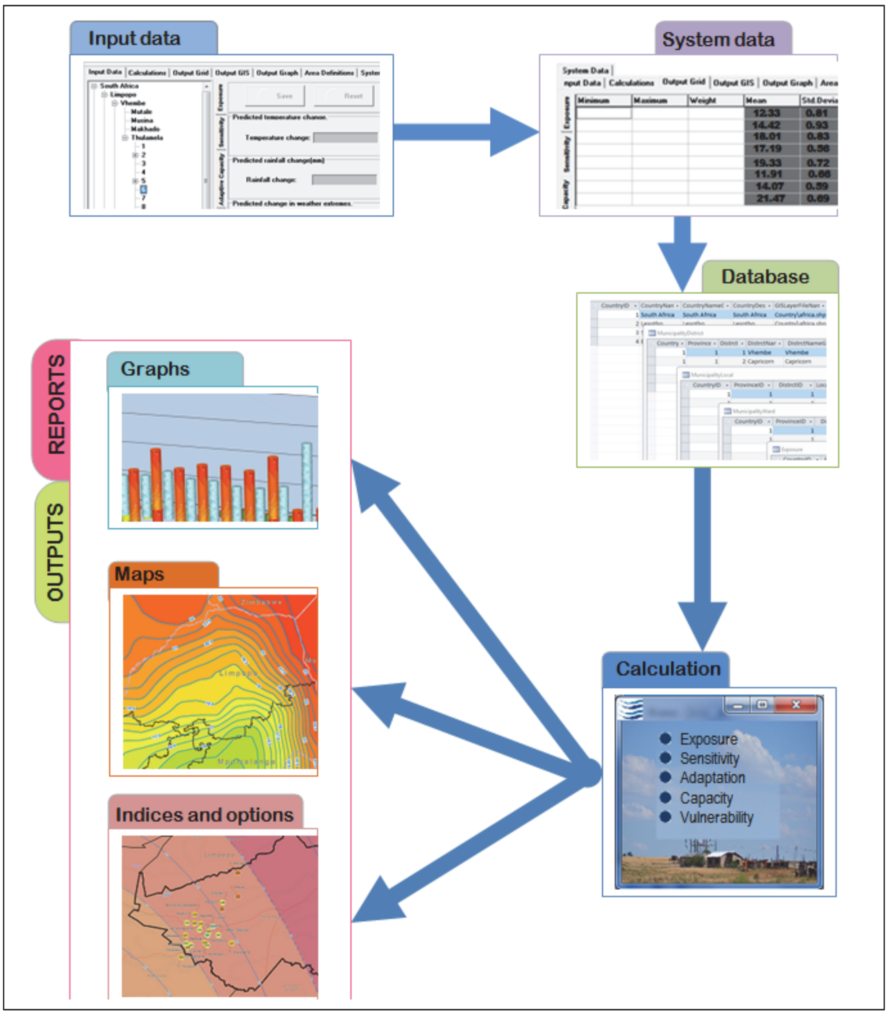

Figure iv: Hydrosoft Climate Change Adaptation Framework

Study findings

Various elements relating to the predominant way of life in a specific area characterise that area's community and institutional needs for adaptation to climate change impacts. The research approach used in the study relied on information from the larger population groups drawn from the general population group in each area. The study found that the water access and climate change adaptation needs of these groups depend on their various incomes and access to resources. The effect that household income levels have on water access needs is most visible in Letsemeng, Madibeng and Thohoyandou, where some well-off communities do not wish to rely on municipal water services. Some communities in these areas have developed their own water provision infrastructure, relying in particular on ground water-based systems. The study also revealed that these private water provision systems are generally more reliable than municipal services. In all the case study areas, with the exception of Letsemeng, some community members rely on privately abstracted water which they purchase from neighbours. Water is widely purchased from private sellers at rates of up to R2.00 per 20 litre container, which is above ten times most municipal rates of less than one cent per litre.

Although literature records show otherwise, most households in the case study areas do not depend on agriculture for their livelihoods. The perception that rural communities practise agriculture for a livelihood is based on widely available literature from international studies originating from developing countries which do not share the same history as South Africa. The perception from these studies generally is that '*if a poor African is in a rural area then he or she is a subsistence farmer who relies on agriculture for a livelihood'*. The four study areas investigated, however, indicate that communities in rural areas have little to depend on, with a large percentage relying on grants, ad-hoc jobs that are usually hard to come by in nearby towns and farms, informal trading on roadsides, as well as financial support from family members employed in distant urban areas. It was also observed that, while a few rural communities could be practising some form of agriculture through gardening or other land-based practices, they cannot be generally classified as being dependent on agriculture for their livelihood. Agricultural activities constitute hardly 20% of their income in most cases. Rural communities in all the municipalities investigated are concentrated in densely populated rural settlements where there is little additional land for cultivation or for carrying out other forms of subsistence farming.

The very nature of community livelihoods, associated with the map of community vulnerabilities in water access, tells an ongoing story of pervasive and persistent poverty. With more than 48% of South African households living below the poverty line, considered here as R342 per household per adult equivalent per month (Jacobs et al*.,* 2009), there is no way that such communities can afford adequate water services at present, or indeed in the future. One has only to consider the pace of service delivery and increased water demands, allied to evaporation, among other impacts of climate change. The assessment of poverty in municipalities (Bhorat and van der Westhuizen, 2010) has the same trend as the general water access vulnerability status exposed in this study. In this study, areas with poor communities, especially rural areas, had the highest sensitivities with very little potential for adaptation. This is worsened by the fact that municipal water services in poorer communities are either of a very low standard or non-existent.

The deterioration of water services in Petrusburg took place during the study period. Responses to questionnaires during an earlier visit to Petrusburg did not reveal the problematic water access challenges which the community was facing as this was during the period when boreholes in the area were generating good yields. In the second visit during summer, the area was already experiencing chronic water shortages, with some suburbs having gone for at least two weeks without water services. This sort of situation demonstrates that the analysis and mapping of water access and vulnerability should not be a once-off exercise but should rather be regularly implemented to capture the dynamic nature of the problem. As such, the adaptation framework was developed in such a way that input data and parameters for determining adaptation options can be changed regularly to capture minor and major changes.

The quantitative assessments in the HCCAF generate values for adaptive capacity, sensitivity, exposure and vulnerability at the ward levels. These values were then augmented to provide a general trend for each local municipality. The findings were also mapped onto the GIS maps, together with other data layers such as the images taken at each site, description of water access, adaptation options and exposure values. The exposure values were illustrated as lines to show temperature and rainfall over the two sets of periods considered, as well as other relevant changes

(Figures i and ii). In Table iii below the values for the main variables and vulnerability are shown for each of the pilot study areas.

Table iii: Overall results of pilot study assessments in case study areas.

Vulenerability	Max	Min	Range	Median	Average	Rank
Thulamela	4.363	1.107	3.257	3.227	3.132	4
Letsemeng	1.305	-0.191	1.495	0.813	0.748	1
Madibeng	4.566	1.060	3.506	2.297	2.407	3
Msunduzi	3.602	-2.812	6.414	1.248	0.780	2

Sensitivity	Max	Min	Range	Median	Average	Rank
Thulamela	2.639	0.821	1.818	1.885	1.885	4
Letsemeng	1.908	1.112	0.797	1.705	1.622	2
Madibeng	2.317	1.125	1.192	1.812	1.791	3
Msunduzi	2.461	0.313	2.148	1.531	1.388	1

Exposure	Max	Min	Range	Median	Average	Rank
Thulamela	2.597	1.095	1.501	1.846	1.912	3
Letsemeng	0.968	0.968	0.000	0.968	0.968	1
Madibeng	2.597	2.597	0.000	2.597	2.597	4
Msunduzi	1.140	1.140	0.000	1.140	1.140	2

Adaptive Ca	Max	Min	Range	Median	Average	Rank
Thulamela	1.935	0.000	1.935	0.610	0.665	1
Letsemeng	2.327	1.251	1.076	1.881	1.842	3
Madibeng	2.790	0.348	2.442	2.125	1.981	4
Msunduzi	4.323	0.000	4.323	1.302	1.749	2

In the findings on vulnerability assessments, Table iii, Letsemeng proved to be the best performing community in respect of the overall vulnerability of local communities to impacts of climate change on water access and use. This overall assessment relates to communities both in urban and rural settings, with an emphasis on datasets for water access at household level. Data from commercial agricultural farmers were not used in the pilot study to ensure that the outputs could be compared as representing communities in similar water access and use circumstances in all study areas.

Communities in Msunduzi showed the least sensitivity and also performed fairly well in both Exposure and Adaptive Capacity. Thulamela, with a mostly rural population, proved to be the worst performer with respect to most of the indicators. In the analysis, Thulamela showed up as an area where not only were communities exposed to the worst levels of climate change vulnerabilities and the poorest levels of water access as things stand today, but also as having the least scope for major improvements in the future. The high levels of adaptive capacity obtained for Madibeng reflect the improved prospects of future bulk water provision, especially as more areas in this municipality are connected to the better performing Rand Water system. The area, however, is still compromised by poor reticulation infrastructure and the poor performance of the main water institution, the Madibeng local municipality.

Conclusion

Study approach

A bottom-up approach was emphasised in this study. In this approach, communities provided the initial inputs used to characterise the nature of water access issues both at present and in the future. Further data and information were collated from institutions and other stakeholders who usually provide a top-down approach. The investigations at a local level, starting with households, indicated a general lack of institutions suitable for roles in support of improved water access. In contrast to this finding, many reports tend to suggest that such institutions are in fact actively supporting programmes to extend water access in local communities. While the municipality was considered in this study as the main institution supporting community adaptation responses, there are a few other institutions which have some influence in respect of water access and use by communities. The roles of other institutions in improving water access are best captured as a part of the variables used in the HCCAF indicators defining water access. Further, this factor may be captured directly in instances where support is provided for adaptation initiatives.

The conceptualisation and functions of HCCAF were based on the premise that adaptation in water access is built on the current state of water services provisions. The adaptation framework is intended as a tool providing the opportunity to interrogate how adaptation can be part of water service development planning by institutions, as they work with communities in addressing present and future water access and use challenges.

The climate change adaptation framework (HCCAF) was developed to be the link between communities which are exposed to climate change impacts and the local institutions that help them to adapt.

Climate change impacts

The CISRO CCAM Mk3.5 dataset used in the study showed temperature increases of around 2°C and rainfall increases of up to 17% when modelled climate data for the period 1961 to 1990 were compared with projected climate data for the period 2071 to 2100. While the general rainfall increases are not commonly discussed in past research, such as the results captured in the IPCC (2007) report, similar findings which show even higher rainfall increases of up to 36% were predicated in the dataset used in the recently completed DWA project on the climate change Status Quo Analysis report (DWA, 2013b).

HCCAF outputs

HCCAF findings for the pilot study scenario showed that communities in rural areas are usually subject to a poorer state of water access than their counterparts in urban areas. The investigations in the local settlements also showed that communities in rural areas were most likely to have no contact with any supporting institutions for water access in the present or in the future. Thulamela Local Municipality, where the majority of community members are in rural areas, has the worst levels of water access at present, and there is little prospect of everyone receiving the minimum levels of water access as stipulated by national water legislation. Multi-faceted issues restrict water access and the potential to adapt in rural communities. This is indicated by the overall poor performance of rural community settlements for most indicators used in the HCCAF. However, the HCCAF presents the issues in these rural communities in a way that allows a user to compare the water access and adaptation performance within one set of outputs for all areas, irrespective of whether they are urban or rural.

Comparison with 2011 census data

In the Climate Change Adaptation Framework, the findings on water access vulnerability and adaptation needs showed that the measure of performance was at its worst in the Thulamela Local Municipality, while the Letsemeng Local Municipality gave the best overall performance after considering all indices. The findings clearly demonstrate that the areas currently observed to have the greatest need for institutional support to access water are also the same areas with the lowest levels of economic development and the highest levels of unemployment (Stats SA, 2011). The investigations at community level also revealed that generally very poor communities are also poor in the amount of water they access, how they access the water and their ability to use the water to satisfy other needs apart from the most basic. For example, the many communities in RDP houses and informal dwellings do not even have house fittings to bring water to a shower, a sink or a tub. These communities tend to collect water in a bucket from a distant location. This water is then used for the whole day. As such, less well-off communities demonstrate very basic water needs and even if there was more water, they would not be able to use the additional water due to lack of in-built infrastructure. It is important that in-house plumbing is included in the development of RDP housing units. In this way, communities can also access adequate water to meet most of their basic needs.

Institutional capacity in community adaptation

The investigations revealed that the institutions which serve local communities in urban and rural areas have no comprehensive plans to elevate the communities they serve to a level of comfortable water service provision. Instead, they target the very minimum RDP level of water service delivery. The study areas with the fewest prospects for sustainable water services delivery also come across as the municipalities with the lowest level of current service delivery. In Vhembe and Bojanala, the level of service delivery at present is very poor, and the local municipalities find it difficult to deal with climate change and adaptation when they are constantly struggling with current water service delivery challenges. The use of a HCCAF framework will ensure that each municipality will have fewer challenges in incorporating adaptation at the water development planning stages.

The way forward

This study focused on developing a method that will be utilised in the delivery of institutional support for community adaptation to water access and use. It is envisaged that this tool will be applied nationally to provide the basis for national, regional and municipal development in improving water access, and also in developing communities' requirements for adapting to the changing climate. The framework is expected to be used by a wide range of institutions, including various local water institutions as well as higher level institutions such as the Department of Water Affairs, Department of Cooperative Government and Traditional Affairs, Water Boards, CMAs and the Development Bank of South Africa. The higher level institutions can use the tool to decide on the areas to target for water access development, as well as which adaptation options to include in the development of water infrastructure and other water service provision initiatives. It is envisaged that the project team will take the project to the next stage by inviting partnerships with the institutions targeted in the use and application of the framework.

The states of water access and vulnerability of communities to climate change impacts are dynamic, changing over time, and the changes may affect members of the same community differently due to their own specific circumstances. The HCCAF captured several variables in a way that allows the user to develop new scenarios and account for changes, as well as taking advantage of better data and information for one or all areas under consideration. As such, it is envisaged that the framework can be used regularly to capture and develop understanding of water access, water use, exposure to climate change, sensitivity to impacts, adaptive capacity and vulnerability in water access, as well as climate change adaptation options. Municipalities are expected to take advantage of the freely available HCCAF to build scenarios for their settlements and wards.

In the early stages of the development of the adaptation framework, it became evident that water access and adaptation issues for domestic water users and water use in agriculture and other sectors are driven by largely different variables. These variables, as well as how they should be interpreted, are better represented in separate frameworks. Water management and planning in the agriculture sector could be improved if the approach utilised in this study is developed specifically for water access and adaptation in agriculture. Plans for further development with the focus on agriculture have been presented for consideration to the Department of Agriculture.

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Acronyms

ACRU:	Agricultural Catchments Research Unit
ADB:	Asian Development Bank
AIDS:	Acquired Immuno Deficiency Syndrome
AMCEN:	African Ministerial Conference on the Environment
AOGCMs:	Atmosphere-Ocean General Circulation Models
ARC:	Agriculture Research Council
BRIC:	Brazil, Russia, India, China
CBD:	Central Business District
CC:	Climate Change
CCAF:	Climate Change Adaptation Framework
CCAM:	Cubic Conformal Atmospheric Model
CCSR:	Center for Climate System Research
CFO:	Chief Financial Officer
CGCMs:	Coupled General Circulation Models
CMAs:	Catchment Management Agencies
CoGTA:	Cooperative Governance and Traditional Affairs
CORDEX:	Coordinated Regional Climate Downscaling Experiment
CSAG:	Climate Systems Analysis Group
CSIR:	Council for Scientific and Industrial Research
CSIRO:	Commonwealth Scientific and Industrial Research Organisation
DBSA:	Development Bank of Southern Africa
DEA:	Department of Environmental Affairs
DPLG:	Department of Provincial and Local Government
DST:	Department of Science and Technology
DUCT:	Duzi-uMgeni Conservation Trust
DWA:	Department of Water Affairs

DWAF:	Department of Water Affairs and Forestry
EDRC:	European Documentation and Research Centre
ENSO:	El Nino Southern Oscillation
ESRI:	Environmental Systems Research Institute
GAM:	Global Atmosphere Model
GCMs:	Global Climate Models
GFDL:	Geophysical Fluid Dynamics Laboratory
GHG:	Greenhouse Gas
GIS:	Geographical Information Systems
GTZ:	German Organisation for Technical Cooperation
HCCAF:	Hydrosoft Climate Change Adaptation Framework
HIB:	Hartbeespoort Irrigation Board
HIV:	Human Immuno Virus
HSRC:	Human Sciences Research Council
IDPs:	Integrated Development Plans
IPCC:	Intergovernmental Panel on Climate Change
ITCZ:	Intertropical Convergence Zone
IWMI:	International Water Management Institute
LDCs:	Least Developed Countries
LHWP:	Lesotho Highlands Water Project
LM:	Local Municipality
MAP:	Mean Annual Precipitation
MAR:	Mean Annual Runoff
MDGs:	Millennium Development Goals
MIG:	Municipal Infrastructure Grant
MLM:	Madibeng Local Municipality
NAPA:	National Adaptation Programmes of Action
NCCC:	National Climate Change Committee
NGOs:	Non-Governmental Organisations

NIES:	National Institute for Environmental Studies
NOAA:	National Oceanic and Atmospheric Administration
NWA:	National Water Act
NWDACE:	North West Department of Agriculture Conservation and Environment
NWRS:	National Water Resource Strategy
OECD:	Organisation for Economic Co-operation and Development
ORWUA:	Orange River Water User Association
PCA:	Principal Component Analysis
PRECIS:	Providing Regional Climates for Impact Studies
RCM:	Regional Climate Model
RDD:	Recommended Design Discharge
RDP:	Rural Development Program
RMF:	Regional Maximum Flood
RVFV:	Rift Valley fever virus
RWH:	Rainwater harvesting
SA:	South Africa
SADC:	Southern Africa Development Community
SAFCEI:	Southern African Faith Communities' Environment Institute
SANBI:	South African National Biodiversity Institute
SANCOLD:	South Africa National Committee on Large Dams
SANS:	South African National Standard
SAWS:	South Africa Weather Services
SIDA:	Swedish International Development Cooperation Agency
SRES:	Special Report on Emission Scenarios
TCTA:	Trans-Caledon Tunnel Authority
TN:	Total Nitrates
TP:	Total Phosphates
UCT:	University of Cape Town
UN:	United Nations

UNDP: United Nations Development Programme

UNEP: United Nations Environmental Programme

UNESCO: United Nations Educational, Scientific, and Cultural Organisation

UNFCCC: United Nations Framework Convention on Climate Change

UNISA: University of South Africa

USA: United States of America

VDM: Vhembe District Municipality

WARMS: Water Authorisation and Registration Management System

WCRP: World Climate Research Programme

WDM: Water Demand Management

WHO: World Health Organisation

WMA: Water Management Area

WMO: World Meteorological Organization

WRC: Water Research Commission

WSP: Water Service Provider

WTW: Water Treatment Works

WUAs: Water User Associations

WWF: World Wide Fund

WWF-SA: World Wide Fund-South Africa

WWTP: Waste Water Treatment Plant

1 Introduction

1.1 Climate change, water access and water uses in South Africa

1.1.1 Climate change

No environmental issue has been of such truly global magnitude as the issue of climate change (Low, 2005). United Nations Development Programme (UNDP) (2007) characterises climate change as an environmental issue with global development implications. Indeed, climate change is a major development issue which is already negating the benefits of previous developmental gains and frustrating new development initiatives in developing economies. Climate change impacts are varied across the globe, and it is inevitably the poorest who are least equipped to deal with the impacts. Dinar et al. (2008) argued that in all the global climate change model results up to 2008, Africa, with the largest number of countries classified as poor, is the most vulnerable continent to climate change. Poor communities, inevitably more vulnerable to climate change impacts because they lack infrastructure, have little or no financial backing and invariably depend on diminishing natural resources for their survival (Ensor and Berger, 2009, Nyong 2009, Mendelsohn 2009).

Lacking any consideration of climate change, many communities are known to be already vulnerable, and their livelihoods extremely sensitive to even minor disturbances, and more so to major impacts caused by climate change. Any changes in the climate, including increased hydrological variability, expose these vulnerable communities to extreme stresses for which they cannot plan or even begin to contemplate solutions. Such vulnerable communities include the majority of South Africans. The fact remains that it is the poor communities which suffer the worst impacts of climate change, and yet have the least potential to cause or influence it. The focus in such communities should, therefore, be adaptation rather than mitigation. The impacts of climate change are seen at their worst in the way they affect the survival of, and any developmental initiatives within communities. It is, therefore, a developmental issue that tends to eradicate any developmental progress achieved by those who are most vulnerable.

There is consensus among scientific bodies that the average surface air temperature of the earth increased over the last century, and that it will continue to do so over the current century by between 1.1°C and 6.4°C (IPCC, 2007a). The finer details of climate change, however, remain uncertain since there are a number of factors which still cloud the certainty of climate change data and information. In the first instance the processes involved in climate change are numerous and highly complex. Secondly, available knowledge is still very limited, particularly when it comes to an understanding of feedback mechanisms as the planet warms, and finally, we cannot predict the extent of Greenhouse Gas emissions in the future. Currently, the volume of Greenhouse Gases being added to the atmosphere is not reducing globally, and the gases already in the atmosphere will continue to warm the planet for many years to come.

In the long term, however, global mitigation is the only rational adaptive response to climate change, as a 6°C warming would be so severe in its impact that it simply must be averted. Furthermore, we also need to adapt to the warming that has already been set in motion. There is still great uncertainty over the consequences of a rapid change in global temperatures for the earth's climate patterns, and the subsequent effect on water resources (Hughes, 2012). The Intergovernmental Panel Report on Climate Change of 2007 (IPCC, 2007a), however, indicates that, compared to earlier reports, there is now higher confidence in projected patterns of warming and regional scale features, including changes in wind patterns, precipitation and some aspects of extremes, creating an emerging picture of how the impacts of climate change will unfold in different parts of the world.

1.1.2 Water access and uses in South Africa

The question of water access has been addressed from a variety of angles, all of which depend on a number of variables. When water access is discussed in South Africa, important considerations include equity in supply, water of good quality and in relevant quantities for its particular uses. Clause 27 of the South African constitution stresses that everyone has the right of access to sufficient food and water (Republic of South Africa, 1996). The National Water Act (NWA) (Republic of South Africa, 1998a) provides a sound basis for improvements to water access by all. The history of the South African water sector, however, like any other service sector, is founded on a system of segregation and high levels of inequality, all of which have complicated efforts to make adequate potable water available to everyone.

The implementation of the act and the drive to improve access to water has been protracted since many historical hurdles have had to be overcome in the process. These hurdles have been encountered in many key areas such as the processes of accounting for available water resources, identifying and stopping illegal water usage, recording available water licences, re-issuing water licences and developing water infrastructure in areas previously underserviced, or with no water services at all. Critics are already blaming the NWA for shortcomings in water services and the continued failure to meet the constitutional obligation of water access for all. The additional variable of climate change is complicating initiatives to make water accessible to all citizens.

In a study on the impact of climate change on small municipal water resource managements, Mukheibir (2007) points out that scarcity of water is often blamed for poor access to water by some communities. The reality, however, is that many other variables are active in most cases where communities fail to adequately access water. Mukheibir (2007) blames problematic political and economic policies as further problems that are not usually discussed and dealt with. As a result of such policies it is observed that geographically, economically and socially marginalised communities suffer the most from water access problems in South Africa (Mukheibir, 2007). Water access and use by rural and urban communities is better understood in the context of water use by all user groups. The distribution of water use per sector is shown in Figure 1 below.

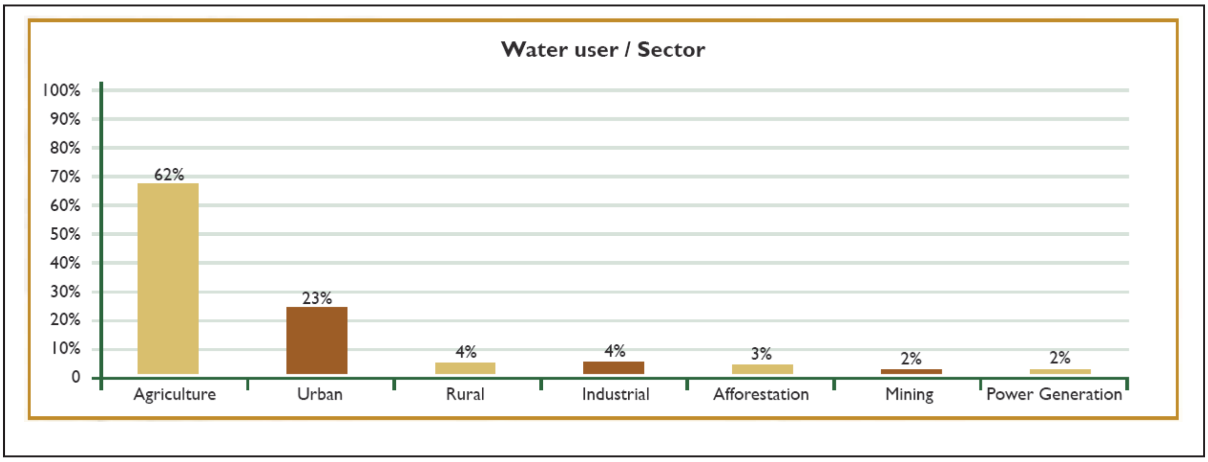


Figure 1: Use of water by sectors (Department of Science and Technology, 2010).

Empirically, water use by one sector has a bearing on the availability of water for other sectors. Although it would seem that the use of water by the smallest user groups should have the least impact on available water for other groups, this is not always the case. Water characteristics such as its quality have a major impact on availability. Effluent from industries and water passing through urban areas usually become so polluted that they are no longer useful to certain sectors, such as agriculture. This problem is experienced in most urban areas. The mining industry also uses a small proportion of available water resources. Poorly rehabilitated mines, however, have for some time been polluting vast quantities of water around the country, and this inevitably reduces available water resources. This problem is especially noticeable in Gauteng's old gold mines and Mpumalanga's old and current coal mining activities. The water which has passed through mining operations tends to contain a large concentration of heavy metals and low pH corrosive compounds which are expensive to remove and which generally render water unusable.

Howard and Bartram (2003) present guidelines on what constitutes domestic water access. These guidelines single out the quantity of water of acceptable quality that is available, and the distance from which that quantity can be obtained as the main criteria for measuring access to water (Table 1). People are considered to have limited or no access to water even though they may be able to obtain large quantities of water at the source, but have to walk long distances or spend long periods waiting to collect water. Such long distances or periods spent fetching water reduce the time available for economic activities that could otherwise contribute to poverty reduction (Larson et al., 2006). Similarly, people who have water supply infrastructure at their homes but suffer long periods without a water supply, or are restricted to small quantities of water per day by means of, for example, water rationing are also deemed to have limited or no access to water.

Table 1: Water access service levels for healthy domestic supply (Source: Howard and Bartram, 2003)

Service level	Access measure	Needs met	Level of health concern
No access (quantity collected often below 5 ℓ/c/d)	More than 1 000 metres or 30 minutes total collection time	Consumption – cannot be assured. Hygiene not possible (unless practised at source)	Very high
Basic access (average quantity unlikely to exceed 20 ℓ/c/d))	Between 100 and 1 000 metres or 5 to 30 minutes total collection time	Consumption – should be assured. Hygiene – hand washing and basic food hygiene possible; laundry/bathing difficult to assure unless carried out at source	High
Intermediate access. (average quantity about 50 ℓ/c/d)	Water delivered through one tap on-plot (or within 100 metres or 5 minutes collection time)	Consumption – assured. Hygiene – all basic personal and food hygiene assured; laundry and bathing should also be assured	Low
Optimal access. (average quantity 100 ℓ/c/d and above)	Water supplied through multiple taps continuously	Consumption – all needs met. Hygiene – all needs should be met	Very low

The 2011 census demonstrated that South Africa has made significant strides in achieving household access to tap water. The number of households with tap water either inside the home or their property is now 73.4%, compared to the 62.3% counted during the 2001 census (Stats SA, 2012). Furthermore, only 6.2% of households have to walk more than 200 metres to reach tap water, and only 8.8% have no access to water from a tap, whereas this figure was 15.6% in the 2001 census (Stats SA, 2012). This means that 85% of South Africans now have a tap within 200 metres of their homes.

The National Water Act of 1998 and the Water Services Act of 1997 (Republic of South Africa, 1998a and Republic of South Africa, 1997) emphasise the need for water services to recover costs. Higher payments by high volume users were intended to cross-subsidise the free basic allowance. Cross-subsidisation, however, has been problematic in poor areas where there are few high volume water users to pay for the service. Municipalities in such poor communities often have no adequate revenue to sustain the water provision service. There is an on-going tension between making adequate water available to ensure the health and safety of populations, and the need to control consumer demand and recover costs.

1.2 Research motivation

There is indisputable evidence that the global climate is changing (Arnell, 1996). While mitigation of anthropogenic climate change is vital, the blunt reality is that all countries are already affected, and developing countries, are experiencing the worst impacts which calls for urgent adaptation. (Unver and Cosgrove, 2009). Even if Greenhouse Gas concentrations stabilise in years to come, some impacts from climate change are unavoidable, with such impacts on humans and the environment mainly occurring through water (UN, 2009). Despite the resolve by many nations to mitigate further climate change, there is compelling evidence that our climate will become hotter and more variable long before we are able to slow down or reverse the current trend. Thus, we need to adapt (Seager and Mohlakoana, 2007).

Connor et al. (2009) elaborate on this argument and state that climate change is not only a fundamental driver of changes in water resources, but also an additional stressor through its effects on other external drivers. Climate change is both a supply and demand side water resources driver, and it will in due course determine how much water we can access. Furthermore, it will also increase water demand, especially in the agricultural sector where seasonal water demand by crops will increase, while evaporation is generally expected to rise due to increased temperatures. More subtly, climate change is altering the timing, magnitude and duration of precipitation events, which could pose problems for the sustainability of water supplies and the continuity of water treatment regimes. Climate change will directly alter the yield of water catchments and increase the risk associated with uncertainty in the availability of catchment water.

Southern Africa is home to a very large proportion of a population that relies on climate-sensitive economic activities such as rain-fed subsistence agriculture (Connor et al., 2009). Countries in the region are struggling to cope with the burdens associated with disease, conflict and the mismanagement of natural resources. These factors, combined with limited human, economic and infrastructural capacity, leave the Sothern African regional countries vulnerable to climate variability and change.

The vulnerabilities of both rural and urban communities to climate change are widely varied and still poorly understood. The existing local institutions are under-capacitated and not ready to take on the additional burden of supporting climate change adaptation measures. Institutional support for community adaptation to climate change could be delivered with little need to expend additional resources if the adaptation initiatives were built into planned and on-going programmes. The development of mechanisms for ensuring that relevant institutions can support communities in adapting to climate change challenges is already overdue. The research was planned to generate a generic framework for institutional support in the adaptation of communities as they respond to climate change. The development of a framework for adaptation can only be successfully accomplished when the constraining variables are researched and understood. In developing the Hydrosoft Climate Change Adaptation Framework (HCCAF), this research was also designed to develop understanding of the following building blocks:

- Comprehensive maps of climate change vulnerability at community level;
- knowledge base of climate change as an additional stressor that has to be considered as part of several complex stressors in water access and use;
- long-term goals for water access and use. These goals were to be set as part of community-driven targets on ideal livelihoods status as perceived by members of communities;
- capacities of communities and institutions. This factor was set to entail mapping out the capacities of both communities and institutions in climate change adaptation measures;
- toolboxes of possible adaptation measures. This was to involve mapping out the possible adaptation measures, outlining the roles and responsibilities of various institutions and identifying the gaps in the provision of community support;
- policy and legal frameworks for supporting climate change adaptation; and
- community reception mechanisms for adaptation measures. This will occur by developing community ownership and empowering communities through involvement from the onset as part of a bottom-up research approach.

1.3 The objectives of the study

The study objectives were set up as follows:

1. Identify water use-related climate change responses by local communities and define the role of institutions in ensuring adaptive capacity of those communities;

2. baseline investigation into the degree and level of vulnerability imposed on communities due to climate change impacts and their responses;

3. baseline investigation into the role of institutions in supporting communities' livelihoods;

4. conduct needs analysis on community livelihoods and rural institutions;

5. develop appropriate analytical tool(s) on environmental risks, reductions in livelihood opportunities, and stresses on existing resources and social institutions;

6. identify and develop policy framework for communities' adaptation practices, including migration, diversification and other adaptation options in response to climate change impacts; and

7. undertake piloting in a rural setting and at urban community level to clarify roles of local institutions in adaptation actions of communities to climate change impacts on water supply.

1.4 Methodology

1.4.1 The research process

The research process involved the following research stage activities:

Stage 1:

Stage 1 covered the study of appropriate literature, desktop investigations and direct consultations. This stage entailed understanding of available information on the research subject. The climate change impacts were mapped out based on collected data from international institutions formatted for local use by the Council for Scientific and Industrial Research (CSIR).

Stage 2:

The first workshop was held, to which members of targeted local institutions and communities were invited. At this workshop, participants shared their understanding of the subject and provided inputs to the research process. Project targets were revised based on the expectations of the workshop participants and the project client.

Stage 3:

This stage entailed the identification, analysis and mapping out of community vulnerabilities to climate change impacts. Results from the vulnerability assessments were mapped and a Geographical Information System (GIS) data layer was developed.

Stage 4:

This stage involved the implementation of a needs analysis on community livelihoods and local rural/urban institutions. Community interests were made central to the research, with information on needs and water access being obtained through direct consultation with community members at the household level. This stage involved both communities and institutions in understanding the needs associated with water access and use within an environment of climate change.

Stage 5:

The understanding of the study baseline was developed to account for the state of water access and use, as well as the state of water provision. It also established how communities were adapting to other water stressors, and their level of understanding of climate change and adaptation. The boundaries of the framework for adaptation to climate change were also established.

Stage 6:

Possible adaptation initiatives were identified and evaluated for various communities in different localities and these subsequently constituted the adaptation toolbox. The adaptive capacities of communities and how institutions can support them were investigated. At this stage of the study, an understanding of the activities and programmes of existing local institutions involved in water access, use and provision was developed.

Stage 7:

A Climate Change Adaptation Framework (CCAF) for local institutions in their quest to support local rural and urban communities was developed. The adaptation framework was software-based and set on a GIS platform to capture the spatial nature of climate change impacts and the geographical references of affected communities.

Stage 8:

A pilot study was undertaken in both rural and urban community settings. This involved quantifying climate change impacts for the different communities in case study areas, analysing the variables associated with vulnerability to impacts and identifying possible adaptation options. This pilot study also entailed testing of the Climate Change Adaptation Framework through application in selected rural and urban communities, while building further functionality to allow for future expansion of the framework to include usage in other communities. The pilot study involved other role-players with the aim of developing widely acceptable functionality where skills could be transferred to possible users. A second workshop was also held as part of this stage of the research. In this workshop, the researchers sought to extend the dissemination of project findings and to secure further stakeholder inputs in the final stages of the research.

Stage 9:

The last activities of the project entailed the final output packaging and synthesising of project deliverables into a publishable output.

1.4.2 Selection of the case study areas

The aim of this study was to analyse the different types of water access opportunities available to local communities in both rural and urban settings in different parts of the country. In order to define the study area selection criteria, additional factors were established in the early stages of the study. These included the following:

- Areas in different climatic regions of the country;
- area delineation according to national planning;
- the need to work in areas with different settlement patterns;
- areas with varied livelihoods;
- communities with varied population densities;
- communities in both urban and rural settings;
- dealing with water access issues representative of South Africa;
- areas where similar studies have not been done; and
- areas supplied by largely different river systems and dams.

The areas described in Tables 2 and 3 constitute the study areas and their location, and are based on all the above factors as well as inputs from the first study workshop.

The case studies employed in the whole project were focused on local communities within their local municipalities. This focus was influenced by a desire to ascertain the manner in which a large percentage of the population was accessing water. The investigations showed that water access and provision for more than 90% of the population is planned and implemented at the local municipality level. Furthermore, it was clear that there were other water users who obtained water from other water provision entities not working through the municipalities or metropolitans. Although the investigations of the study dealt with a range of water institutions, it still maintained a particular interest in the manner in which the majority of the population accessed water, and that is through the support of municipalities.

Table 2: Statistics for the four study areas (Stats SA, 2011)

	Thulamela LM	Msunduzi LM	Madibeng LM	Letsemeng LM
Area in km^2	2 966	649	3 839	10 180
Households	156 594	163 990	160 724	11 242
Population	618 462	618 536	477 381	38 628
Change in population between 2001 and 2011	Increase of 0.6%	Increase of 1%	Increase of 3%	Decrease of 1%
Population density (per km^2)	208	953	124.4	3.7
Size of population of largest town	Thohoyandou 69 000	Pietermaritzburg 500 000	Brits 123 000	Koffiefontein 9 000
Unemployment rate	43.8%	33.0%	30.4%	22.3%
Piped water inside dwelling	15.2%	47.91%	22.2%	49.8%
District Municipality	Vhembe	uMgungundlovu	Bojanala	Xhariep

Table 3: Information for districts where study areas are located (Stats SA, 2011)

District Municipality	Bojanala	uMgungundlovu	Vhembe	Xhariep
Population	1 268 618	988 837	1 240 035	127 627
Province	North West	KwaZulu-Natal	Limpopo	Free State
Households	911 120	217 876	137 852	37 245
Area in km^2	18 332	8 942	21 407	34 249
Capital	Rustenburg	Pietermaritzburg	Thohoyandou	Trompsburg
Unemployment rate	30.7%	30.4%	38.7%	26.8%
Piped water inside dwelling	26.0%	42.7%	15.4%	42.7%

The 2011 census (Stats SA, 2011) indicated an increase in population in three of the study areas, with the exception being Letsemeng, where a 1% decrease was recorded (Table 2). The fluctuations in population levels over time have a major bearing on how water will be accessed in the future. Madibeng Local Municipality has the most rapid population increase and as a result, the strain on available water will increase rapidly if suitable measures are not taken to extend water sources and bulk water delivery to the area. On the other hand, Letsemeng Local Municipality, with a negative population growth, could theoretically have a lower water demand in the future. In practice, however, water demand increases with development since all users strive to improve their water access habits by having and utilising, for example, in-house plumbing, and benefiting from higher water use tendencies usually associated with more modern lifestyles.

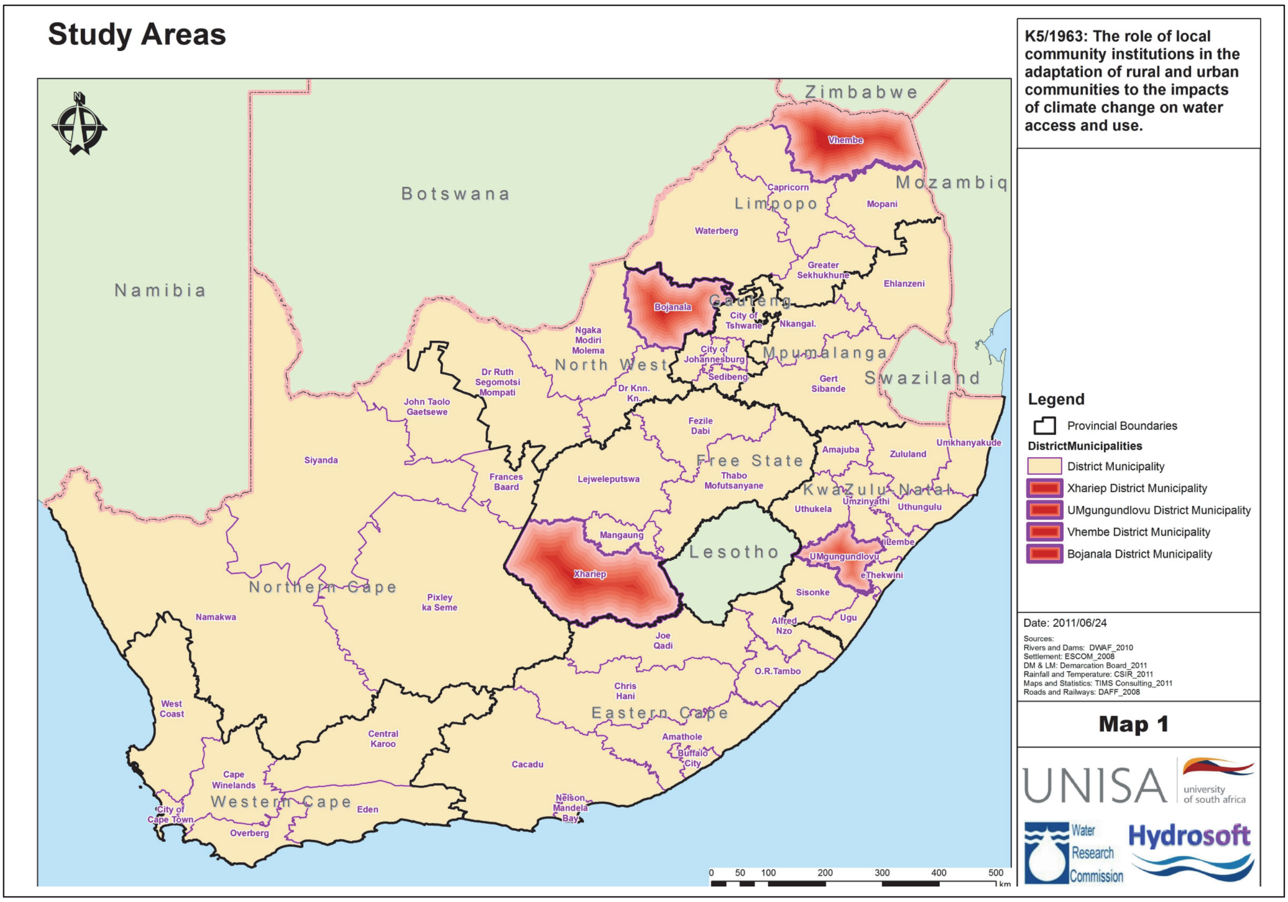


Figure 2: Location of study areas used in pilot study

1.4.3 Data collection in the case study areas

1.4.3.1 Household questionnaires

Information concerning vulnerability at local community level was obtained by interviewing a number of households in different community areas in each of the local municipalities. Generally, four households were found to be sufficient to gain an overall picture of the circumstances prevailing in a particular community. A local community was determined as an area with a group of households existing within the same geographical setting, such as a suburb, a residential township, a ward or other area as defined by local municipal boundaries. The aim was to select communities representing the typical range of types of community members normally found in the municipality in terms of their access to water, type of housing and, on the rural urban continuum, from a formal town, a former township, an informal settlement, a mining town, a dense rural village, a small rural village, rural scattered or a farming area.

The unit of analysis in each community was the household. An adult household member was approached and requested to share information about water uses and access based on the questionnaire. Most interviews took place at the respondent's home, and that meant that almost two-thirds of those interviewed were female. This was not, however, by design as it could reflect the fact that more women are at home during the day on weekdays, when the interviews took place. Only adults were interviewed, meaning only residents more than 18 years of age. Information from household questionnaires was aggregated for the different local communities.

The interviews were guided by the two questionnaires developed by the research team. The first, the vulnerability questionnaire, was designed to capture information developed into indicators of exposure, sensitivity and adaptive capacity. The questionnaire consisted of 51 questions and covered general vulnerability indicators such as education level, income, livelihood, household sources of income and housing, as well as specific water vulnerability indicators such as water uses, water access and levels of service. The questionnaire, presented in Annexure 1 of this report, also addressed strategies and coping mechanisms in the face of water access constraints, communication and interaction with relevant institutions. A total of 312 people responded to the first questionnaire as part of the field surveys in the four case study areas. Households were visited in a total of 14 areas in Thulamela, 15 in Msunduzi, 12 in Letsemeng and 10 in Madibeng.

The administration of the second questionnaire was aimed at supplementing the information obtained in the initial community and institutional surveys in order to determine community vulnerability. As such, team members had to select new community members and exclude those households already dealt with. Households that were visibly unique cases, or somewhat unrepresentative of the general nature of the community were also excluded to avoid dealing with data outliers as the main input data. Some of the same local communities were visited a second time using a second questionnaire consisting of 41 questions. The questions covered the same general vulnerability indicators and then probed the respondents' water needs and constraints, climate change knowledge and concerns, adaptation ideas, and the resources that would be required for adaptation. Different households in the same local communities were interviewed using the second questionnaire, meaning that in total 488 households and 31 farmers were interviewed.

1.4.3.2 Developing and administering the questionnaire

The case study-based research work provided an opportunity to engage with a number of students in terms of local capacity-building. Twenty-four research assistants and four researchers participated in the development and administration of the questionnaires in the four case study areas. A few of the students provided considerable research assistance in the districts where the questionnaires were administered. A list of the students who participated in administering questionnaires is included in Annexure 4. The questionnaire was piloted in a number of communities around Thohoyandou with the participation of five research assistants. The research assistants provided feedback at report-back sessions during which difficulties and misunderstandings relating to the questionnaires were identified. As a result, the questionnaires and the questionnaire information documents were further developed in terms of structure, content and document formatting.

Securing research assistants involved various techniques. In the Thulamela and Madibeng areas, research assistant positions were advertised through the daily newspapers, while in Msunduzi and Letsemeng, university lecturers and the Orange-Riet Water User Association (WUA) were approached to recommend possible candidates. The research assistants for Thulamela came from the University of Venda. The Msunduzi research assistants came from the University of KwaZulu-Natal, Pietermaritzburg Campus, while in the Letsemeng and Madibeng municipalities, student researchers came from the Universities of South Africa (UNISA), Pretoria and Vaal. The research assistants were required to have a working knowledge of the local languages spoken in the areas where they would be operating.

The research assistants initially received training in administering the questionnaires. Each research assistant carried an introductory letter and was briefed on how to introduce and explain the project objectives to respondents. Furthermore, each assistant was provided with an information document in which the more difficult questions were explained. Figure 3 shows research assistants interviewing participants in Madibeng and Msunduzi Local Municipalities.

Figure 3: Research assistants administering questionnaires in Madibeng and Msunduzi Local Municipalities

1.4.3.3 Ward level survey

Detailed information from a number of local communities was later supplemented with a quick survey of every ward in each municipality. The process involved a photographic survey of the level of housing, rural/urban features, livelihood activities and water access features of the ward. Discussions with local inhabitants or a telephone call to the local ward councillor supplemented the information. These discussions helped by being less formal than the questionnaire process. The quick survey aimed to cover the following issues in each ward:

- Water resources in the area;
- the service provider;
- the level of service;
- water metering and billing;
- water access problems;
- groundwater access;
- farming activities and their source of water; and
- water developments taking place in the area.

The ward is an important unit since municipal Integrated Development Plans (IDPs) should ideally start from a community-based planning process at ward level. Nevertheless, the challenge for researchers in working with ward boundaries proved to be that the number of wards in a municipality and their boundaries change from time to time.

1.4.3.4 Interviews and literature relating to local institutions

Interviews conducted with relevant personnel in municipalities, WUAs, irrigation boards and NGOs probed each institution's functioning and capacity, water development plans, water development constraints, ways of communicating with its constituency and human and financial resources. Reports such as IDPs, water development plans, water safety plans, water reconciliation studies and technical plans were obtained from local officials or websites. A questionnaire was also used to obtain information from irrigation boards and the Orange-Riet WUA.

1.4.4 Institutional and local community data entry and analysis

The data obtained from questionnaires were entered into a spreadsheet-based database. Missing data were obtained by contacting the relevant respondents and, in some instances, the ward councillors, who were contacted to provide more holistic information about areas in their wards. The raw data were screened, and indicators where inputs from communities were poorly formulated or generally inadequate were excluded. A local community dataset containing summary and average values for each local area was then developed to capture information from the individual respondents residing in each common local area. The local area summary datasets were used for the quantification of indicators in the indexing and mapping processes.

1.5 Limitations and possible sources of errors

Shortcomings in representativeness: The study makes conclusions based on samples of local communities which formed part of the case studies. Although attempts were made in most cases to investigate households of the local municipality areas, these areas are not completely representative of the whole local municipality, and less so for the whole district municipality. In order to improve the representativeness of data from community-based study questionnaire outputs, researchers also tried drawing from general observations made in the whole local area for which the indicator was being calculated. Information from the Integrated Development Plan (IDP) reports, recent community survey reports (Stats SA, 2008) and other local references were also used in drawing up average or representative values for each local area.

Limitations in accuracy: Some of the information provided by the respondents tended to be approximate in terms of the real circumstances rather than completely accurate. This problem was mostly encountered in questions regarding incomes.

Consistency amongst research assistants: The inputs relied heavily on how the research assistant administered the questionnaire. While much effort was expended in training research assistants, there were differences in how certain questions were asked. This led to a level of inconsistency regarding the manner in which individual inputs were captured. The vulnerabilities were generally assessed based on several inputs from a local area. This tends to reduce or even remove negative implications of inaccuracies in data inputs from individual households.

Extent of input variables was limited: There were many other variables that could have been included in a study of this nature. For example, some studies have suggested that the gender of a household head resulted in major implications on access to resources and the type of livelihood. In order to reduce the number of questions in the questionnaire, this study did not ask certain questions directly. The study did, however, focus on a questionnaire where 87 different responses, covered in the 51 sets of questions, were possible. The questions used were based on the need to obtain information from variables with high significance in the determination of water access status and vulnerability.

Assumptions made could generate errors: The study assumes that the nature of adaptive capacity and sensitivity experienced by communities will influence future vulnerability. This is not always the case, however, since many developments can change the vulnerability scenario over the years. For example, the development initiatives in the municipalities are set to change the state of community vulnerability over a number of years. The study also assumes that the current capacities of institutions will prevail as we move into the future. The reality, however, is that the nature and capacity of institutions to assist communities in adapting to climate change are never static. The changes observed in the recent past have pointed to the need for increased strategic initiatives for bringing about improvements in service delivery. Without major changes to current practices, the long-term scenario is characterised by very weak municipalities which will be daunted by the tasks of addressing the needs of much larger and very needy communities. The UN (2003), however, concluded that access to basic resources such as water empowers people to make better choices and to fend for themselves in times of crises. Indeed, future adaptation in water access will also depend on the present state of affairs in communities.

Not all information on water uses and access could be captured to the same depth: The focus in the community engagements was largely on domestic water users. While agricultural water use is described for each of the case study areas, it was not practical to carry out detailed research on both communities' domestic use of water and on smallholder farming communities, where water forms part of a range of interrelated requirements for successful farming, including finance, transport, markets, etc. The focus was, therefore, primarily on water use and needs in non-farming urban and rural communities.

1.6 Report structure

The report is laid out into 12 chapters and three themes. The study is introduced in Chapters 1-5, which investigate available knowledge on climate change, vulnerability, adaptation and the role of institutions. The understanding of available knowledge is extended in Chapters 6-8 through a presentation of further information from literature, and desktop studies which were targeted at study areas. In Chapters 9-10, the discussion is centred on the discussion of feedback from case study areas, including community and institutional inputs obtained from field studies. The development of the Hydrosoft Climate Change Adaptation Framework (HCCAF), as well as the entry of data into the framework, is also captured in this section. In Chapters 11 and 12, the researchers demonstrate how the framework performs in a pilot study and conclude the study with assessments of findings and recommendations.

The specific chapters are laid out as follows:

Chapter 1 presents an introduction to climate change adaptation, water access and use, the research objectives, the study motivation, selection of study areas, research methodology and research limitations.

In Chapter 2, relevant aspects of the literature on climate change and climate change modelling and downscaling are discussed. A review of literature on climate change impacts globally and locally on hydrology, livelihoods and society is also included.

The understanding of available literature on adaptation is captured in Chapter 3. This chapter also considers the existing community knowledge and community members' experiences in adapting to adverse climate conditions, including climate variability and climate change.

Chapter 4 contains a discussion of the concepts and available literature on vulnerability, as well as the basis of the procedure used in quantification and ranking of sensitivity, adaptive capacity and vulnerability.

In Chapter 5 the research examines the institutions that are important for water access and use in South Africa, and also provides a discussion of institutional roles with a view to articulating these roles in the framework as part of adaptation.

Chapter 6 provides an overview of the case study areas, geography, weather and climate, demographics, socio-economic status and nature of water resources.

Chapter 7 presents the research findings on water access and use in communities in the case study areas. The findings in this section are based on the questionnaires which were administered in these areas.

Chapter 8 presents the research findings on institutions that are responsible for water access in the case study areas. The findings are based on desktop investigations, questionnaires and interviews.

Climate change impacts are mapped and presented for each case study area in Chapter 9. The impacts are presented as the nature of exposure affecting different locations in case study areas.

Chapter 10 discusses possible adaptation initiatives for communities in the case study areas. The adaptation options are also discussed in terms of the spatial scales involved.

The development of the Hydrosoft Climate Change Adaptation Framework (HCCAF) is covered in Chapter 11. A short discussion on how to build the framework scenario and enter inputs is also discussed, and the user referred to the user manual for detailed guidance on the framework software.

Finally, Chapter 12 analyses the finding and adaptation options discussed, followed by the study conclusions and recommendations.

2 Climate change and climate change impacts

2.1 Introduction

The earth's climate is rapidly changing (IPCC, 2007a), and different understandings of these changes are found in the manner in which climate change is defined by various bodies. The definition of climate change put forward by the Intergovernmental Panel on Climate Change (IPCC) refers to any change in climate over time, either due to natural variability or due to human activities (IPCC, 2007a). The United Nations Framework Convention on Climate Change (UNFCCC) refers to climate change as a change of climate variables attributed directly or indirectly to human activity. In essence, this refers to the degree to which the composition of the global atmosphere is altered over and above that of natural climate variability observed over comparable time periods (UNFCCC, 2007).

Climate models and evidence from ice caps suggest that climate forcing in the past has been consistent with changes in solar irradiance and volcanic activities, while in recent years anthropogenic Greenhouse Gases have contributed to the increase in climate forcing (Crowley, 2000). Carbon dioxide is the main culprit among gases that absorb thermal radiation from the earth's surface, resulting in less net thermal radiation leaving the earth's atmosphere, the combined effect of which is global warming (Houghton, 2005).

Although global warming has the net effect of increasing the global temperature, the changes on the earth are not uniform, with some areas experiencing an increase in temperature while others experience a reduction during the same period. The scales of this spatial variability vary from local to sub-continental and global scale. In the past, climate change scientists had to rely on climate change prediction model outputs where the smallest units of resolution were in thousands of square kilometres. It is now possible, however, to obtain climate predictions for much improved resolution, down to as detailed as 50 km^2 (Houghton, 2005). This is critical because while the causes of climate change are global, the impact felt is local, and adaptation measures should be implemented at these local scales.

2.2 Climate change, variability and cycles

The climate system is driven by the radiation process and an alteration in this process causes a change in the climate system. According to the Milankovitch theory, major changes in the radiation processes are caused by the variations in the earth's orbit around the sun, with cycles ranging from about 20 000 years to about 100 000 years (Hewitt, 2000). The earth's orbit is such that there are periods when the earth is closer to the sun and others in which it is further away from the sun. Such changes result in cycles of warm climate periods and ice age periods during which a large part of the earth is covered by ice (Bertrand et al., 1999; Hewitt, 2000). The last ice age period was about 20 000 years ago, with ice covering a considerable landmass of the northern hemisphere, as shown in Figure 4 below (Hewitt, 2000). Ice caps and marine sediments provide valuable evidence of the climate change during the past thousands of years.

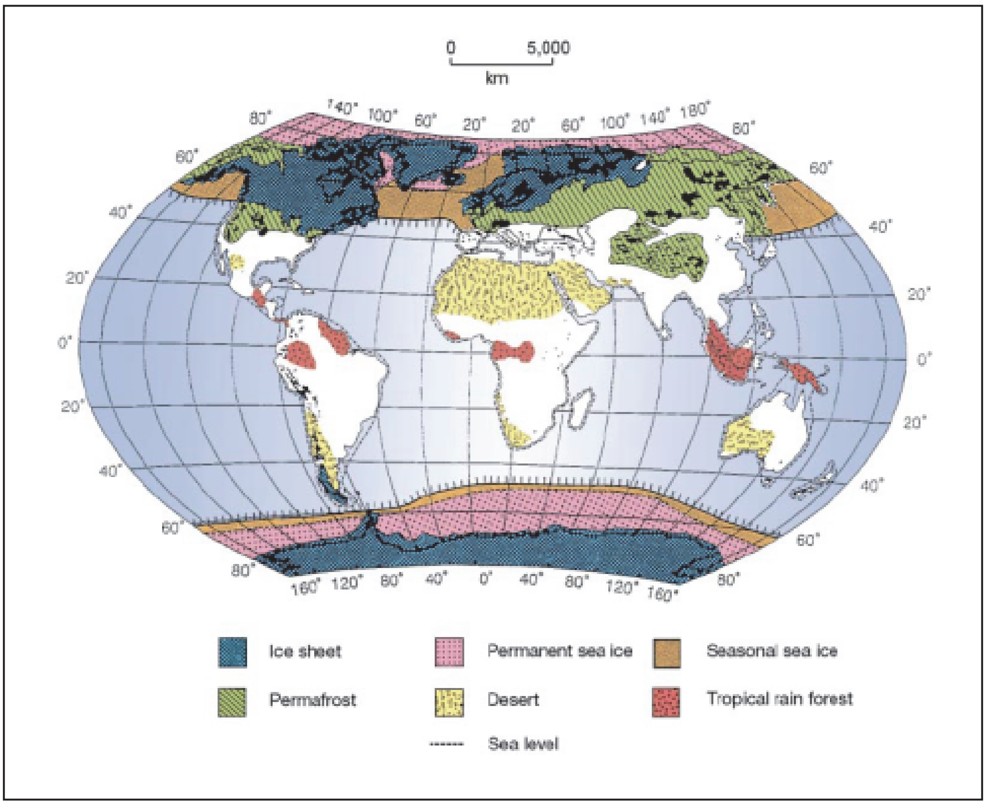


Figure 4: Extent of ice sheets at the end of the last ice age period (Hewitt, 2000)

Historic natural climate forcing can be examined through historical ice core evidence (Thompson, 2000). Ice caps from high elevation tropical areas such as Kilimanjaro in East Africa, Andes of South America and Himalaya in Asia, as well as the polar regions, provide evidence of pre-industrial historical variation in temperature, atmospheric dust and Greenhouse Gas concentration that can be compared with recent variations, which also include anthropogenic contributions. Apart from ice core evidence of natural forcing, evidence on climate change can also be obtained from marine sediments (DeMenocal, 2003). Evidence from aeolian dust obtained from such sediments shows that African climates have changed periodically from wetter to drier conditions (DeMenocal, 2003). Evidence from sediments preserved in the Pretoria Saltpan was also used by Partridge et al. (1997) to determine rainfall variation during the late Pleistocene period. The assessment of the historic sediments is currently assisting scientists in determining the prevailing climate conditions at the historical periods when the sediments were deposited.

Apart from the ice age cycles at intervals of thousands of years, shorter term climate variability caused by more frequent natural climate forcing, exists, with typical examples being volcanic activities. More recently anthropogenic activities have also contributed to this short-term variability. Periodic and shorter-term climate cycles are also due to changes in oceanic currents such as El Niño Southern Oscillation (ENSO). Large-scale warming and cooling of sea surface temperatures have been observed in the Pacific Ocean at comparable time scales of about three to four years. The recurrences of the warming El Niño events have been more frequent since the 1970s, with a long sequence between 1991 and 1995 further pointing to the effect of an increase in Greenhouse Gases. El Niño also has implications for the occurrence of droughts in some parts of southern Africa (Mason, 2001).

Even without climate change, access to water by most communities is affected by highly variable hydrological patterns. This research will look at climate change in an environment of climate variability, with associated problems affecting communities across all levels of society. Considerable levels of water storage have been achieved in South Africa to mitigate the effects of highly variable surface water flows, exhibiting both quantity and spatial variability. Years of dam construction have increased the firm yield in the supply of water across the country. While the dams are expected to mitigate the impacts of climate variability, their inflows are still highly variable, causing problems with frequent shortages for some communities. Figure 5 below shows the variability of the volume of water stored in South African dams from 1980 to 2011. Apart from the shortages associated with climate variability, communities can only benefit from constructed water storage infrastructure if this water is treated and reticulated. Shortcomings due to 'the human element' in the provision of water services tend to magnify what are perceived as effects of climate change in water access and use.

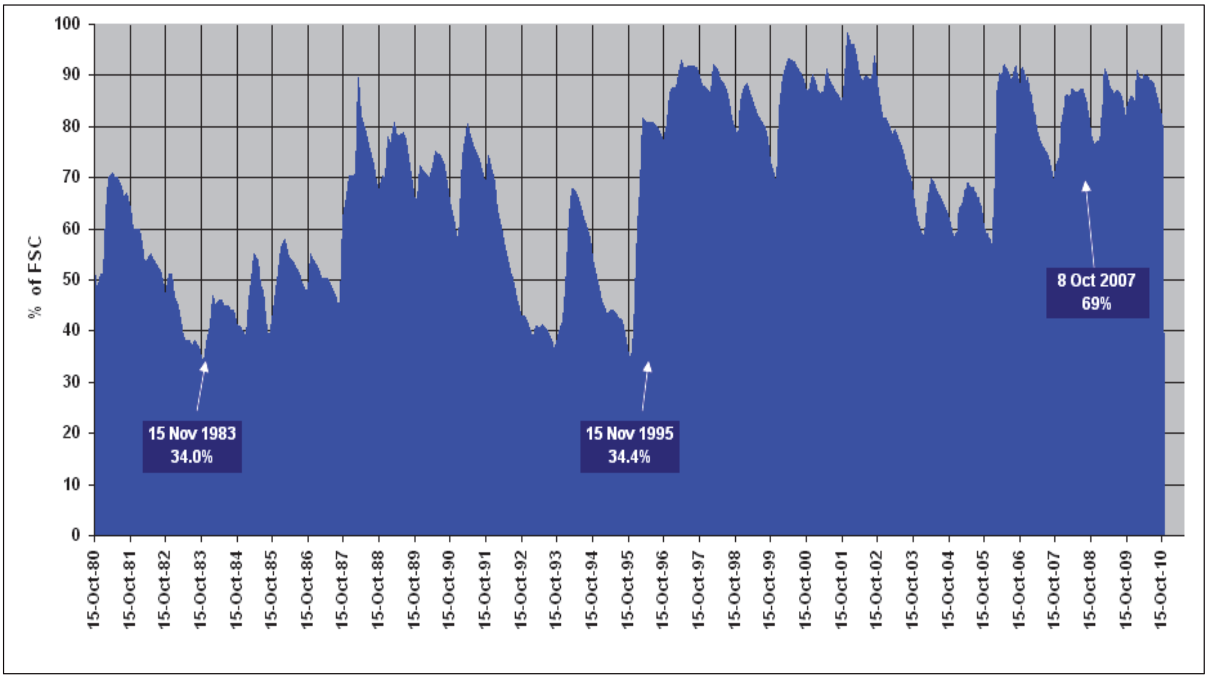


Figure 5: Temporal variation of reservoir storage for South African dams measured weekly from 1980 to 2011 (DWA, 2011f)

2.3 Climate change investigations

Trends and changes in climate over past centuries and millennia can be examined through historical ice core evidence (Thompson, 2000). Ice caps provide evidence of pre-industrial historical variation in temperature, atmospheric dust and Greenhouse Gas concentrations that can be compared with recent variations. Evidence of climate change can also be obtained from marine sediments (DeMenocal, 2003), where evidence from accompanying aeolian dust shows that the African climate has changed periodically from wetter to drier conditions (DeMenocal, 2003). Recent changes in the climate have been considered to be inconsistent with natural climate forcings. In the twentieth century the upper bound, which had persisted for at least 1 000 years, was exceeded as a result of global warming. The characteristic J-shaped graph has now become known as the 'Hockey Stick

Curve'. Michael Mann, the official creator of the 'Hockey Stick Curve', produced the graphical representation of temperature for the past 1 000 years (Hamblyn, 2009) using proxy techniques.

The temperature data was obtained from signatures left on ice cores, tree rings and isotopic analysis of corals. Former US vice-president Al Gore used the 'Hockey Stick curve' and other information from Michael Mann and other scientists to produce the 2006 documentary entitled *An Inconvenient Truth*. Hamblyn (2009) later wrote that in the climate change documentary, the 'Hockey Stick Curve' is sensationalised by 'letting the stick end go into the roof'. While parts of the work by Michael Mann and some of his colleagues in climate change research generated many controversial discussions in 2010, the international climate change institutions have nevertheless used the 'Hockey Stick Curve' to convey complex science to the public (IPCC, 2007a). The temperature reconstruction by Mann giving rise to the 'Hockey Stick Curve' was criticised by some researchers, such as Hans von Storch, who argued that the temperature data was underestimated (Hamblyn, 2009). They did not, however, disprove the impact of human activity on climate change, and also agreed that some of the temperature increase was indeed due to anthropogenic effects.

Climate change over future decades is predicted through the use of Global Climate Models (GCMs) (Houghton, 2005). These atmospheric and oceanic models analyse the global circulation of air masses and ocean currents as they respond to solar and thermal energy input. Such models operate at a relatively coarse scale of the order of 2.5^0 latitude and 3.75^0 longitude, which translate to a minimum horizontal scale distance of 500 km (Fowler et al., 2007). Examples of Global Climate Change Models that are in use include: Commonwealth Scientific Industrial Research Organisation (CSIRO); Coupled General Circulation Models (CGCM) (Vimont et al., 2003); National Oceanic and Atmospheric Administration Geophysical Fluid Dynamics Laboratory (NOAA/GFDL); Global Atmosphere Model (GAM) (Wilcox and Donner, 2007) and Hadley Centre Climate Simulations (HadCM2 and HadCM3) (Pope et al., 2000), which are all Cartesian grid-point models (Figure 6). The results of these models are therefore averages of larger spatial scales in the order of thousands of square kilometres.

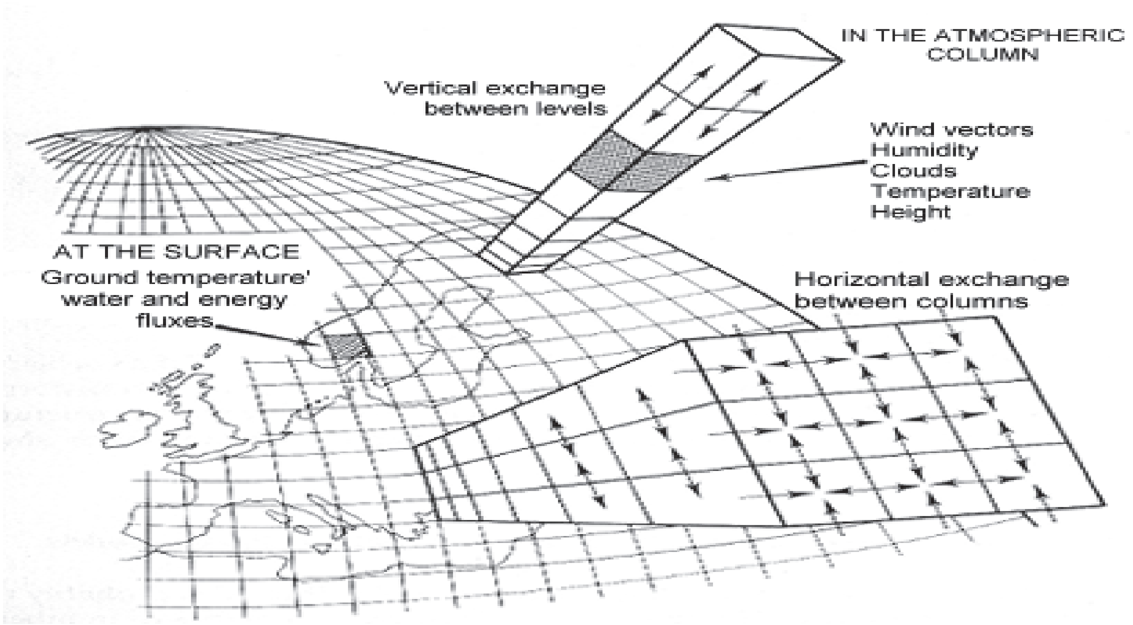


Figure 6: A typical Cartesian grid used in Global Climate Models

While the global changes predicted in Global Climate Models indicate a general increase in temperature, the regional prediction shows a variety of implications at localised scales (Houghton, 2005). The global scale perspective is translated to local scales after taking into account local forcings.

2.4 Regionalisation of climate change, impacts and adaptation

Global Climate Models operate at a scale of the order of 2.5^0 latitude and 3.75^0 longitude while hydrological impact assessments are carried out at scales of the order of 0.1250^o latitude and longitude. This gap in resolution between climate change models and hydrological impact assessments can be solved through regionalisation and other downscaling techniques.

To date, most regional climate change information has been based on the use of Coupled Atmosphere-Ocean General Circulation models (AOGCMs) enabled by the World Climate Research Programme (WCRP) during the past 30 years (Giorgi et al., 2009). While current AOGCMs have proved quite successful in reproducing the main features of the general circulation (IPCC, 2007b), they do not adequately represent the effects of regional-to-local-scale forcings such as those due to the topography and other local conditions. The Coordinated Regional Climate Downscaling Experiment (CORDEX) framework was developed to take advantage of developments in regionalisation and downscaling. CORDEX essentially has the two-fold purpose of providing a framework to evaluate and benchmark model performance (model evaluation framework), and of designing a set of experiments to produce climate projections for use in impact and adaptation studies. In South Africa, the Climate Systems Analysis Group (CSAG) at the University of Cape Town has been actively involved in the CORDEX framework.

Scaling down from the large global scales to regional models allows researchers to draw more accurate and meaningful conclusions applicable to selected communities in the study. Several downscaling techniques exist and these can be categorised into three main approaches, as follows: dynamical downscaling, statistical downscaling and sensitivity downscaling (Fowler et al., 2007; Lenart, 2008). With dynamical downscaling, a higher resolution climate model is embedded within a general circulation model, and it fits output from GCMs into regional meteorological models to produce regional scale climatic features. Statistical downscaling uses statistical methods to convert global-scale output to regional-scale conditions. Sensitivity analysis involves bringing climate projections down to the scale of a sector or business (e.g. water sources, timber producers or a single farming community). Such analyses may use several approaches to consider the impacts of changing climate on a specific sector or institution.

Dynamic downscaling provides results consistent with physical processes. Statistical downscaling is simple, cheaper and more easily transferable, but requires a long-term series of reliable observed historical data for calibration. Statistical downscaling is most suitable where mean characteristics are adequate to achieve the main objectives (Fowler et al., 2007). Hewitson and Crane (2006) of CSAG developed a statistically based empirical downscaling technique and applied it to downscale precipitation from Global Climate Models in South Africa. Ziervogel et al. (2008) observed that not all institutions in South Africa use the CSAG downscaled outputs, but instead many researchers and practitioners continue to rely on output from a regional climate model, PRECIS, a dynamical model developed by the Hadley Centre.

Ziervogel et al. (2008) also discussed a further step to downscaling, namely empirical downscaling, described by certain other authors as statistical downscaling. The description from Ziervogel et al. (2008), however, sheds more light on the empirical downscaling techniques. Empirical downscaling uses the quantitative relationships between the state of the larger scale climatic environment and local variations sourced from historical data. By coupling specific local baseline climate data with GCM output, it provides a valuable solution to overcoming the mismatch in scale between climate model projections and the unit under investigation. Empirical downscaling can be applied to a grid or to a particular meteorological station. The later sub-set of empirical downscaling is more common, however, and is referred to as statistical empirical downscaling. Figure 7 is an illustration of empirical and dynamic downscaling.

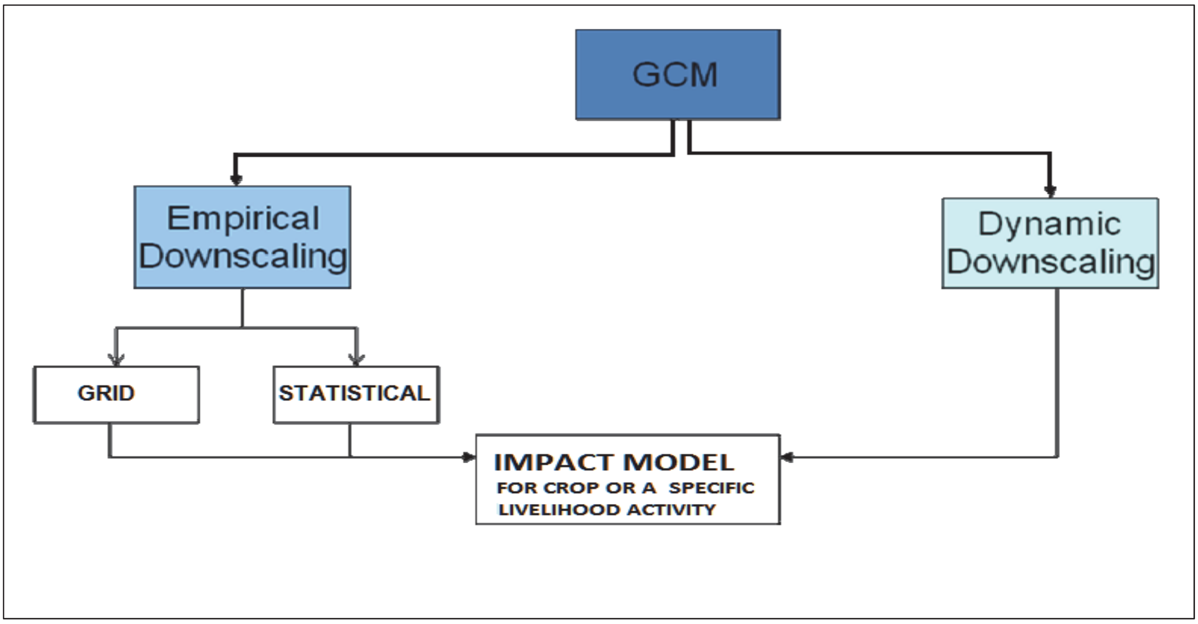


Figure 7: Dynamic and empirical downscaling (Ziervogel et al., 2008)

2.5 Climate change impacts in the world

The phenomenon of melting glaciers, reductions in Artic sea ice in summer, shrinking lakes, changes in the growing season in different parts of the world and shifts in the habitat ranges of birds, insects and other creatures are the evidence that scientists point to when speaking about global warming. The planet as a whole has warmed nearly 0.8°C since 1900 (World Bank, 2012). The rise has generally been greater over the northern hemisphere continents than over the tropics, especially at higher latitudes.

Climate change will inevitably have impacts on hydrology. The 2007 IPCC assessment states that rainfall is very likely to increase across most mid- and high latitude countries of the northern hemisphere by between 5% and 20%, but is likely to decrease in most subtropical land regions. A study by Westra et al. (2012) investigated trends in precipitation from a global dataset of 8 326 high quality land-based observing stations with more than 30 years of records over the period from 1900 to 2009. They found a statistically significant increasing trend globally, with close to two thirds of stations showing increases. There was also a statistically significant association with globally averaged near-surface temperature. The research team tested the Clausius-Clapeyron ratio, which predicts that for every 1°C, saturated air will hold 7% more water vapour, and found that the observed extra rainfall related to the predicted ratio. The greatest increases were in the tropics and higher latitudes, with the greatest uncertainty being near the equator. There were fewer weather stations there with sufficiently long records and the researchers noted that there is an urgent need to improve data collection.

2.6 Climate change impacts in Africa

The IPCC fourth assessment report states that the entire African continent is projected to warm up during the 21st century, in all seasons and faster than the global average. The drier subtropical regions are projected to warm more than the more moist tropics (Department of Science and Technology, 2010). Precipitation is projected to decrease in sub-regions of Africa such as the Mediterranean, north of the Sahara, the winter rainfall areas and the western margins of southern Africa (IPCC, 2007b). The East African and Equatorial African sub-regions are generally expected to experience an increase in precipitation (UNFCCC, 2007). The IPCC fourth assessment report states that there are limitations on how well regional models can downscale precipitation over Africa in the current period.

Climate change is expected to increase the incidence of droughts and floods. Both of these extreme events are known to lead to loss of life, damage to private property and public infrastructure, as well as disruption of people's livelihoods (Toulmin, 2009; Burley and Haslam, 2008; Rahman, 2009).

Investigations of projected temperature changes using various GCMs and applying the variable resolution global model CCAM showed that the temperature for southern Africa will generally increase. The magnitude of increases will range from zero to as much as 6°C by the year 2100 (Department of Science and Technology, 2012). Figure 8 below shows the projected change in minimum temperature over southern and tropical Africa (degrees Celsius) for the period 2041-2070 vs 1961-1990 under the A2 emission scenario of the Special Report on Emission Scenarios (SRES). This projection was obtained by forcing the variable resolution global model CCAM of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) with the bias-corrected sea-surface temperatures and sea-ice of the six coupled climate models (Department of Science and Technology, 2012).

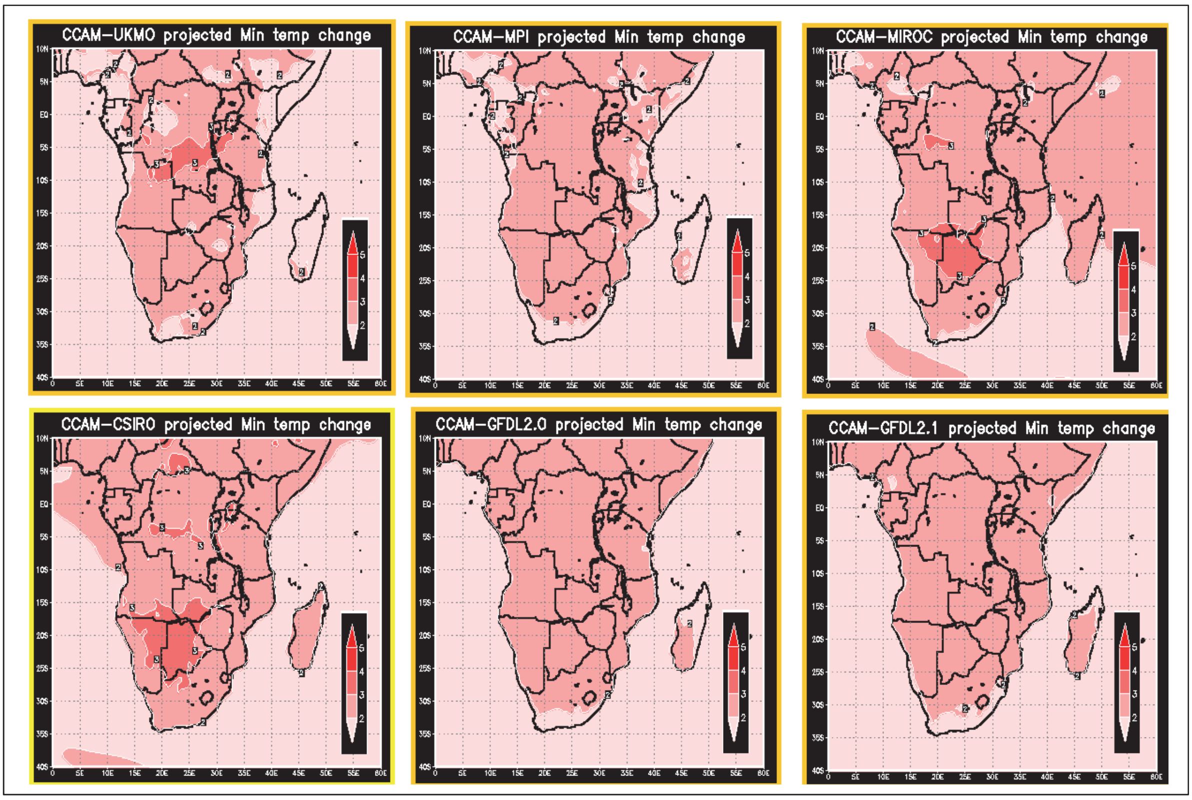


Figure 8: Projected change in minimum temperature over southern Africa and tropical Africa from the period 2041-2070 vs 1961-1990 (Department of Science and Technology, 2012)

2.7 Climate change impacts in South Africa

Climate change is expected to cause temperature increases all over South Africa, with the lowest increases being along the south and east coastal areas. The CSIR CCAM projections using various GCMs, as shown in Figure 8 above, further indicate that higher rates of temperature increases of up to 4°C could possibly be experienced in the north-eastern parts of South Africa.

In this country climate change is projected to cause significantly increased precipitation in areas receiving orographic rainfall in the north-east and south-eastern coastal areas. In the rest of the country comprising the interior and western coastal part of the country largely receiving convective rainfall, however, the increases due to orographic rainfall will not occur (EDRC, 2003; Lumsden et al., 2009).

Impact of climate change on stream flow is also expected to vary in response to changing rainfall. Major rainfall increases projected in this study based on the CCAM CSIRO dataset for the Lesotho Highlands and surrounding areas are expected to generate major increases in runoff in a key catchment area. The major Orange-Senqu River System provides most of the water used in Gauteng and the main agricultural and industrial areas of South Africa (DWAF, 2002).

The South African Risk and Vulnerability Atlas (Department of Science and Technology, 2010) states that climate change poses three major risks to our nation's water resources:

- increased incidence of drought due to extreme rainfall incidences;
- increased incidence of floods due to the high incidence of very heavy downpours; and
- increased risk of water pollution linked to erosion, disasters and algal blooms. The higher temperatures will create conditions that are conducive to a rapid increase in algal blooms.

2.8 Conclusion

This chapter discussed available knowledge on climate change and variability in addition to the manner in which climate change impacts are determined. The understanding of climate change impacts is developing and indeed some ideas from the past are already being challenged as new tools and data for evaluating climate change become available. The limitations in long-term climate data have major implications on how climate change projections can be understood. It was also established that the different groups dealing with the subject of climate change tend to use different models, which results in significantly different projections. Climate change will affect patterns of precipitation and runoff globally, but the impacts will differ from area to area. In South Africa, while recent climate simulation and downscaled findings tend to predict increased rainfall for most of the country, past studies tend to report that South Africa will be significantly drier.

In planning and implementing adaptation strategies, each water resource system in the country should be considered in its uniqueness such that catchment responses and possible adaptation options will need to be correctly selected and optimised for the unique situation.

3 How have communities traditionally adapted to climate change and variability?

3.1 Introduction

South Africa is generally characterised by a harsh hydro-climatic environment with high rainfall variability and periods of drought. The methods by which communities have adapted to climate and weather extremes follow inherently the same techniques which could be extended for application to adapt to climate change impacts. Given the already high incidence of extreme weather and climate conditions in different parts of South Africa, survival has always demanded different adaptation techniques and resilience, long before the additional anthropogenic-related climate stress came under consideration.

Population growth, urbanisation and industrialisation have increased water consumption and now demand ever more sophisticated water resource management and engineering. It follows then that, whereas mitigation of climate change is new, adaptation is an extension of on-going processes. This chapter examines strategies and practices that have been used in the past to manage water resources in the context of climate variability, population pressure, and, more recently, climate change. Some practices, such as water harvesting in homestead ponds, have been used for generations. Other practices, forgotten or not recently utilised, are now being revived, and some even modernised with the use of new materials, but they are based on the same principles. Modern technology, for example satellite technology, is now also available for weather forecasting.

The international convergence of various countries on issues of climate change is making it possible to share knowledge across communities in different countries. Many countries have centuries of knowledge available on how to adapt to an arid climate, and have developed techniques for extracting, storing, conveying, using and governing water in a context of scarcity or uncertainty. The past few years have seen efforts by organisations such as the United Nations Framework Convention on Climate Change (UNFCCC) to encourage the documenting and sharing of existing adaptation strategies and technologies. To encourage this worthy goal, databases for sharing climate change adaptation and coping strategies have been developed and documented. One such database is available through the UNFCCC dissemination platform, which consists of internet-based information and publications.

3.2 Climate change and adaptation at local community levels

Adaptation decisions are made at various levels, with the lowest level of adaptation being the household level, followed by a local community. Other levels at which decisions are made include governmental and non-governmental entities at various levels in relation to the community and the society in which this community exists. A farmer deciding to change the crop that he/she plants to one that needs less water is said to make a decision at household level. Such a decision can be relatively easily reversed, whereas the decision to create a new water augmentation scheme for a large community is a long-term decision usually made by a public utility. The output in this institutional decision could be the creation of infrastructure with a lifespan of decades.

The UNFCCC (2006) publication, *Technologies for adaptation to climate change,* categorises the different types of adaptation initiatives into private and public, reactive and proactive. Adaptation responses are classified as either proactive or reactive. Enforcing strict water regulations in anticipation of reduced water availability is an example of proactive adaptation, while provision of water using tankers to supply communities in distress is an example of reactive adaptation. Planning for adaptation and anticipatory initiative are the ideal. Decision-making processes by communities tend to lack formal planning processes since they are usually responding to adverse situations rather than being proactive.

Institutions have always had the opportunity and the means to use various sources of information to plan and allow for proactivity in adaptation strategies. This study is concerned with the role of institutions in supporting communities to adapt to climate change. The success of institutional support relies on decisions made at an individual or household level in most cases. The local institutions will support individuals or households through support structures which target the adaptation processes and the variables associated with decision-making by members of the community. In the case of rural and commercial farmers the requirements for a decision to change farming practice could include:

- Knowledge of projected weather patterns;
- recognition that current practice is no longer viable;
- knowledge of more appropriate alternatives;
- agricultural and agricultural-economic information;
- information about the market for the crop;
- a source of seeds and other inputs; and
- possibly, a risk reduction mechanism such as insurance for the crop.

For many years now farmers have been making decisions based on interaction with various institutions which, along with other support structures, include the following: agricultural extension officers, company sales representatives, informal and formal farming networks, local agricultural co-operations, media reports, agricultural literature, markets, sellers of seeds, and financing and credit institutions. Furthermore, the question of whether such networks or service providers exist at all depends largely on institutional decision-making at different levels. For instance, the availability of a local extension officer depends on policy and financial decisions made by national governments, and in particular the Department of Agriculture. The provision of rainwater harvesting tanks to improve water access for communities was one such community support initiative provided by a government bill aimed at improving water access (DWAF, 2004a). While implementation takes place at household level, the main support came from the Department of Water Affairs, which drafted the Bill to support the programme, and the Department of National Treasury which provided the funding for this initiative.

3.3 Traditional approaches in rural communities

Some rural communities in South Africa, dependent largely on agriculture for their livelihoods, as farmers and as labourers on farms. The agricultural practices often suffer from very low rainfall thus exposing these communities to very poor states of livelihoods. The situation is aggravated by the fact that South Africa is a country emerging from a history characterised by oppression before becoming a nation of exemplary democratic values. As such, a large group of the population continues to exist on marginal lands where productivity is sensitive to climate variability and changes.

A history of community relocations has left communities in areas to which they are ill-equipped to adapt, thus creating problems in their ability to fend for themselves. UNESCO (2006) reported that while South Africa has already attained its Millennium Development Goal targets to halve the size of the population without access to water, 8% of the population still has no access to any water supply infrastructure, and up to 39% of the population does not even receive minimum basic water supply services.

Despite an oppressive background, rural communities have developed some coping and adaptation strategies in response to environmental realities. One such reality is groundwater, which is the main source of water for rural areas. UNESCO (2006) reported that, although groundwater represents only about 9% of available water resources, 74% of South African rural communities are dependent entirely on it, with another 14% partially dependent on it. Rural communities are located in areas where the use of surface water is associated with major risks due to highly variable rainfall and river flow regimes. Water quality is also poor and it is becoming rapidly worse due to an accumulation of pollutants, a problem which has failed to be addressed over decades. It is hardly surprising, then, that communities in rural areas have resorted to groundwater, the supply of which is more reliable, when available, and in most cases of a better quality.

This section surveys and discusses some traditional methods used in rural areas to cope with harsh climatic conditions. Furthermore, the section also analyses various community and institutional responses to other environmental threats similar to those due to climate change.

3.3.1 Agricultural rainwater conservation and harvesting

One of the ways in which communities have adapted to rainfall variability in arid and semi-arid areas around the world is through rainwater conservation and harvesting. Denison and Wotshela (2009) documented indigenous water harvesting and conservation practices in South Africa. Kahinda et al. (2008) discussed a number of rainwater harvesting practices found to be suitable in various locations around the country. Methods used can be grouped into in-field and ex-field techniques, where the former are associated with improving water availability for crops, while the latter involve water storage from mountain sides, roof tops and other structures. Some examples of commonly practised rainwater harvesting techniques in rural areas are as follows:

- **Gelesha** – the practice of tilling the soil after the autumn crop harvest to loosen the earth crust and ensure that any falling rain, dew or frost moisture can infiltrate the tilled soil;
- **Stone terracing** – the purpose of this practice is to arrest and divert surface run-off, while preserving the soil;
- **Homestead ponds** – the practice of creating homestead ponds, or 'matamo', was common among the Sotho-Tswana people who expanded into the drier highveld of South Africa. It began in the nineteenth century and was widespread until the 1970s, when it began to die out;
- **Saaidamme** – a form of infield rainwater harvesting technique. The name is derived from a local name for floodwater farming practised in the arid Northern Cape. Fertile, silt-laden floodwater is diverted into flat basins ringed by a low earth wall. The water is allowed to stand for a period to saturate the very deep soils, and is then drained out. Planting takes place immediately after the flood event and the plants rely entirely on the receding water table;

- **Contour ridges** – these serve as local infield water accumulation areas developed parallel to the contours in an area for cultivation; and

- **Pitting** – this is a technique used since 1100 AD to rehabilitate grossly degraded, eroded rangeland. Pits dug at regular intervals collect runoff water and allow it to infiltrate. Pitting has also been used in the Loess Highlands of China (Erikson, 2003) along with reforestation to prevent water loss and soil erosion on steep slopes. Semi-circular holes are dug into the slope and the excavated earth is used to form a wall around the semi-circle, thus preventing water from running off. The pits temporarily store water flowing down the slope, allowing it time to permeate into the ground and thereby store sediments. Trees can then be planted in the pits.

3.3.2 Infield and roof rainwater harvesting

Rainwater harvesting (RWH) using tanks to collect run-off from hard surfaces such as roofs was practised in the past, and has in recent years undergone a revival. Galvanised iron rainwater tanks were used decades ago, before municipal services were available, and corrugated iron tanks, which inhabitants have erected, are currently in use in the Eastern Cape. Commercial farms, now mainly supplied by boreholes, also have evidence of old rainwater tanks. South Africa has well-developed water supply systems for formal urban areas, and the intention of the post-1994 government has been to extend piped water to every area. In many rural areas, however, homesteads are very scattered, making reticulated supplies prohibitively expensive. The Department of Water Affairs has instituted a national programme to provide rainwater harvesting resources, including installations for needy communities (DWAF, 2004a). Kahinda et al. (2008) has developed suitability maps for infield rainwater harvesting in South Africa which take into consideration a number of variables on which to make decisions for suitable rainwater harvesting.

3.3.3 Fog water harvesting

Fog or dew harvesting has always been practised in various forms. The techniques range from use of rocky surfaces or leaves to installation of larger surface areas on which water vapour in the atmosphere can condense and then be channelled and collected, providing clean, potable water (Olivier and van Heerden, 2002). Dew harvesting has been practised by humans and desert beetles from ancient times in desert areas. In recent years, the University of South Africa has been involved in ongoing research into the method, using large nets in isolated rural communities where water sources are distant. The system is only practical where fog occurs for at least 40 days a year, and for a period of several hours at a time. Projects are taking place in Venda, Limpopo, the West Coast, the Western Cape and, most recently, the Eastern Cape. The technology is simple and does not require electricity. The project in Limpopo is providing an average of approximately 200 litres of water per day (UNISA, 2010).

3.3.4 Irrigation systems

Irrigation as a technology is estimated to have existed since 6000 BC in Mesopotamia and North Africa (Postel, 1999). In areas which could not rely on rain to feed plants, it was essential to learn how to bring water to plants. Irrigation started with farmers carrying water to crops, and methods still used today include carrying water in pots on one's head or suspended from a yoke placed across the shoulders.

Irrigation expanded to diversions from streams or building bunds for flooded areas (Trimble et al., 2008). The ancient Egyptians developed canals to divert water, catch-basins to store water, dikes to control the flow of water and the shaduf to transport water. The shaduf is a bucket on a long cord hung from a pivoted boom weighted at one end. It enabled more land to be made productive because water could be lifted to irrigate higher-lying land (Postel, 1999).

The damming of rivers exists from ancient times, as do aqueducts, which were originally developed in the Middle East by the Babylonians. Reservoirs have been found in India dating from 3000 BC, while wells have been used for centuries to abstract groundwater.

The 'qanat', also known as 'Karez', is one of the few known ancient water storage conveyance systems used for irrigation in arid and desert conditions (Chinese Hydraulic Engineering Society, 1991). This technique involves diverting water from water wells on higher ground through a series of connected wells, and was established more than 2000 years ago in the desert of north-western China, before spreading to some Asian and African countries over the years.

Globally, the world's annualised irrigated areas now exceed 467 million hectares (Mha) (IWMI, 2008). Population increases and higher standards of living demand ever-increasing amounts of food, and the technology of motorised pumps has made it possible to draw large amounts of water from surface and ground sources to extend irrigation. The required levels of water use were becoming unsustainable even before the added pressure of climate change and consequent damage to the environment became apparent. This has resulted in poor water quality which ultimately threatened livelihoods and food security. Other technologies to improve efficiencies in irrigation practices have been developed by communities all over the world, and these are subsequently packaged into gadgets sold globally. Irrigation techniques such as drip irrigation produce the least wastage and are therefore more suitable in drier climatic conditions. Similar water-saving irrigation technologies are also widely practised in wetter climates to make more water available for other uses.

3.3.5 Adapting to sea water intrusion

About 60% of coastal aquifers are affected by seawater intrusion. While this is an ongoing phenomenon due to over-exploitation of aquifers, projected rises in sea levels are expected to worsen the situation. This has been a common phenomenon in coastal areas for hundreds of years, and adaptation measures have been developed which involve:

- Careful monitoring to increase knowledge of aquifers on an individual basis;
- reduced pumping or extraction of water; and
- artificial recharge using clean water obtained from urban sewage purification. Such water is used not only for irrigation of crops, but also to create a hydraulic barrier against seawater intrusion. Artificial recharge of aquifers has also been used in the Northern Cape to reduce salinity of groundwater in over-exploited aquifers (Tredoux and Cain 2010).

3.3.6 Farm level adaptation strategies

Research by the Tyndall Centre for Climate Change in Limpopo and KwaZulu-Natal indicates that small-scale farmers are experiencing climate change effects which, combined with land degradation and soil erosion, are increasing their vulnerability. The Tyndall Centre research records strategies and adaptations that farmers are using to reduce risk (Oxfam, 2009). These include:

- diversification of foods grown to avoid reliance on one crop which could fail;
- experimentation with new, more drought-resistant varieties;
- forming groups to grow some foods together, opening opportunities for mutual support, economies of scale and commercialisation;
- seeking new opportunities external to the village, e.g. land, social networks, markets, work in urban areas; and
- conservation measures such as water storage.

3.3.7 Migration, an ancient adaptation strategy

Migration has long been used as an adaptation strategy when the climatic environment became unbearable. Pandey, Gupta and Anderson (2003) have attributed “human migration, cultural separation, population dislocation and the collapse of prehistoric and early historic societies” to climate change. As the climate becomes drier, relocating to more humid areas has always been an adaptation option for some. McLeman (2011) noted that harsh environmental conditions can influence human migration. He also noted, however, that migration may not be an adaptive measure in the strict sense of the term since it entails moving away from negative climate changes rather than implementing adaptive measures without relocating.

Seasonal migration, such as that undertaken by the Masai, has been practised as a way of coping with an environment barely suitable for agriculture and livestock breeding. The Masai tribe of Kenya are pastoralists who move their cattle herds and families from place to place depending on the suitability of the area for their pastoral livelihood. The mobility of Masai herds allows for maximum and equitable exploitation of patchily distributed water and pasture in an environment where annual rainfall is approximately 450 mm, and climate change is worsening the variability of water availability in both space and time (Mwangi, 2005). Their pastoral movements have been developed over many years as communities learnt to adapt to climate change. The Masai, however, are now threatened by the need to restrict movement as some community members are starting to pursue individual property rights on the commonly owned land where pastoral activities have always been practised.

3.3.8 Diversification of livelihood activities and industrialisation

Since the impacts of climate change are worse on communities that depend on natural resources, becoming less reliant on such climate-sensitive resources is an essential adaptation measure. Developing infrastructure and mechanising agricultural practices, as well as the industrialisation of rural communities, have been utilised through government-driven practices and, in some instances, by the communities themselves (Yifu Lin and Yao, 2009). The industrialisation of Europe in the eighteenth century and the rural industrialisation which started some thirty years ago in many Asian countries are examples of large-scale revolutions that have moved millions of people away from climate-sensitive livelihood activities. Although the identity of the drivers of the industrialisation revolution continues to be debated, the outcome has created communities and nations that are now in a better position to adapt and mitigate climate change.

3.4 Traditional approaches in urban communities

Water use activities in urban areas differ greatly from rural areas. Over the years, availability of and access to water for domestic use in urban communities have depended on a variety of drivers, most of which had little to do with the final water consumers. In most urban settlements, water availability for people and industries are a sole responsibility of the municipality for that area. The institutional role, especially that of the municipality, water board or water-providing company, is greatest for urban communities. In spite of there being water institutions tasked to provide water, communities have developed their own initiatives to improve access to water or to extend the available water supply. This section discusses the various initiatives in urban areas which constitute or aid adaptation in water access and use.

3.4.1 Planned urban settlements

In order to reduce the effects of climate change, human settlements are planned in such a way that water provision is easy and water pollution is minimised. Examples include settlements that follow the topography of the land for easy distribution of water, and easier flow of wastewater by gravity. Prohibitive water provision costs are already experienced when a community or household is built on a mountain or other isolated and less accessible locations. Communities in urban areas have benefited from urban settlement plans, where their housing units are favourably located to readily receive water.

3.4.2 Learning from approaches used in arid areas

Mukheibir and Sparks (2005) investigated the adaptive capacity of small towns and communities in the Northern Cape Province, where the climate is characterised as semi-desert to desert. Communities in the area are heavily dependent on groundwater, and this is most prevalent in rural areas, which make up 74% of supply. They noted three basic areas of adaptation for water resources, as follows:

- **Increased water supply**: This includes modified catchment vegetation, construction of reservoirs and dams, reduction of evaporation, development of groundwater resources and utilisation of inter-basin transfers, desalination of groundwater and sea water.
- **Reduced water demand:** This refers to initiatives such as demand side management, re-use, pressure management and recycling of water.
- **Different management of supply and demand**: This method refers to methods such as crop substitution and application of climate forecasts to manage water resource operations.

A few measures instituted to adapt to water scarcity in arid areas could be used in adapting to climate change in areas where arid conditions are expected to prevail in the future, including:

- Conjunctive use of surface and groundwater, including diluting saline groundwater with fresh water until the salinity is at acceptable levels (De Wrachien and Fasso, 2007);
- artificial groundwater recharge – diverting surface water into an aquifer from rainfall runoff, treated wastewater or urban storm runoff, to be stored in the aquifer where loss due to evaporation will not take place (Martin and Dillion, 2002);
- re-use of grey water: grey water was used to irrigate small gardens. This practice relieves the load on the waste water treatment works as well as reducing water demands (Finley, 2008);
- loss control and demand management through pressure control;
- stop leakages through the implementation of leak detection and repair programmes (Mukheibir and Sparks, 2005);
- efficient water usage and reuse of return flows to extend water availability;
- Thebaut et al. (2010) also advocated that there should be suitable public policies and strategies to deal with drought and water scarcity. A strong scientific basis for water management decisions is also advocated as an important component for dealing with water scarcity;
- wide-scale implementation of rainwater harvesting such as the national initiative in South Africa to install rainwater harvesting tanks to all targeted poor communities (DWAF, 2004a); and
- desalination: a desalination guide has already been produced for South Africa through the support of DWA and the WRC. Swartz et al. (2006) have identified and recommended treatment options for desalinating seawater from both the Indian and Atlantic oceans, or brackish water from boreholes in South Africa.

3.4.3 City responses to climate change

Networks for cities to cross-fertilise ideas have been formed. Two examples are the Asian Cities Climate Change Resilience Network and “Sub-Saharan Cities: A Five City Network to Pioneer Climate Adaptation through Participation Research and Local Action”, which was launched in 2009 and to which Cape Town is party. Through networks such as these, urban communities have benefited from shared knowledge on and experiences in adapting to various climatic conditions.

All through history, cities have had to adapt to population water availability problems associated with various factors, including climate variability, population growth and increased industrial water demands. The use of large water storage facilities such as dams has been practised for thousands of years. Locations for such dams, however, are being exhausted. In the Cape Town area, for example, the last water scheme to be built was the Berg River Dam in Franschhoek, where the dam location is considered to be the last site suitable for a large dam in the area. In addition to the non-availability of dam locations with suitable hydrology and topographical characteristics, the Berg River project suffered intense resistance from environmentalists (Brown and Magoba, 2009). It was relatively easy to find a suitable site and build a dam in the past, but this is no longer the case. The promotion of large-scale water infrastructure for urban communities is becoming less viable, and it is becoming clear that future water supply infrastructure to mitigate highly variable water availability will have to take advantage of other factors rather than the concept of storing large quantities of water over long periods.

3.4.3.1 Water demand management

In urban areas water demand management has emerged as a tool for balancing water supply and demand. A regional Water Demand Management programme, funded by the Swedish International Development Cooperation Agency (SIDA) and hosted by the Development Bank of Southern Africa (DBSA), drove several SADC regional initiatives for water demand management (Herbertson and Tate, 2001). Such water demand management measures include:

- Installation of water-saving technologies;
- water awareness campaigns;
- water restrictions;
- pressure management;
- the elimination of automatic flushing urinals;
- leakage repair programmes;
- metering and tariff controls;
- the promotion of private boreholes and grey water use;
- retrofitting to move towards water-efficient fittings;
- penalising water wastage; and
- extending virtual water concept in all water-using sectors.

A nationwide drive to promote and implement water demand management is driven by DWA through all the institutions responsible for water storage and distribution. Water demand management is used to balance supply and demand and to manage water use intensity (Herbertson and Tate, 2001).

3.4.3.2 Applying differentiating water quality requirements for different uses

Eales (2010) notes the value of differentiating water requirements, which entails using treated effluent when drinking quality standard water is not necessary. The eThekwini Metropolitan Municipality pioneered large scale municipal effluent recycling whereby instead of discharging wastewater to sea, it was treated to a high standard. Using this treatment method, 30 Mℓ a day of high quality treated effluent water is sold to two industries next to the treatment works at a lower price than potable water. Similar schemes are successfully operated in Cape Town (Brown and Magoba, 2009) and in the North West Province (Eales, 2010). Differentiating water quality requirements for various uses extends the coverage of the available water resources, and polluted water which would otherwise be lost from the system is also utilised.

4 Current approaches in adaptation to climate change and variability

4.1 Approaches emanating from various regions

Climate change and variability affects communities in different ways, and their responses as well as their adaptation approaches are also varied. Ensor and Berger (2009) gave examples of extreme weather events thought to be due to climate changes where various communities were affected at the same time. These were the Hurricane Mitch in Central America in 1998 and the Bangladesh floods experienced the same year. These extreme events called for different responses. As a result of Hurricane Mitch, five Central American countries joined forces to rebuild their societies into productive and democratic communities less vulnerable to such natural hazards. Following the floods in Bangladesh, government institutions and NGOs set up various structures to encourage trade, while the government also liberalised trade to permit private sector imports of rice from India to stabilise local markets. At the same time increased borrowing by households was encouraged by the introduction of more favourable terms, and the government also made targeted financial transfers to benefit some of the affected populations (del Nino et al., 2001).

The IPCC (2007b) climate change synthesis reported that for many regions in southern Africa, the overall area suitable for agriculture, the length of growing seasons and yield potential, particularly along the margins of semi-arid and arid areas, are expected to decrease. In some countries, yields from rain-fed agriculture could be reduced by up to 50% by 2020, while increased flooding in mountain regions was also predicted. Increased water stress due to reduced precipitation is expected to aggravate water quality problems by 2020, and approaches to adaptation will need to vary according to the impacts and the community vulnerability.

Although individuals are capable of learning to adapt on their own, as has been the case in many instances, synergies with local institutions bring about stronger and more sustainable responses. Adger et al. (2009) pointed out that, “adaptation to climate change is both a social and a political process”, and hence the need for the involvement of not only the affected, but also those who have potential to assist and bring about positive results.

IPCC (2007b) observed that adaptation in Africa, including South Africa, is proceeding slowly. This report, based on more recent climate studies, confirmed that Africa is one of the most vulnerable continents to climate variability and change as a result of multiple stresses and low adaptive capacity. Figure 9 below presents a summary of projected impacts in different regions of the world, based on scientific literature (Stern, 2007).

Apart from the differences in impacts, communities will also adapt differently due to other constraints from financial, ecological, institutional and technological causes (Rahman, 2009).

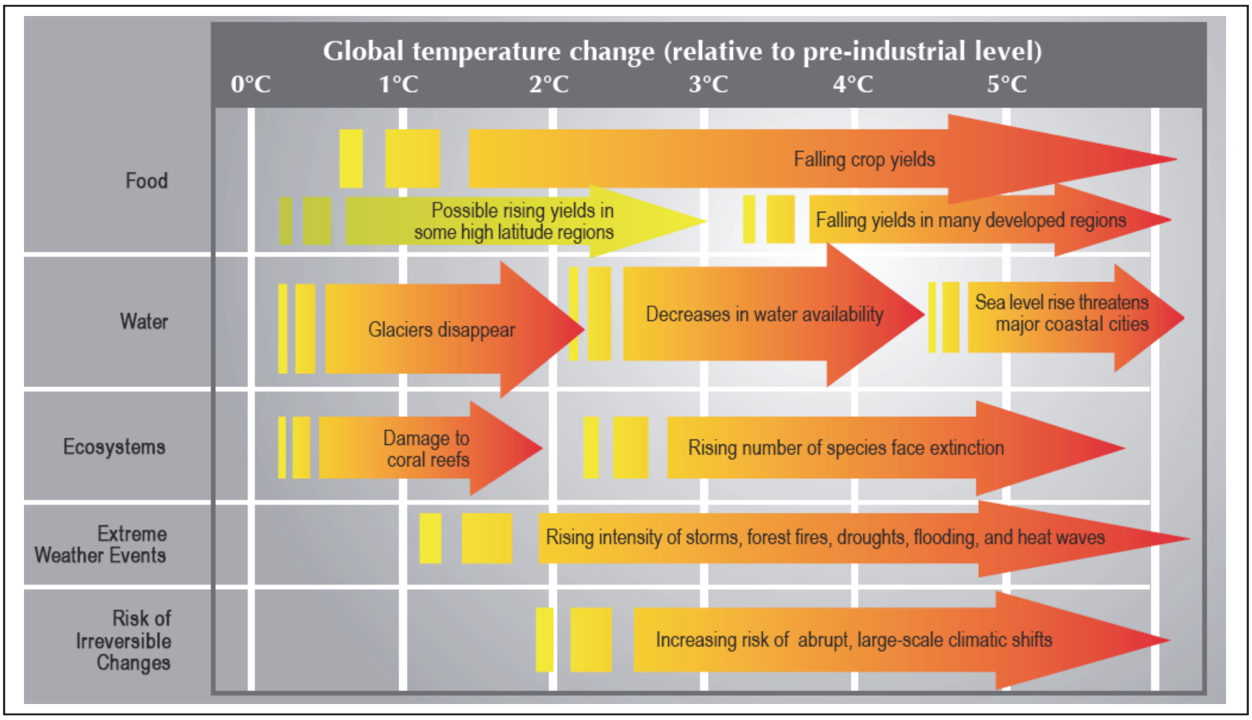


Figure 9: Projected Impacts of Climate Change. Source: Stern Review in ADB (2007)

4.1.1 Asia

The Asian Development Bank (ADB) predicts that the impact of climate change on land and water systems in Asia will decrease crop yields by 2.5-10% by 2020, and by 5-30% by 2050 (ADB, 2007). Food shortages are also envisaged as a result of changes in the climate. In South, East, Central, and South-East Asia, it is predicted that by 2050 (ibid) there will be a reduction in availability of fresh water affecting more than a billion people. IPCC (2007b) also pointed out that flood occurrences will become more numerous due to glacial melt and a higher number of extreme rainfall events caused by the increased incidence of tropical cyclones. The impacts on water will be huge for Asia as more than 60% of the population are dependent on agriculture for food, income and employment (Rahman, 2009). The following discussion looks at a selection of Asian countries and the adaptation strategies they have implemented, or wish to implement.

The case study by Lin et al. (2005) demonstrates the positive outcomes of anticipatory adaptation. The Asian continent is home to several middle income developing countries. The majority of the population has long been directly dependent on agriculture, meaning adaptation to a changing climate is of considerable importance to communities (Lin et al., 2005). China's adaptation to climate change is "set in a context of a developing country with poverty, resource and infrastructure constraints", but can serve as an example of what preparedness can achieve in the face of climate change (Lin et al., 2005). In China, as in other East Asian countries, there has been a conscious change by many communities from agriculture to industry-based livelihoods.

While this has assisted communities in adapting to climate changes, the forces behind the changes are much broader than the mere effects of climate change. The Chinese government has enacted policies and utilised other legal tools to create environments designed to encourage industrialisation in rural areas. Yifu Lin and Yao (2009) reported that the output value of the rural enterprises in the Chinese industrial sectors accounted for only 9.1% of the national total in 1978. Twenty years later, this figure had risen to 57.9% and has continued to rise. Similar levels of rural industrialisation through industrial clustering around farming communities and formation of village-based enterprises have taken place in Thailand, Korea and Taiwan (Yifu Lin and Yao, 2009). The result of these changes has meant that communities are less reliant on climate-sensitive agriculture-based livelihood practices.

Desertification is another climate change threat affecting communities in Asia, and Shili (2006) reported that the formation of sand desertification ('sandification') is caused by climate change, with the impacts being aggravated by human activities. To adapt and cope with the desertification problem, countermeasures and desertification combating programmes have been introduced.

The essential strategy in combating desertification has been to control the structure and function of the agro-forest complex ecosystem, rationally using water and land resources in order to promote a virtuous cycle within the ecosystem. Adaptation and coping programmes being implemented in Asia include: reforestation, grassland protection and watershed integrated management.

Northern China has experienced increased precipitation as temperatures increased in the past decades. Farmers, with the help of various institutions, have managed to take advantage of this by incorporating the strategies shown below:

- Cultivation of new disease- and pest-resistant crop varieties;
- improvement in agricultural infrastructure;
- strengthening and monitoring, forecasting and early warning systems for control of fire, disease and pests;
- use of irrigation to combat spring droughts;
- diversification of crops;
- modification of the composition and structure of crops to suit the new warm temperature;
- cropping system adjusted to suit local conditions (and this was done in all provinces of China);
- cropping system also adjusted so that planting season starts earlier than was previously the case in order to prolong the growth period;
- research on a new variety of rice to be grown in North-East China;
- more efficient water management proposed;
- giving land rights to farmers so that they have autonomy and decision-making power on what to plant and how to adapt. [Lin et al. (2005) points out that this was achieved through trial and error and by learning from other farmers];
- use of advisers; and
- relocating from arid, inhospitable and poor areas into regions not as constrained in terms of their resource base and economic opportunities. Lin et al. (2005) pointed out that the relocation was encouraged by the government's decision to offer $1,300.00 to farmers willing to move.

Due to some economic constraints, not all the adaptation strategies they wish to use have been put in place. For example, water-saving irrigation still has to be introduced as well as water-saving crops (ibid.). Lin et al. (2005) noted that the extent of adaptation depends on affordability.

In Inner Mongolia, migration was used as the main adaptation option. Allied to the increase in human population and livestock, and the fact that the area itself is arid, it proved to be impossible for people to continue inhabiting the area. Migration, officially termed “ecological migration” (West, 2009), was formally implemented by the government in an area of Mongolia called Alxa league. The region experienced a severe drought in 1983-1984 followed by another in 1998, reported to have lasted several years (ibid.). As Pandey et al. (2003) point out, human migration is documented as a typical response to local aridity. Raleigh and Jordan (2010), however, do not see migration as being an option of choice for many in the next twenty years. Instead ecological migration is viewed by Raleigh and Jordan (2010) as a reflection of policy and response failures of public institutions rather than the nature of the hazard.

Central Asia is experiencing water woes due to the breakdown of the Soviet Union. This breakdown resulted in the formation of smaller states like Kazakhstan that now had to depend on rivers, some of which were within their own territories, but with the balance being others which they sometimes shared with up to three countries (Severskiy, 2004). Severskiy (2004) observed that the breakdown of the Soviet Union resulted in a decrease in the productivity of irrigated farming. Though the experience in Central Asia is due to states seeking sovereignty rather than climate change, a need to adapt arose as the area itself is semi-arid and, with new water management needs, adaptation has of necessity come into play. In one of the new states, small ponds and water storage reservoirs have been constructed for use in irrigation. In other parts return flow is being used for irrigation purposes (Severskiy, 2004).

Ensor and Berger (2009) describe Bangladesh as a low-lying densely populated country prone to most natural disasters: floods, cyclones, storm surges, tornadoes, earthquakes and droughts. In Bangladesh, research has indicated that climate change is increasing rainfall intensity and glacial runoff, resulting in higher sea levels. Having become accustomed to natural disasters, Bangladeshi communities have tried to adapt using indigenous knowledge. Floating gardens are now used in times of drought, providing rain-harvested water in saline-infected areas, and encouraging the rearing of ducks which can exist freely in floods. Adaptation strategies were tailor-made to suit the specific climatic change impacts in Bangladesh. Rahman (2009) concluded that information-sharing through social networks created when the research was carried out in Bangladesh acted as catalysts for adaptation activities.

4.1.2 Africa

It is considered that new approaches to climate change adaptation in Africa are shifting towards facilitating an environment in which local communities have diverse livelihood options within and beyond natural resource reliance (Thomas and Twyman, 2005). Many communities in Africa have few resources at their disposal for use in adaptation. Improved access to resources, empowerment and direct governmental or institutional support is an essential element for sustainable adaptation.

Programmes targeted at improving information on climate change have been used to assist communities to adapt, with the case of Haramata being one example. Haramata is an educational bulletin available in print for the dry lands north of the SADC region. For over twenty years Haramata sought to “carry seeds of change and hope” for the dry lands communities by making “connections between the multiple NGOs and community-based groups, and the dispersed range of dry land scientists, planners and donor agencies" (Haramata, 2010), and spreading information about more productive use of water, sustainable livelihoods and more recently, climate change.

Climate variability and change have been making it increasingly difficult to continue pursuing rain-fed agriculture in drier areas of Africa. In Kenya, Tanzania, Namibia, Zimbabwe and South Africa, governmental and non-governmental institutions have been involved in supporting programmes whereby community livelihoods in suitable areas are transformed from subsistence farming to community-based wildlife and tourism. Different programmes for wildlife management, profiting from tourism and the sale of wildlife and meat, are being implemented by communities on their own or in partnership with established natural resource management institutions. Although community members share the proceeds from these programmes, observers have noted that these practices are not providing adequate benefits to individual families, but are rather benefiting the local authorities running the programmes (Ashley and Jones, 2001).

New approaches have not been totally oblivious to past adaptation strategies, which have seen crops being modified or diversified to suit present climates. The need for more suitable crops for the new and future climates has been revived, and possibilities are being investigated. In the East African countries of Kenya, Tanzania and Uganda, research is also underway to find crops suitable for their future climates (Haramata, 2010).

In communities that have no financial resources to deal with adaptation beyond those already available, the indigenous environment has been a source of food and livelihood. In Kenya, indigenous plants are used for various livelihood activities such as the hanging of beehives, firewood for sale or cooking snacks for sale (Eriksen, 2005). This type of adaptation may, however, increase vulnerability since the cutting down of trees might expose the land to erosion and rapid water flows in times of rain.

In urban areas, water demand management is emerging as a tool for coping with water shortage, and some guidelines have been developed in the SADC region (Herbertson and Tate, 2001). A regional Water Demand Management (WDM) programme hosted by the DBSA is driving several SADC regional initiatives for water demand management. The WDM programme, funded by the Swedish International Development Cooperation Agency (SIDA), is but one initiative for adapting water use to an environment characterised by, amongst other factors, reduced water availability. Weather early warning systems are used all over Africa to improve the state of community readiness for weather events, and enable better planning in all livelihood activities. The SADC early warning system is now being used to advise farmers of the nature of the forthcoming agricultural season.

4.1.3 Western countries

In recent years adaptation to climate change impacts has slowly become established in developed economies as an important and complementary response to Greenhouse Gas (GHG) mitigation (Gagnon-Lebrun and Agrawala, 2006). IPCC (2007b) reported that limits on emissions at present and in the future will not be enough, or happen soon enough, to avoid all impacts of climate change. Carbon dioxide and other Greenhouse Gases will remain in the atmosphere for decades or even centuries after they are produced, and the positive results of mitigation are only likely to take full effect over many years. Therefore, adaptation has now been mainstreamed into the climate change response strategies of western countries. In these countries, adaptation approaches are focusing on technological development, government programmes and insurance, production management and financial management (Smit and Skinner, 2002). As a result of adaptation being mostly urbanised, techniques used have tended predominantly to be based on the management of water by water management boards. In southern England, for instance, (Arnell and Charlton 2009), there are five independent private sector companies responsible for water provision for the region. Water use is highly regulated by means of a periodic process in which companies produce projections of their investment requirements (ibid.). Water use planning in itself is a tool in the adaptation strategy, as it would be possible to change the plans if the projected needs are not likely to be met by the available resources.

Western countries are using the Climate Change Agenda, including adaptation, as a platform for accelerating further development as groups of nations, while building capacities in partnering countries. At the continental level, a Green Paper published by the European Commission in 2007 entitled ”Adapting to climate change in Europe – options for EU action” sets out four lines of priority action at the community level (Swart et al., 2009):

- The first covers **early action** in areas from agriculture to trade that are backed by EU policies and available community funds;

- the second recommends **integration of adaptation into existing EU external actions**; in particular, its promotion in developing countries;

- the third calls for **intensified climate research**; in particular, on the impacts of global warming and technological innovation; and

- the fourth is about **involving all segments of society**, business and the public in the further development of adaptation strategies.

Most developed countries are parties to the United Nations Framework Convention on Climate Change (UNFCCC), and as such are committed to report on their implementation of the Convention (Article 4.1 of the UNFCCC). A three-tier framework for assessing attention to adaptation via national communications in economically developed countries is used to evaluate progress and engage countries on their adaptation commitments. Figure 10 below demonstrates the communications framework used by the developed countries (Gagnon-Lebrun and Agrawala, 2006).

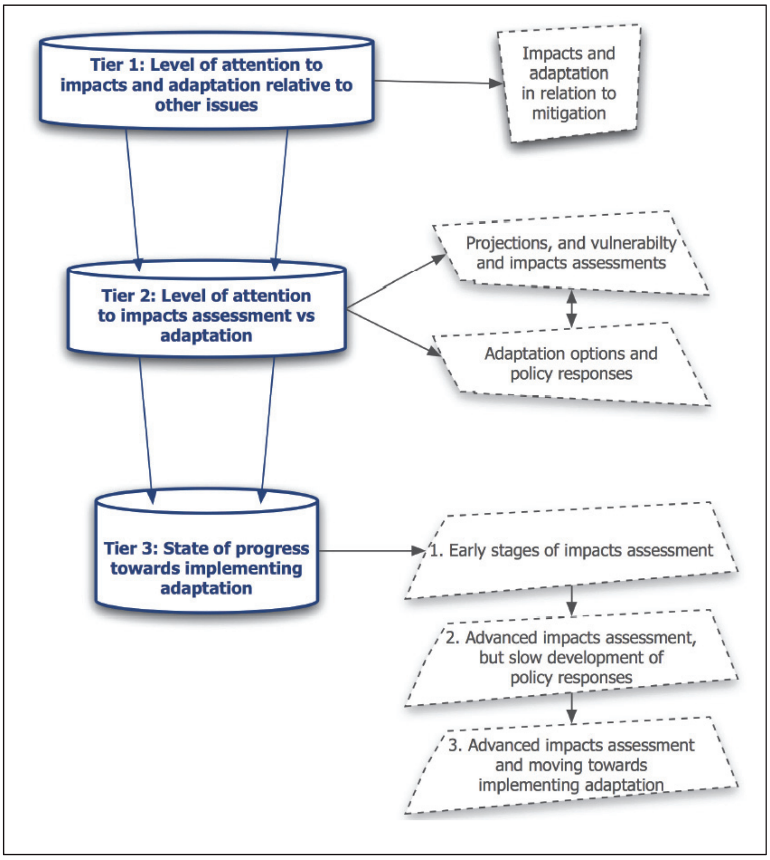


Figure 10: Three-tier framework for assessing attention to adaptation in National Communications in developed countries

4.2 Approaches being developed in South Africa

South Africa, already a semi-arid country, has been identified as one of the countries that could experience chronic water stress by 2025 (IPCC, 2007b). Nevertheless, the goal of equitable distribution of water, as per the National Water Act of 1998, seeks to make water accessible to all.

Several initiatives are used in South Africa to deal with climate change and variability. Rainwater harvesting is being used in most provinces to deal with highly variable water availability, a characteristic of much of the country. Strategies and rainwater harvesting implementation programmes put in place by the government seek to develop rainwater harvesting for identified households, schools and other community groupings around the country, but more especially for rural areas. The programmes, started in 2005, include the installation of tanks to harvest rainfall from roofs, as well as underground tanks to harvest surface runoff for small scale irrigation. In this programme, the Department of Water Affairs provided funding of up to R22 000 for capital expenditure and installation of rooftop rainwater harvesting tanks up to 30 cubic metres in capacity (DWAF, 2004a; Kahinda et al., 2008). Kahinda et al. (2008) advise, however, that this water is prone to contamination and requires chlorination or other methods of purification to remove pathogens before any potable uses, such as drinking. The national programme to install rainwater harvesting tanks for poor communities around the whole country is ongoing (DWA, 2013a).

There is also a drive towards alternative livelihoods less reliant on high volumes of water resources, including the present initiatives for promoting wildlife management and tourism as a source of income for communities in rural areas. Compared to subsistence agriculture, more widespread amongst rural populations, tourism and wildlife are less susceptible to climate change (Ashley and Jones, 2001).

In urban areas, water demand management is practised by all major water boards and municipalities, with a nationwide drive to promote and implement water demand management being driven by the Department of Water Affairs. The demand management programme is intended to restrict demand and utilise available resources more efficiently without needlessly requiring more. Demand management programmes form an important part of the current DWA business plans (DWA, 2013a).

South Africa also uses an intricate water conveyance and transfer system to connect all catchments with high water yields. This system of canals, dams, tunnels and large capacity pipes is used to connect catchments across the whole country, and is of major strategic importance in adaptation and coping in regions with very different water availability and use capacities. With such a system, conveyance of water from high yielding areas can be achieved with relative ease, even when those regions which normally have adequate water resources are affected by extreme dry conditions (DWAF, 1999).

By means of various treaties South Africa has further improved water availability by using water resources from other countries. In one major example, the Lesotho Highlands Water Project, South Africa is using water from the Lesotho highlands where annual rainfall averages 1 000 mm (De Villiers et al., 1996). South Africa and Lesotho have cooperated in developing the Lesotho Highlands Water Project to the stage where it will ultimately supply 70 m^3/s of water to the South African integrated river systems. The LHWP is directly connected to the Vaal River System through a network of tunnels, pipes and pumped water storage facilities. A major asset of the Vaal River System is that it is connected to water supplies for most cities and communities where points for potable water provision and return flows stretch across several catchment areas and river systems.

4.3 Integration of water development planning and climate change adaptation

4.3.1 Integration of adaptation into national development

Adaptation is a development issue which should be taken into account by various ministries as well as by a number of different sectors (e.g. private sector, associations, private institutions and non-governmental organisations, etc.) (Niang, 2007). Development at the community level usually takes place as a result of development strategies and plans at the national level and, in many cases the national budget makes provision for such development. Among other functions, local institutions support communities in providing them with or linking them to channels where development can take place. Climate change adaptation in developing countries can never be divorced from development initiatives (OECD, 2009).

Strategic priorities, challenges and some actions for integrating adaptation into development at the national level could include the following:

i) Improvements in availability and quality of climate information – many countries, including South Africa, have inadequate infrastructure for weather and climate monitoring (Middleton and Bailey, 2008). Limited technical and research capacity for climate change, adaptation, mitigation and impact modelling are other typical hurdles affecting developing countries;

ii) enabling policies for incorporating adaptation in development programmes. Climate change adaptation is still not viewed as a development issue and consequently is not recognised as a high priority (OECD, 2009). There is a need to raise awareness of the specific consequences of climate change on development priorities, as well as how to account for adaptation; and

iii) mainstreaming climate change and adaptation in all spheres of development. Climate change is still pigeon-holed as the focus of environmental or ecological sections of organisations, government departments, and other institutions. Incentives should be built into the governance systems to change existing structures and practices in order to enable alignment with climate change factors.

4.3.2 Adaptation in water infrastructure development

Adaptation can be implemented through 'Soft' or 'Hard' options. The World Bank (2009) observed that 'Soft' options, for example policy changes, tend to be unsustainable over long periods. They are affected by socio-economic and political eventualities such as changes in leadership or the political party controlling a specific area. The preference has, therefore, been to support hard options such as water infrastructure. The relevant water infrastructure in South Africa, a generally dry country, includes dams as well as water treatment and conveyance systems. The predictions of climate change for South Africa have shown that flooding events with extremes of both high and low runoff events are escalating with time. Water infrastructure, such as dams, is designed to withstand its recommended design flood. In South Africa, the SANCOLD guideline on design floods (SANCOLD, 1991) is used, and at present, the Recommended Design Discharge (RDD) is based on the flood return period, as shown in Table 4 below.

Table 4: Suggested Return Periods for the Recommended Design Discharge (SANCOLD, 1991)

Dam Size Class	Hazard Potential		
	Low	Significant	High
Small	20-50 Years	100 Years	100 Years
Medium	100 Years	100 Years	200 Years
Large	200 Years	200 Years	200 Years

Other preferred methods for the RDD utilise the Regional Maximum Flood (RMF). All these methods depend on what are determined or estimated to be the flood regimes in the catchments where the dam is built, or is to be built. Climate change is altering these flood regimes, their frequency, their intensity and other key variables such as those which affect concentration time. A typical example is land cover. Anderson et al. (2007) advised on how adaptation can be built into rehabilitation or maintenance of existing infrastructure, or in the design of new developments. Water projects sensitive to climate change need to be identified so that adaptation and coping mechanisms are built in.

In dam developments, the design freeboard changes if the floods, wind directions and intensity change with climate change. The most important factors to be considered when determining the required freeboard on a dam are (Cullis et al., 2007):

- Wind-generated waves;
- wind set-up;
- seiches (resonance);
- flood surges;
- landslide-induced waves; and
- earthquake-induced waves.

Predicated changes in the variables listed above need to be quantified and integrated in the rehabilitation as well as the development and design of dams or flood control infrastructure.

4.4 Proactive adaptation

The UNFCC (2006) publication entitled 'Technologies for adaptation to climate change' categorised different types of adaptation into private and public, reactive and proactive. An example of private adaptation that is also reactive is when a farmer decides to change the crop that he or she plants to one more suitable to the new climate regime, such as a drought-resistant crop in areas where rainfall droughts are increasing. On the other hand, the decision to create a new large-scale augmentation scheme for a community is usually made by government or a public utility and, in many cases, this could be done well before the impacts of climate change are felt, thus making it a proactive initiative. Enforcing water conservation when the water source is almost dry is another example of reactive adaptation.

A typical case of a proactive measure is found in New Mexico, USA, where rules and other legal measures were put in place to establish a system known as Active Water Resource Management. This system can now be activated when drought is anticipated and is a legal framework designed to deal with adverse climate conditions that could be the result of climate change. In this particular case, the agreed policy has the objective of prioritising the highest economic use (Cottrel Propst, 2012).

In South Africa, legal provisions have been made available for municipalities to develop strategies that are proactive in dealing with adverse climate conditions. These include the Disaster Management Act (Republic of South Africa, 2002), the Disaster Management Regulations and the Disaster Management Guidelines (Department of Provincial and Local Government, 2005). In Chapter 5 of the Disaster Management Act, provision is made for municipal disaster management practices, whereby each municipality is required to establish and implement a framework for disaster management for its designated area. Municipalities are also expected to be in a state of readiness to deal with disasters (Republic of South Africa, 2002). The Minister of Provincial and Local Government was responsible for developing the Disaster Management Regulations as well as guidelines for dealing with disasters (Department of Provincial and Local Government, 2005). In the disaster management guidelines, hazards caused by extremes in natural processes (such as floods and droughts) are classified as disasters requiring municipal response. Municipalities are also required to carry out vulnerability assessments, and to determine and implement proactive measures before envisaged disasters strike.

4.5 Conclusion

The section discussed climate change impacts, how these impacts are being interpreted by different communities in different countries, and pointed out how institutions could assist communities in adaptation initiatives. Cases of both increased precipitation and rainfall droughts, desertification, increased intensity of cyclones, floods, land degradation and other climate impacts in different continents, and how communities have responded, are also presented. Communities depending on natural resources, including the poor with little financial means, are presented as most vulnerable to climate change. These communities are also designated as being most in need of institutional support. It is noted that South Africa, like most of Africa and Asia, has many such communities which tend to be very sensitive to and hence more vulnerable to climate change impacts.

5 Climate Change Vulnerability

5.1 Introduction

In developing coping mechanisms and responses to climate variability, communities learn to adapt when some of these changes become permanent as a result of climate change. Over the years communities have managed to deal with disasters, some of which are consistent with the nature of impacts associated with climate change. Severe disasters are still experienced on an annual and occasionally more frequent basis in many communities around the world, and they have had to learn to adapt. Their adaptation initiatives, however, have been limited to local knowledge and experiences, and are therefore usually not well coordinated and implemented to provide all possible benefits. In consequence, in seeking to implement climate change adaptation measures, or provide adaptation support, institutions should seek to build on the experiences and knowledge of targeted communities in their unique environmental setting and background. Unlike responses to climate variability and uncertainty, which tend to fall within a certain known band, however, climate change brings a new unique angle in which the risks are not necessarily known, and thus adaptation requires new strategies which have to be responsive to the extent of impacts and vulnerability.

5.2 What is vulnerability?

An understanding of community adaptation, or the role that institutions have to play in community adaptation, must of necessity start with an understanding of a community's vulnerability. The level of, motivation for and extent of adaptation all have to be based on the level and extent of vulnerability. In essence, and in the words of Ensor and Berger (2009), "vulnerability underpins adaptation". An adaptation process requires a full understanding of what vulnerability is and what it entails. In essence, vulnerability relates to an inclination or tendency to be badly affected in risky or hazardous environments (Lavell et al., 2012). The Intergovernmental Panel on Climate Change (IPCC) defined vulnerability to climate change as the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with the adverse effects of climate change, including increased variability and downside risk (IPCC, 2007b).

Climate change risks are about exposure and do not necessarily affect everyone, but their environmental nature means that they are widely felt (UNDP, 2007). Vulnerability of communities to climate change impacts on water access and use can depend on whether the communities' livelihoods are affected by climate change or not, and what their current water access methods are. Vulnerability can also be aggravated by the interplay of various forces which include, but are not limited to, socio-political and environmental issues (Department of Environmental Affairs and Tourism, 2006). For instance, assumptions can be made about the vulnerability levels of urban communities versus those of rural communities. In fact, urban communities' vulnerability to climate change impacts on water access and use are not necessarily different from those of rural communities.

In line with the Municipal Structures Act of 1998 (Republic of South Africa, 1998b), equitable and sustainable provision of water is the responsibility of municipalities. In rural areas communities are most likely to have alternative water sources such as rivers or boreholes, while urban communities generally do not have such alternative sources, which may make them more vulnerable. At the same time, urban communities are almost certainly in a better position to access financial resources and employment opportunities enabling further water provision through private vendors, thus to some extent mitigating their own vulnerability. Vulnerability is thus a complex matter involving an array of variables, and it measures the capacity to manage risks without serious or irreversible losses (UNDP, 2007). According to IPCC (2001), vulnerability to climate change is defined by three elements: exposure, sensitivity, and adaptive capacity.

Exposure

Exposure is a type of direct danger (i.e. the stressor), and the nature and extent of changes to a region's climate variables (e.g. temperature, precipitation, likelihood of extreme weather events) (Gbetibouo and Ringler, 2009). In general terms, exposure relates to the risk associated with the dangers of drought occurrences and extreme events such as floods or heat waves.

Sensitivity

In respect of sensitivity to climate change, the IPCC (2007b) ascertained that this is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. Sensitivity to the impacts of climate change plays a major role in society's adaptive capacity, and an understanding of vulnerability alone is thus inadequate as adaptive capacity intertwines with both vulnerability and adaptation (Smit and Wandel, 2006).

Adaptive capacity

Adaptive capacity is intrinsic to the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (Brooks, 2003). It also represents the potential to implement adaptation measures to help avert potential impacts. Over the years, members of communities have developed resilience and the ability to adapt to various changes in their environment. This ability has been passed down through generations, and those generations which could not cope were lost over time. A study carried out by Marschke and Berkes (2006) in Cambodia showed that fishing villages are able to cope with and adapt to fluctuations in resource availability through diversification in activities, such as operating small businesses from home, and through household members migrating to cities to seek alternative income for strategic periods, or even sometimes relocating permanently. This same trend of diversification of livelihood activities is practised by many South African local communities which have the ability to revert to various livelihood activities, and who have been affected at varying degrees by climate variability, thus providing a variety of opportunities for communities to adapt to impacts of climate change.

The ability to understand and practise the livelihood activities of members in other community groups where the climatic conditions are different has been useful over many years in adapting to or dealing with climatic or environmental changes. As evidenced by the continued existence of societies in all the climatic regions (Adger et al., 2003), societies have the flexibility to adapt to climate change or similar risks. Some sectors and groups in society, however, are more vulnerable and therefore less able to adapt than other groups.

In South Africa, where rainfall is low and very variable, investment in water infrastructure is an important element in enhancing the ability to adapt to climate change by extending potential for water access. Sadoff and Muller (2009) observed that the ability to adapt for water resources should follow a threefold investment in terms of better and more accessible information, stronger institutions and infrastructure, natural and man-made, to store, transport and treat water. In urban areas, several initiatives are being implemented to improve water treatment, conveyance and reticulation in various municipalities.

One such initiative is the Municipal Infrastructure Grant (MIG) programme by means of which infrastructure is being built to extend water service provision to all members of the community, especially those to which reticulated water can be delivered (DBSA, 2010). The Department of Water Affairs is also involved in projects to improve infrastructure at household level, with one such example being the drive for increased water storage at household level by providing rainwater harvesting storage tanks to identified community members. The rainwater harvesting programme is aimed at ensuring water access for all as well as achieving the shorter term goal of meeting the MDGs targets on water provision (DWA, 2009a). The infrastructure development programmes will directly improve community ability to adapt to climate change in time.

5.3 Quantification of vulnerability

Institutional support for communities facing increasing water access challenges due to several stressing factors, including climate change, needs a well-founded plan based on, amongst many other variables, community needs, state of vulnerability, nature of challenges being faced, and capacity to deliver. Water access programmes, projects and activities for communities require prioritisation to ensure that the neediest cases are addressed first. It is the need to understand and plan water access which has its basis in an assessment of vulnerabilities in the target communities. Quantification of community vulnerability provides the basis for decisions to be made in providing water access support.

Vulnerability quantification is a process that involves identifying the exposure and sensitivities causing community vulnerability to climate change impacts, and then taking those stressors and converting them to figures that are in turn used to map out the ranges of vulnerability, by stressor, per community. Vulnerability mapping provides improved communication of risks as well as the knowledge of what is being threatened by climate change. The maps will also allow for better visual presentations and understanding of the risks and vulnerabilities so that decision-makers and other stakeholders can see where resources are needed for adaptation to these risks. Corrective action can then be taken before the impacts escalate into disastrous scenarios.

5.3.1 Vulnerability indicators

Vulnerability is composed of three main elements, namely exposure, sensitivity and adaptive capacity. The elements of vulnerability are composed of indicators, and the intensity or implications of these indicators differ between individuals, households and communities. Figure 11 below provides the listing of the indicators considered in this study and drawn from the biophysical, geophysical and social conditions of the case study communities.

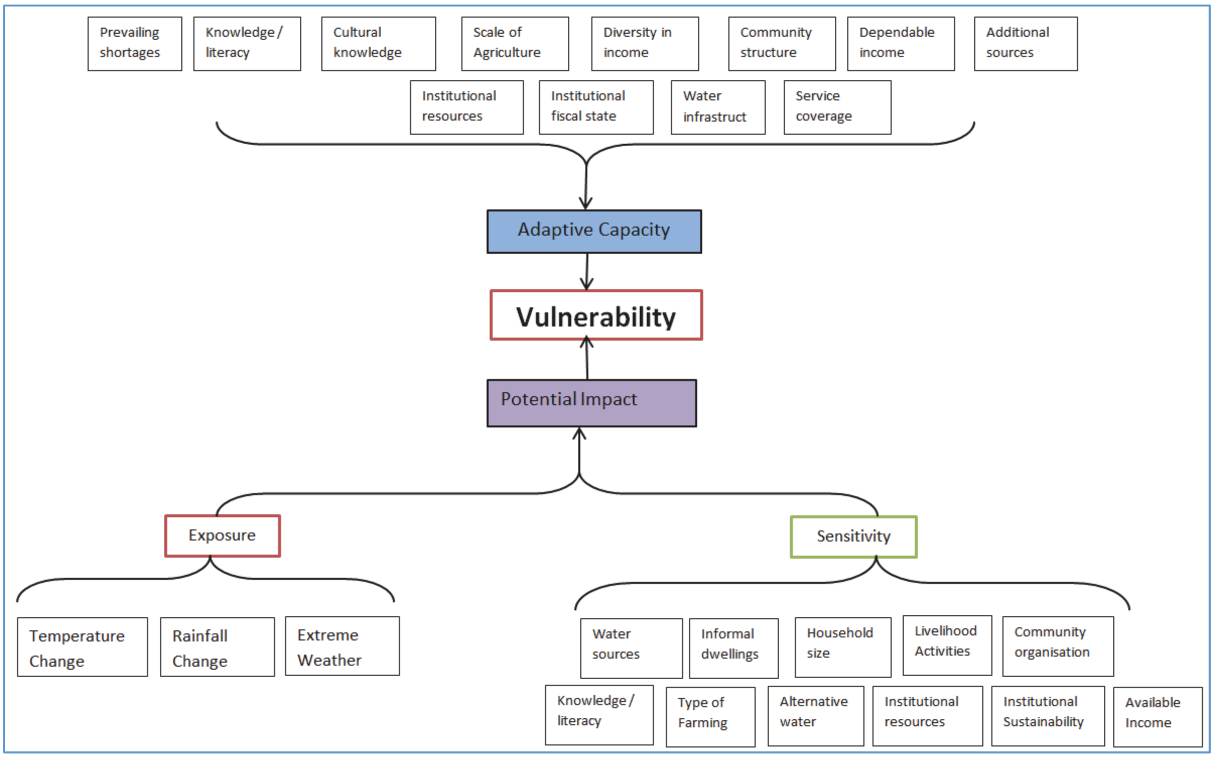


Figure 11: Aggregation of vulnerability indicators (Source: Authors)

While some studies tend to look at communities with similar livelihoods, this study maps out specific characteristics of communities' livelihoods with the aim of building up representative sensitivity and adaptive capacities with little or no generalisation. The vulnerability formula derived from the IPCC definition of vulnerability is also applicable to communities where livelihoods are not the same. Shewmake (2008) studied the impact of climate shocks on households from twenty districts of the Limpopo province in South Africa and found that some households in the same community were more vulnerable than others. It follows that the term 'community vulnerability', tends to assume similar vulnerability levels for all members who constitute that community. To address the differences, weights are used which are associated with the indicators aggregated to obtain a quantification of vulnerability.

Vulnerability is quantified using the definition of vulnerability provided in IPCC (2001). This definition is used to derive the formula conceptualised in Equation 1 below. The equation gives vulnerability indices which can be compared for different areas from which input data is derived.

V = F(E, S, AC)--Equation 1

Where:

V = Vulnerability Index

F = Function of

E = Exposure

S = Sensitivity

AC = Adaptive Capacity

Vulnerability for a given system largely depends on its exposure and sensitivity which, when combined, give the potential impact and the potential for effectively coping with that impact and its associated risks. Vulnerability can then be expressed as in Equation 2 below:

$$V = f(PI - AC) \qquad \text{Equation 2}$$

Where:

PI is the Potential Impact and,

AC is the Adaptive Capacity.

If exposure is high, potential impact is also high. When communities have high sensitivity to the exposure, potential impact is also high. In the study, the values of exposure (E) and sensitivity (S) are maintained above 0 so that potential impact is derived as shown in Equation 3 below:

$$PI = f(E, S) \qquad \text{Equation 3}$$

In the study, the vulnerability variables were determined at local community level and aggregated into the elements of vulnerability. The listing of vulnerability variables and their aggregation towards the overall vulnerability is illustrated in Figure 11 above.

5.3.2 Vulnerability quantification process

The study was conceptualised around a method where communities were central in obtaining information on vulnerability. Whilst several vulnerability studies tend to suggest vulnerabilities for communities, none has targeted the communities used in this study and come out with case-specific vulnerability issues. In the study, quantification of vulnerability was achieved through a method involving several stages in which elements of vulnerability were evaluated. The stages involved in vulnerability quantification in this study are illustrated in Figure 12 below.

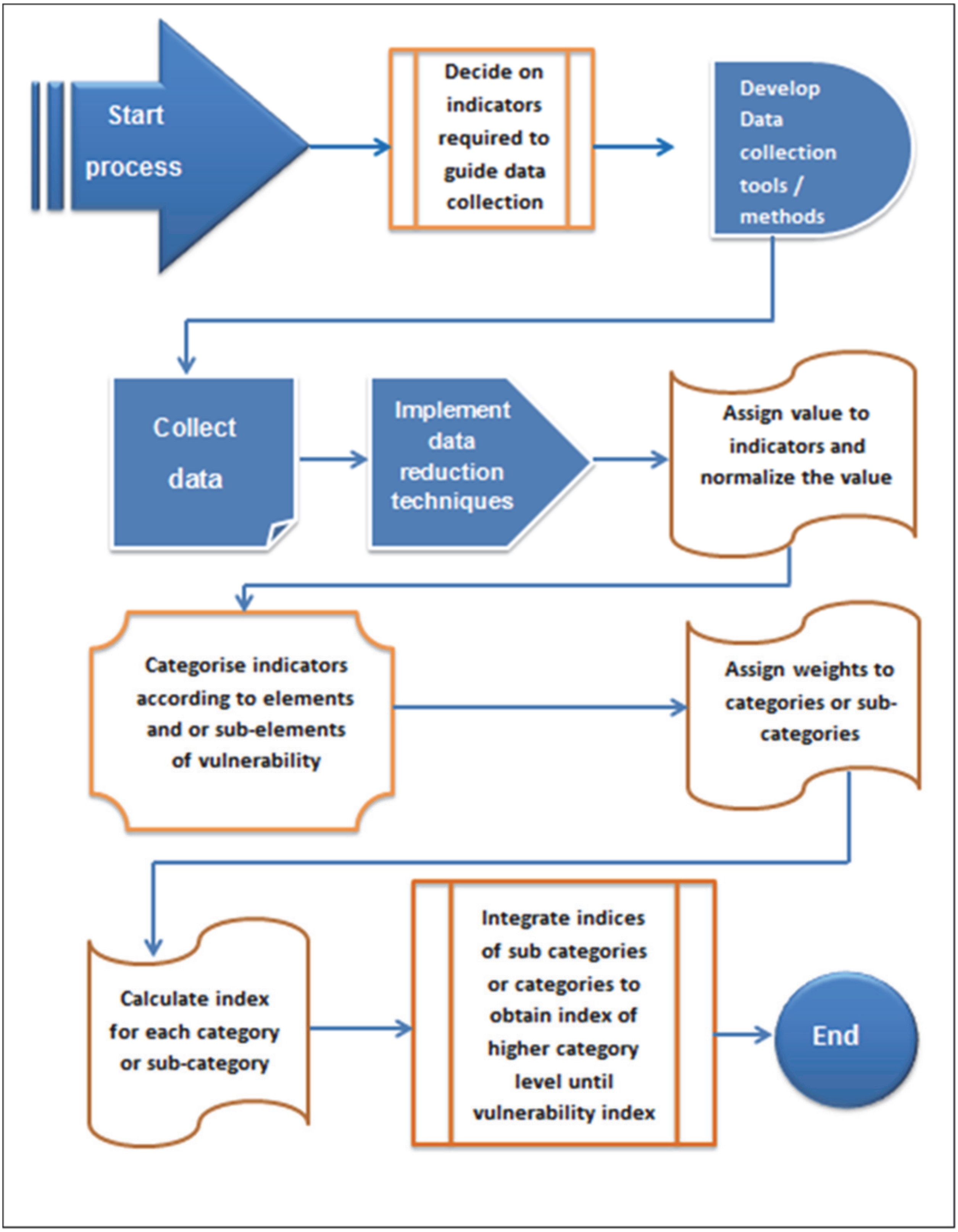


Figure 12: Quantification of vulnerability (Source: Authors)

Data collection for research purposes often falls into a multi-dimensional sphere where several indicators such as community socio-economics, which define adaptive capacity of a community in coping with climate change, are investigated. Out of the many possible variables, the selection of a few indicators for use in vulnerability assessment is an important element in the validity and confidence associated with the overall vulnerability analysis. These variables depend on available data as well as how correctly the data are used to define each indicator. To avoid using too many variables in the vulnerability calculation techniques, several methods can be used to determine which of the variables make the most significant contribution to the definition of vulnerability. One such technique is the Principal Component Analysis (PCA), in which the correlation structure of the data set for each indicator is estimated. In the PCA, the goal is to extract the most important information for the indicator in each data set and ultimately reduce the number of significant indicators, while still maintaining the same overall information pattern. As discussed by Baskilevsky (1983), the importance of the variable to the targeted objective is given by the size of its residual variance. The approach relies on a minimum variance, a cut-off point for indicator selection.

In those cases involving typical communities in rural and urban areas of South Africa, indicators for defining vulnerability elements can be selected not only based on existing understanding of the affected communities, but also with the aim of utilising available data that can be acquired within the study period. The selection of indicators to use in the study were also based on the concept of making maximum use of information that could be obtained from communities in line with the bottom-up approach preferred in the study. The list of indicators and the vulnerability elements selected for the study are summarised in Table 5 below:

Table 5: Indicators used, categories and nature of summary inputs per local community

	Indicator	**Description of Summary Input**	**Category**
1	Predicted temperature change	Predicted change in temperature for the projected period ending 2100	**Exposure**
2	Predicted rainfall change	Predicted change in rainfall for the projected period ending 2100	
3	Predicted change in likelihood of weather extremes	Predicted change in likelihood of extreme weather events for the projected period ending 2100	
4	Location of household	Describe location of household as rural, small town (=>500 people per km^2), large urban town or city (=>1 000 people per km^2) checked against community survey data (Stats SA, 2008)	**Sensitivity**
5	Nature of house	Is the house informal or formal?	
6	Household size	Average number in a household for local community area	
7	Education level /Literacy rate	Most frequent input for education level	
8	Main livelihood activity	Most frequently said type of livelihood activity in the local community	
9	Income of household	Average income based on individual household totals for the area	
10	Diversification of household income	Ability to diversify income as described by respondents	
11	Source of water	Is the most common water source a borehole, dam, river, etc.?	

	Indicator	Description of Summary Input	Category
12	Nature of water service	Describes most common input. Standpipe, inbuilt water points, well and borehole are possible answers	
13	Water shortage	Describes most common input to give frequency of water shortage	
14	Water quality	Describes the most frequently used input to describe water quality	
15	Ability to pay for water	Most common input to describe water bill as a percentage of total household income	
16	Access to suitable alternative water sources	Describes most common input and excludes use of dirty dam, furrow or river water for household use. Borehole water is a good alternative	
17	Distance to institutional water service infrastructure	Gives a measure of distance to the nearest institutional water service infrastructure where community water services can be connected	
18	Type of farming	The nature and type of predominant farming practice	
19	Water shortage in farming	Describe nature of water shortages for farming purposes	
20	Institutional water service provision capacity	Use percentage covered by institutional water service in the ward, locality or community area	
21	Institutional ability to bill and collect rates for water provision	Describes rates collection efficiency in area, i.e. % of possible revenue collected	
22	Results of institutional performance audits in past five years	Most frequent audit report input from national treasury reports	
23	Community organisation and networks with functional leadership	Indicates if community is organised, has leadership and is communicating with water institutions	**Adaptive Capacity**
24	Dependable employment	Describes nature of main livelihood activity	
25	Income	A measure of total income in monetary terms as advised by respondents	
26	Scale of commercial agriculture	Describes most frequent input giving total hectares. Preferably, average farm size inputs from irrigation boards or Water User Association	
27	Ability to diversify agricultural activities	Describes if farmers in the local area are able to diversify agricultural activities	
28	Presence of subsistence farming or small gardens in local community	Describes most frequently entered questionnaire inputs or observations at the site regarding household gardens	
29	Knowledge of climate change	Describes information derived from questions which address climate change	

	Indicator	Description of Summary Input	Category
30	Institutional capacity to provide water services now and into the future	Describes if the institution is meeting water provision growth targets	
31	Nature of water provision infrastructure	Indicates if there are adequate infrastructure facilities and maintenance programmes	
32	Human resources in the local institution	Describes if the local institution has adequate and competent human resources for water service provision	

5.3.3 Normalisation of indicators

The vulnerability assessment indicators consist of quantitative and qualitative data. To obtain common indices, all indicators were converted to a common scale. The approach used in the study involves assigning a value to the indicator. The indicator values were checked against expert inputs to come up with consensus using averages, as well as revising some estimates based on consensus in suggestions. Each value is based on a number of factors, including frequency, intensity and actual average values. In the method developed for the study, the indicator values can be changed in future to capture improved knowledge and data changes. Assignment of values to the indicators which constitute vulnerability requires standardisation and a set of rules to ensure that the final indices are comparable and have the same meaning. The United Nations Development Programme (UNDP)'s Human Development Index (UNDP, 2002) method was used to normalise all the variables in the vulnerability indices to a range of 0 to 100. The value of each variable was normalised to the range of values in the data set for all case study areas by applying the following general formula:

$$z_{j,i} = \frac{Z_{ji} - Z_{min,i}}{Z_{max,i} - Z_{min,i}} \times 100 \qquad \text{Equation 7}$$

$z_{j,i}$ $is\ j^{th}\ normalised\ value\ for\ indicator\ i$;

Z_{ji} $is\ j^{th}\ actual\ value\ for\ indicator\ i$;

$Z_{min,i}$ $is\ minimum\ value\ for\ all\ i^{th}\ indicator\ values$;

$Z_{max,i}$ $is\ maximum\ value\ for\ all\ i^{th}\ indicator\ values$.

5.3.4 Weighting of indicators

Not all indicators have the same significance to the overall vulnerability, which is unique to the different indicators and to varied extents or intensity. To illustrate the use of weights, a look at an urban area setting will reveal that the indicator of 'type of housing' has less significance to vulnerability on water access than the indicator measuring 'availability of water service infrastructure'. In such a case, the indicator for 'type of housing' will have a lower weight than the indicator for 'availability of water service infrastructure'. In this study, the intention is to produce an adaptation framework where the weights can be varied to capture new insights or knowledge. For the purposes of the case studies, an expert judgment approach was used to generate weights. This approach is influenced by determining the extent to which the common information derived from the variables which constitute the indicator are most aligned to pushing the vulnerability indicator in the positive direction, that is, towards increased vulnerability. The value of each weight (b_i) was assigned within the range 1 to 10. The indicator value after weighting is then given by equation 8:

$$\boldsymbol{x_{ji} = z_i \times b_i} \qquad \textbf{Equation 8}$$

Where:

$\boldsymbol{x_{ji}}$ **is weighted indicator value**

$\boldsymbol{z_i}$ ***is*** **indicator value (without weighting)**

$\boldsymbol{b_i \textit{ is weight assigned to indicator } i}$

In the study, the weights were aggregated and factored proportionately to give the total weights of one unit for exposure, one unit for sensitivity and two units for adaptive capacity, such that equation ten of this report gives zero as the resultant vulnerability value for cases where there is no resultant vulnerability.

5.3.5 Calculation of indices and mapping

The vulnerability indices are calculated based on the formula from Filmer and Pritchett (2001), where the weights, indicators and standard deviation of the indicators are used as in Equation 9 below:

$$v_j = \sum_{i=1}^{n} \left[b_i \left(x_{ji} - \bar{x}_i \right) \right] / s_i \qquad \text{Equation 9}$$

Where:

v_j is the index at location j for the lowest category where indicators are agregated to an index;

$\bar{x}_i$ *is the mean of indicator i for all locations*;

n *is total number of indicators*;

x_{ji} *is the normalised indicator at* j^{th} *location*;

b_i *is the assigned weight to indicator i and* $\sum_{i=1}^{n} b_i = 10$; and

s_i *is the standard deviation of indicator i in all locations*

5.3.6 Integration of vulnerability elements

The contribution of each category to the higher level category is based on the weighting system. The weighted values of each category are added to obtain the higher level value of vulnerability quantification process. For example, to obtain the exposure index from the three exposure risks, each hazard risk index is assigned a weight where the three weights are factored to add up to one unit. The resultant three exposure indices are added to obtain the overall hazard index. Similarly, to obtain the overall adaptive capacity index from the ten elements of adaptive capacity, each element is assigned a weight to make up the ten weighted elements. The ten elements of adaptive capacity are then added together.

The resulting exposure index, sensitivity index and adaptive capacity index are added to obtain the overall vulnerability index. At each level of the vulnerability assessment, however, the sum of weights should be equal to one. Furthermore, the indices must be synchronised in such a way that they have the same meaning for an index of one as for an index of zero on a scale of zero to ten. High adaptive capacity values mean less vulnerability while high sensitivity and exposure mean high vulnerability. The mathematical representation of vulnerability is then given as shown in Equation 10 below:

$$\boldsymbol{V_{I,j} = w_e E_{I,j} + w_s S_{I,j} - w_a A_{I,j}}$$ -- **Equation 10**

Where

$\boldsymbol{V_{I,j}}$ ***is the vulnerability index of location j;***

$\boldsymbol{S_{I,j}}$ ***is the sensitivity index of location j;***

$\boldsymbol{E_{I,j}}$ ***is the exposure index for location j;***

$\boldsymbol{A_{I,j}}$ ***is the adaptive capacity index for location j;***

$\boldsymbol{w_e, w_s}$ ***and*** $\boldsymbol{w_a}$ ***are weighted coefficients such that*** $\boldsymbol{w_a}$ ***is negative***:

$$\boldsymbol{w_e + w_s + w_a = 1}$$

5.4 Conclusion

Adaptation strategies and options for climate change impacts in the field of water access and use have to be responsive to the extent of impacts due to the climate change and vulnerability of affected communities. Institutions that are set up to assist communities in adaptation have to first define the nature of the impacts, that is, exposure to the negative climate change stimuli, and also appreciate how sensitive these communities are to the impacts, including their ability or potential to adapt to such exposure. After developing such knowledge, the planned and implemented adaptation options are likely to provide support for targeted communities rather than place the vulnerable communities in a poorer state. Quantification of vulnerability provides a systematic method on which to base the planning of adaptation measures, prioritising the implementation of these measures and ensuring that the identified measures are suitable for the targeted communities.

The extent of climate change-related vulnerability in communities depends on their exposure to climate impacts, their sensitivity and their potential for adaptation. The quantification of vulnerability ensures that the nature of circumstances besetting the different communities can be brought into a common decision-making framework where overall decisions are made and broken down into component programmes and activities, through which adaptation support is provided holistically.

6 Institutions, their role in an environment of climate change

6.1 Introduction

Institutions link individuals with collectives (Agrawal et al., 2008). They are the structures through which people govern and organise human society, and cooperate to achieve specific purposes. Institutions mediate our understanding of climate change and our ability to respond to the challenge it poses. This chapter considers South African institutions and their role in an environment of climate change, particularly in relation to adaptation.

Although the role of institutions in adaptation is clearly defined in literature, in practice many other variables come into play and they tend to mask these roles. Adger (2005), cited in Ospina and Heeks (2010), observed that while institutions play a significant role in climate change adaptation, the capacity to adapt is also dependent on two additional factors, namely, the availability of resources to cope with exposure and the distribution of these resources across the system. Institutions are comprised of different bodies which may include formal or informal organisations, departments within a government, non-governmental organisations, etc. The success of adaptation practices is viewed as highly dependent on institutional arrangements, since no adaptation exists in an institutional vacuum (Agrawal et al., 2008).

What communities have learnt through adaptation to climate variability has created a form of resilience, yet still institutions can help build longer-lasting and better-informed adaptation plans. The role of institutions is also defined by Matczak et al. (2007) as that of dealing with production and sustenance of public goods. The types of institutions that become involved in community adaptation will mostly depend on the adaptation challenge being addressed. Three types of institutions have been identified by Agrawal (2010), and these are civic, public and private institutions. Agrawal (2010) views institutions as being able to “connect households to local resources and collective action”, determining “flows of external support to different social groups” and linking “local populations to national interventions”. Institutions act as a buffer for communities as they shape the extent to which vulnerability is aggravated or improved. Table 6 below shows the various institutions for rural and urban communities.

Table 6: Type of institutions

	Public (state)	Private (market)	Civic (civil society)
Rural	Extension offices, weather departments, environmental offices, municipalities	Seed companies, insurance companies, farmer associations	Stokvels, kinship, NGOs, cooperatives
Urban	Municipalities, weather departments, environmental offices	Insurance companies, water management boards, microfinance	NGOs, cooperatives, media

Institutions are further divided into formal and informal institutions. Matczak et al. (2007) views formal institutions as those introduced or enforced by the government, whereas informal institutions are independent of the government. The latter institutions exist mostly within communities and include those that are based on traditions, social forms of conduct and rules (ibid). The way in which formal and informal institutions interact determines the form of resilience communities achieve (Mearns and Norton, 2010). Matczak et al. (2007) sums up their roles by saying that "both formal and informal institutions have a role in adaptation to climate change. The former offer rigid enforcement (helping to deal with the collective action problems, spill-over effects, externalities), while the latter use locally rooted compliance based on tradition".

Other institutional roles in adaptation include:

- Capacity-building and skills development;
- making information about climate change available to the people;
- community empowerment in taking advantage of available resources;
- linking communities to external support structures, including funding;
- building resilience;
- researching possible adaptation strategies;
- funding or mobilising of resources and allocating them;
- mapping vulnerabilities; and
- provision of leadership.

6.2 Government Institutions

Climate change impacts are affecting communities in ways that will require adaptation initiatives from governments. Governmental institutions' anticipated role in climate change adaptation could take the form of building resilience and informing people about climate change and its effects, as well as funding or mobilising funds and allocating them. Government institutions are already involved at community level in development programmes. These programmes can be developed to incorporate adaptive capacity for the benefit of communities (Anderson et al., 2007). Involvement of government institutions in climate change has so far been mostly in research and less so in implementation (Green, 2008).

In South Africa, the decentralisation of power to regional and local levels places institutions closer to the communities that they need to serve. The constitution of South Africa sets out an elaborate framework of government which enables devolvement of government duties into institutions at various levels in relation to the communities they serve (Republic of South Africa, 1996). At national level, there are three spheres of governance, namely national, provincial and local government. Local government is the sphere of government closest to the people, with many basic services being delivered by local municipalities. In these municipalities, local ward councillors are the politicians closest to communities.

Each metropolitan and each district municipality is responsible for establishing and implementing a framework for disaster management in their municipalities (Mukheibir and Sparks, 2005). Climate change mitigation and adaptation are issues that are considered under disaster management programmes in municipalities. Local municipalities share the responsibility for water services with district municipalities, Department of Water Affairs, Development Bank of Southern Africa, water boards and other private entities such as mines. District municipalities take on more responsibility in rural areas more remote from metros, or when local municipalities have been found to be lacking in capacity. In line with the principles of co-operative government as set out in the Municipal Structures Act of 1998 (Republic of South Africa, 1998b), national and provincial government must support and strengthen municipalities' capacities to manage their own affairs.

Municipalities are the primary spheres responsible for most water services, including household water, sewerage and storm water drainage. Municipalities are required to produce IDPs in consultation with all stakeholders in the municipal area. These plans ensure the logical interrelationship of the plans for different sectors and, through the planning process, priorities are agreed from all the competing demands facing municipalities. IDPs are reviewed on an annual basis and substantially revised every five years.

The next level of local government is the ward. The Municipal Structures Act (1998) (Republic of South Africa, 1998b) requires wards to have ward committees, whose functions are:

- To ensure and improve community input and participation in governance processes;
- to build partnerships for service delivery;
- to disseminate information to communities from municipalities; and
- to identify problems in the ward, and through this structure to bring these problems to the attention of the municipality.

According to the Local Government Municipal System Act (Republic of South Africa, 2000), municipalities are required to facilitate community participation in putting together the municipality's IDPs and municipal budgets. Two measures to strengthen the link between government and citizens are the use of community development workers, who are placed in wards "to facilitate information and state support at household level", and the development of multipurpose centres (Thusong Service Centres) whose purpose is to "promote access to government – wide information and services" (Department of Provincial and Local Government, 2009).

6.3 The Department of Water Affairs

The National Water Act (Republic of South Africa, 1998a) makes provision for water resources management through a multi-tiered system. The Department of Water Affairs (DWA) has overall responsibility for effective water management in South Africa (Figure 13). The DWA's aim is to ensure the availability and supply of water at national level, facilitate equitable and sustainable social and economic development, and to ensure the universal and efficient supply of water services at local level (DWA, 2013a).

Its responsibilities include ensuring efficient use, protection, development, conservation, management and control of water resources in a sustainable and equitable manner for the benefit of all. The DWA issues licences, operates dams and administers water use, and its role is to regulate and monitor all institutions concerned with water delivery and sanitation services. It is a national entity with regional implementation offices.

The National Water Act of 1998 (Republic of South Africa, 1998a) makes provision for decentralisation of some of the DWA's powers to Catchment Management Agencies (CMAs) in order to broaden participation in water management. A CMA is responsible for the management of water resources within its own water management area (WMA), with its functions including co-ordination of the activities of water management institutions within its area, development of a catchment management strategy and the promotion of community participation in water resource management. The process of establishing CMAs is progressing very slowly while the WMAs have recently been reduced in number from 19 to nine.

The third and last tier of the water resources management framework comprises Water User Associations (WUAs). DWAF (2008a) describes WUAs as associations comprising individual water users that undertake water-related activities for their mutual benefit. This vague description was to allow WUAs to be a form of institution that could be used by former irrigation boards, former government irrigation schemes, smallholder and emergent farmers, recreational water users, environmental groups and other similar potential users. Any local group of users who wish to undertake water-related activities can form a WUA, making its purpose clear through its founding documents and constitution.

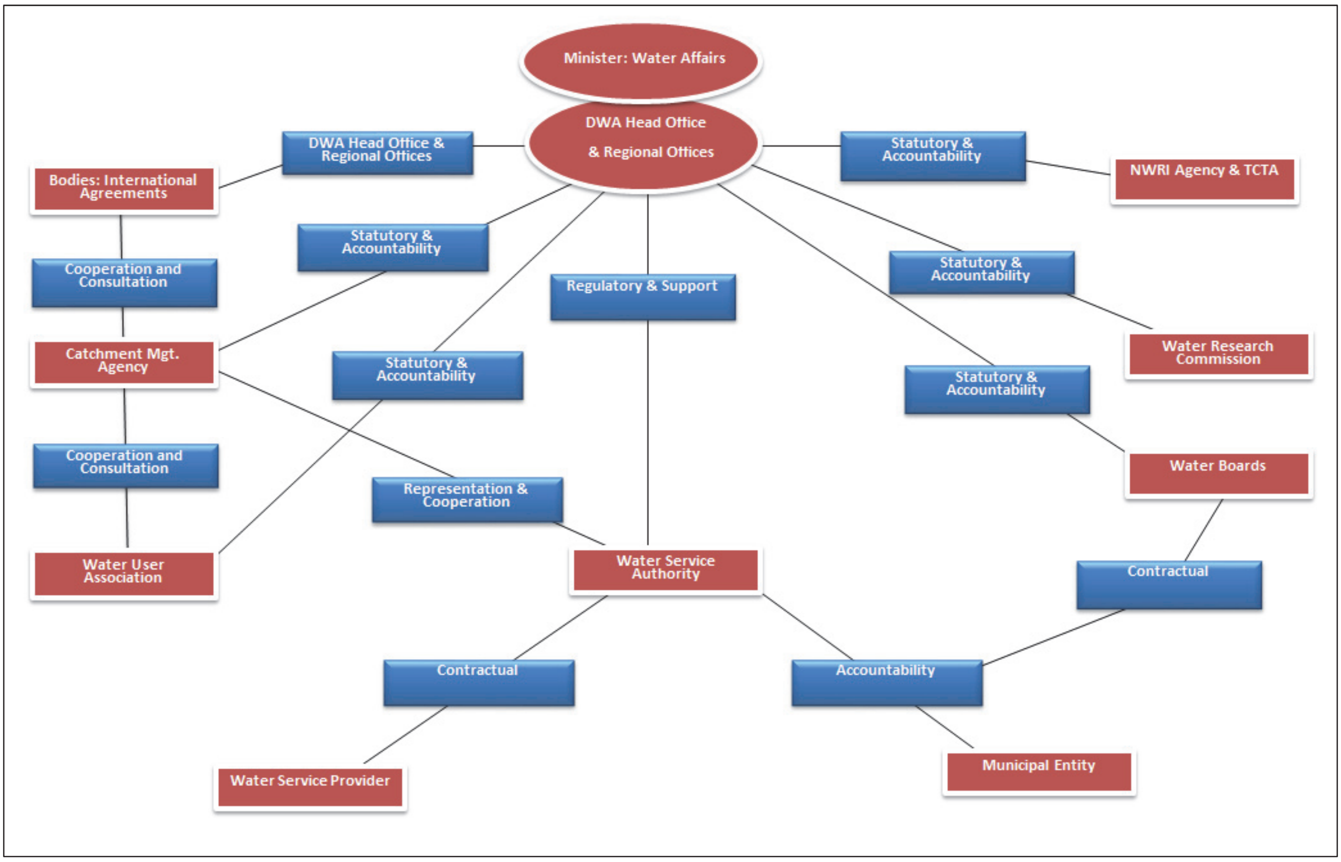


Figure 13: National institutional arrangement of water affairs

6.4 Department of Cooperative Governance and Traditional Affairs

The Department of Cooperative Governance and Traditional Affairs (CoGTA) is tasked with developing national policies and legislation with regard to provinces and local government, monitoring the implementation of acts relating to provinces and local government, and supporting provinces and local government. Part of its role is to create enabling mechanisms for communities to participate in governance.

The structure of local government is dealt with in terms of the Municipal Structures Act (Republic of South Africa, 1998b), which sets out the categories and types of municipalities and provides for elections and other matters.

Municipalities are established in terms of categories A, B and C, with the metropolitan areas constituting the Category A municipalities. There are six metropolitan municipalities, divided into wards, in the biggest cities in South Africa: Johannesburg, Cape Town, Durban, Pretoria, Port Elizabeth and the East Rand.

Category B municipalities are the local municipalities, consisting of areas that fall outside the six metropolitan areas. There are 231 local municipalities and each one is broken into wards, with individual citizens being represented by a ward councillor. Local municipalities also form part of the district municipality in their area.

Category C municipalities are the district municipalities, made up of a number of local municipalities. District municipalities administer and make rules for districts which include more than one local municipality. There are 46 District Councils in South Africa, usually with between four and six local municipalities falling under each one.

Within the local municipalities are different council committees specialising in specific areas. Councillors dedicate their time to specific issues and do their best to become experts in those issues. Committees make recommendations to council and thus save the council from having to deal with every matter in detail. Committees, however, do not make final decisions since most decisions need approval from council as a whole.

There are three different types of committees, with the most important one for community members being the ward committee, which is delegated to:

- Secure better participation from the community to inform council decisions;

- make sure that there is more effective communication between the council and the community; and

- assist the ward councillor with consultation and reports-back to the community.

6.5 Private institutions and NGOs

6.5.1 Private institutions in South Africa

Non-governmental organisations which participate in the water sector can be divided into those that operate on national or local level, and those that work on an international level. The roles of non-governmental organisations in respect of climate change adaptation for the water sector in South Africa include:

• Undertaking risk and vulnerability assessments on behalf of their particular sector and special interest areas, such as insurance. For example, insurance firms such as Swiss-Re have made climate change a central component of their business processes (Brauner, 2002);

• the creation of institutions where private institutions collaborate in responding to climate change, e.g. the SA Green Building Council, Nedbank-founded WWF Nedbank Green Trust and the Nedbank Green Affinity banking products;

• educating and working with suppliers and consumers to promote sustainable practices, e.g. Woolworth's Farming for the Future initiative;

• partnering with other organisations in sustainability initiatives, e.g. Pick 'n Pay's partnership with the World Wildlife Fund's Sustainable Fisheries Programme;

• entrepreneurs innovating and developing the new technologies that will be needed for adaptation, e.g. Siemens' promotion of renewable energy as part of Green Urban Infrastructure, a programme that was set up in response to climate change;

• changing engineering and building regulations and specifications. This, for example, includes designs to withstand extreme exposure to environmental heat and floods due to climate-related factors;

• providing venture capital for new climate change adaptation technologies;

• offering market instruments for managing risk, e.g. insurance; and

• developing new markets, e.g. the carbon market, ecosystems services markets.

6.5.2 NGOS with international links

A number of Non-Governmental Organisations (NGOs) in South Africa are engaged in sustainability, conservation and climate change adaptation work. There are also offices in South Africa of international NGOs such as Friends of the Earth South Africa and WWF-SA, which is the local office of the World Wide Fund for Nature (WWF).

NGOs are working with government and communities in the co-creation of knowledge and policy relating to climate change. NGOs are represented in the National Climate Change Committee (NCCC) discussed below, and the WWF-SA's climate change advocate has been appointed to the National Planning Commission.

South African NGOs are also influencing international climate change debate and conventions. South African NGOs met with NGOs from Brazil, Russia, India and China (the BRIC group) in October 2010 to work on a future agreement, post Copenhagen, on CO_2 emissions in climate change negotiations.

NGOs' strengths lie in raising awareness, encouraging civil society debate, participation and action. South African environmental NGOs are involved in research, analysis, information dissemination, dialogues, media campaigns and seminars. In 2010, WWF-SA initiated a series of four round-table events, the third event being entitled: "*You have struck a rock*", a round table which called for knowledge sharing on the subjects of climate change and adaptation (WWF, 2010).

The strength of NGOs lies in building institutional and community capacity. A number of NGOs are working with communities in a very practical way to implement changes to farming methods that anticipate climate change impacts such as reduced rainfall and higher temperatures. A well-known example is the national NGO Food and Trees for Africa (Food and Trees for Africa, 2012), which has also been strong in fostering climate change awareness among the general public. There are also eco-tourism, community-development organisations, microfinance NGOs and community-based care NGOs. Government are able to harness the skills of these NGOs in supporting local communities with regard to adaptation.

NGOs have also played an important role in disaster management. Agrawal et al*.* (2008) describes how an NGO in the Philippines, which has experienced repeated typhoons, tornadoes and floods, identified local leaders in vulnerable communities. Together they conducted hazard and vulnerability analyses, while establishing village level committees to foster effective disaster responses.

6.5.3 Local civil society organisations

The civil society organisations include rural producer organisations, cooperatives, stokvels, savings and loans groups, and burial societies. A review of 118 cases of adaptation in 46 countries in the UNFCCC database on adaptation shows that most local civil society organisations involved in climate change adaptation tend to be informal institutions (Agrawal et al., 2008). Examples quoted by Agrawal et al. (2008) include: "institutions around labour-sharing, indigenous information exchanges, savings societies, commons institutions and indigenous knowledge institutions around migration and storage." Agrawal et al. (2008) also noted that governments and external interventions rarely support these organisations, despite their importance. The reason could be that they are not immediately visible to outside agencies, and it is suggested that external interventions should rather build on informal processes and recognise them within formal institutions.

There are still very few civil society organisations supporting communities who can take on the role of climate change adaptation support. This problem is worse when one considers the number of civil society institutions that have come out of the South African community, rather than those springing from some international basis. Jagwanth (2003) pointed out that the repressive history which did not allow the participation of civil society has not yet been adequately addressed to ensure wide civil society involvement in addressing issues at community level.

6.6 Traditional and religious institutions

According to Houston and Somadoda (1996), there are approximately 800 traditional leaders assisted by 10 000 traditional councillors in the country, with over 16.5 million rural people living under the jurisdiction of traditional leaders. The place and role of traditional leaders in South Africa's new democratic political system have not been clearly defined in the constitution (Republic of South Africa, 1996), but traditional leaders still fulfil a variety of functions in rural society, including those of presiding officer in customary courts, mediator of disputes, advisor in agricultural and family matters and guardian of young, old, infirm and abandoned. Most of all, traditional leaders consider the control of land to be their primary responsibility. A local chief may allocate land for residential, business, industrial or grazing purposes, as well as access to forests or woodlots. Problems and disputes can arise in the effective administration of these rights, both in recording the rights and in demarcating the land (Goldman and Reynolds, 2008). There can be conflict between a Western freehold system and the traditional system. It is difficult for rural people to engage in markets for ecosystems services if they do not have clear and secure resource rights and tenure (UN, 2006).

In April 2010, a Franco-South African wind-energy operator, InnoWind, signed an agreement with the Eastern Cape House of Traditional Leaders to pursue the development of a number of wind farms in rural regions of the Eastern Cape, the aim being to create community broad-based Black Economic Empowerment trusts for each project. This is an example of positive collaboration among a range of stakeholders, including the House of Traditional Leaders, in one of the poorest areas of South Africa (Van der Merwe, 2010).

Traditional leaders are well respected in rural areas and it is, therefore, easy for them to claim the ear of the community. Just as traditional leaders have been called on to raise awareness and motivate for behavioural change in relation to HIV/AIDS (Palitza, 2012), so the government could call on traditional leaders to communicate key messages relating to climate change, land use and adaptation.

Religious leaders also have a great influence over the large percentage of the population who attend religious institutions, and can therefore be of supreme importance in influencing attitudes to conservation and climate change adaptation. Bearing in mind that the role of water in human life is acknowledged in many religious and cultural rituals and practices, it is clear that religious institutions can regenerate traditional religious and cultural respect for the environment. The Southern African Faith Communities' Environment Institute (SAFCEI) is a non-profit organisation operating from the coastal town of Kalk Bay in the Cape, with the following objectives:

- To raise environmental awareness;
- engage in formulating policy and ethical guidelines within our faith communities;
- facilitate environmental responsibility and action;
- combat environmental and socio-economic injustices; and
- support environmental training and learning.

6.7 Academic and research institutions

As a party to the UNFCCC, South Africa is required to fulfil certain obligations in terms of adaptation which include promoting and cooperating in scientific, technological, technical, socio-economic and other research, as well as systematic observation and development of data archives related to the climate system, intended to further understanding and to reduce or eliminate uncertainties (Mukheibir and Ziervogel, 2006).

Research into climate change adaptation in South Africa is ongoing in a number of universities and institutions, including the Water Research Commission, the Council for Scientific and Industrial Research (CSIR), the Agricultural Research Council (ARC), the Centre for Policy Studies, South African National Biodiversity Institute (SANBI) and the South African Weather Service (SAWS).

Some provincial and local governments are keen to develop greater understanding of the challenges they face in their local area, and they are drawing on research capacity to assist. For instance, the City of Cape Town's environmental planning department commissioned research into a city-wide adaptation framework as a step towards creating a City Adaptation Plan of Action. This research was carried out by the University of Cape Town (UCT)'s Energy Research Centre together with UCT's Climate Systems Analysis Group (CSAG).

Research, both theoretical and applied, both traditional and action-research with communities, is absolutely critical to South Africa's goal to develop a proactive, adaptive management approach that can effectively respond to the impacts of climate change. A further role of academic institutions is to infuse their curricula with a consciousness of climate change and equip new generations with the skills to rise to the challenge. Several local universities are now offering modules on climate change at both undergraduate and post-graduate degree levels.

6.8 International institutions

Concern over climate change led to the formation of the Intergovernmental Panel on Climate Change (IPCC) in 1988 by the United Nations organisations, WMO and UNEP. The role of the IPCC is now well established in that it does not conduct its own scientific inquiries, but reviews worldwide research, issues regular assessment reports (there have now been four), and compiles special reports and technical papers (IPCC, 2012a).

The IPCC finally succeeded in convincing the world that climate change was indeed a fact of life, which led to the United Nations Conference on Environment and Development of 1992, at which the United Nations Framework Convention on Climate Change (UNFCCC) was tabled with the objective of stabilising concentrations of Greenhouse Gases (UN, 1992). The South African government ratified the UNFCCC in August 1997, and during the same year the Kyoto Protocol was adopted with the aim of strengthening the UNFCCC (Department of Environmental Affairs, 2004). The South African government acceded to the Kyoto Protocol in July 2002 and ratified it in 2005. Since 1992 there have been numerous international meetings and conferences in which South Africa attempted to seek inclusion of issues key to this country, such as climate change adaptation in the water sector.

As a party to the UNFCCC, South Africa has made certain commitments relating to adaptation. These include:

- Formulate and implement national, and where appropriate, regional programmes to mitigate climate change and facilitate adequate adaptation to climate change;
- cooperate in preparing for adaptation to the impacts of climate change; and
- take climate change considerations into account in the relevant social, economic and environmental policies and actions with a view to minimising adverse effects on the economy, public health and the quality of the environment.

The UNFCCC has recognised that there are costs involved in adaptation and that some of the Least Developed Countries (LDCs), who have contributed very little to climate change, are particularly at risk, while not having surplus resources that can be diverted into adaptation measures. An LDC adaptation fund has therefore been created and a National Adaptation Programmes of Action (NAPA) process set up, which starts with LDCs sending in NAPAs to the UNFCCC. The NAPAs must identify priority activities that respond to a country's urgent and immediate needs to adapt to climate change. NAPAs are expected to take into account existing coping strategies at the grassroots level, and build upon them. Prominence is given to community-level input as an important source of information, recognising that grassroots communities are the main stakeholders. Some countries neighbouring South Africa, such as Lesotho and Mozambique, have sent in NAPAs (AMCEN, 2009).

6.9 Conclusion

A number of institutions involved in water access and use in the country are guided by various acts and policies enacted in the past two decades. As such, the South African water sector’s legal and policy provisions are relatively new, and have also benefited from earlier developments in other countries. In the existing legal and institutional framework, water access and use are adequately covered. The issues of climate change and adaptation, however, are only starting to become part of institutional plans and water service delivery. South Africa developed its first national document on climate change only in 2004 (Department of Environmental Affairs, 2004). This document was developed only after South Africa ratified the Kyoto Protocol and became a party to the UNFCCC (Department of Environmental Affairs, 2012). Private institutions are also starting to become involved in climate change, but with little yet being discussed under special topics such as adaptation. The participation of the private sector and indeed, many other institutions in the water sector, is not well defined or even discussed in national policy at this stage. A strategy for climate change response in the water sector is, however, being developed in the Department of Water Affairs (DWA, 2013b).

On a national scale, the Department of Water Affairs carries the main responsibility for water access and use in the country, overseeing all other institutions engaged in water-related activities. Other important government institutions are water boards, local government, water service authorities, other water service providers and institutions, the Development Bank of Southern Africa and the Trans-Caledon Tunnel Authority (TCTA).

At local community level, the provisions as set out in the Municipal Structures Act (Republic of South Africa, 1998b) and the government Municipal System Act (Republic of South Africa, 2000) guide the municipalities and wards in the delivery of services, including that of water provision.

7 An overview of the case study areas

7.1 Introduction

Investigation of local communities' water access and use in the study focused on four case study areas selected using criteria described in Section 1.4.2 of this report. This chapter presents the four selected case study areas in terms of their geographical location in South Africa, demographics, socio-economic situations, access to water resources, water use, current climate, water resources and hydrology.

7.2 Location and geography

Although the software accompanying this report does allow for addition of data from other countries, the study areas used in this research are all in South Africa. Figure 2 shows the geographical locations of the four districts in which the four local municipal areas used in the study are located.

The Vhembe district is in the Limpopo province, which is the northern-most district and which borders on two other countries, Zimbabwe to the north and Mozambique to the east. The study focused on Thulamela Local Municipality in the north-east of the district, a mountainous area bordered to the east by the Kruger National Park. The seat of the municipality is the town of Thohoyandou, which is also the seat of the district and the political, administrative and commercial centre of the area. A large percentage of households in the municipality live in formal houses, although the road network is underdeveloped, with many communities residing far from surfaced roads. Inaccessibility is one of the reasons given for slow progress in the development of water services (Thulamela, 2010). The area was historically part of the Venda homeland and about 90% of its municipal land is still under tribal ownership. About 6% is exclusively owned by the state, with only 4% being privately owned (Thulamela, 2012). Thulamela was observed in the study to have few informal settlements, and this fact is confirmed.

uMgungundlovu District Municipality is in the province of KwaZulu-Natal, situated in the far east of the country. It is a mountainous area and remains relatively green all year round as a result of good rainfalls. The study focused on Msunduzi Local Municipality, the seat of which is in Pietermaritzburg, also the capital and the second largest city of KwaZulu-Natal. It is, however, not a metropolitan municipality. During apartheid, the city was segregated into various sections, with almost the entire Indian population being moved to the suburb of Northdale, while most of its Zulu inhabitants were forced to reside in the township of Edendale, where the majority of the population (60%) still live in low-income townships. This municipal area has the highest population density of the four case study areas, with 935 people per square kilometre.

Xhariep District Municipality is in the Free State province, just east of the centre of the country and bordering Lesotho. Xhariep is the southernmost district of the province. The study focused on Letsemeng Local Municipality in the southwest of the district. This municipality consists of extensive commercial farmland and five small towns which exist mainly to serve the surrounding agricultural areas. The seat of the municipality is the small town of Koffiefontein. Although most people in Letsemeng live in formal brick houses, there are a few informal settlements in the towns and on several farms. With less than four people per square kilometre, this municipal area has the lowest population density of the four case study areas.

Bojanala District is the easternmost area of the four district municipalities making up North-West province, which borders Botswana on its western border. Bojanala District, however, is still east of the centre of the country, as can be seen from the map in Figure 2 of this report. Bojanala District covers areas which were part of the former Bophuthatswana homeland. The Magaliesberg, a distinct large mountain range, is located to the south with flat bushveld extending northwards. The study focused on Madibeng Local Municipality in the east of the district. A large percentage of the population in Madibeng is located in dormitory towns, historically set up to provide a large pool of labour to the economically active Pretoria-Witwatersrand-Vereeniging area. Given its history as a grouping of dormitory towns, Madibeng, with a population of at least 477 381, does not have urban centres commensurate with its large population.

7.3 Demographics and socio-economic characteristics

In terms of land area Letsemeng is by far the largest of the study area municipalities, but it has a very small, and at the same time, decreasing population. Msunduzi is the smallest municipality in land area but has a high population density. Thulamela has almost the same size population as Msunduzi, but the population in not concentrated in a large city or town as is the case in Msunduzi, or even in a number of small towns, as is the case in Letsemeng. Instead the population is dispersed, making it that much more difficult and expensive to deliver services such as water. The municipality where the population has in fact increased most over the past ten years is Madibeng, which is perhaps due to economic opportunities in mining and agriculture, as well as good access to the Gauteng economic centre of the country. The area, population and employment statistics for the four local municipalities is presented in Table 2 of this report.

Thulamela has the highest official unemployment rate which stands at 43.8% thus higher than any of the other three case study areas. Letsemeng, with its relatively small population, has the lowest rate of unemployment (22%), although it is still considered to be high. The official unemployment rates include only those people who are actively seeking employment. The unemployment figures given in municipal IDPs were higher and probably reflect the broader definition of unemployment which includes other members of the communities who are frustrated or for other reasons have stooped to actively seek employment. With Thulamela's unemployment rate being so high, few people are earning an income and it is impractical to recover costs of municipal services and capital investment from service revenue, given the present model where services are to be provided for everyone. In the case study areas, the distribution of wealth is such that those municipal areas with a large rural population tend to have a higher percentage of the population that is economically disadvantaged, especially in the two areas of Madibeng and Thulamela, which were formally parts of homelands. Indeed, research by Noble and Wright (2012) into multiple deprivation also indicates that the most deprived areas in South Africa are located in former homeland areas.

Thulamela has little formal industry, with much of the employment being provided by retail services in the town of Thohoyandou and government-related administrative services. Informal businesses such as vegetable vending, roadside food outlets, roadside car washing, domestic work and brick-making are common in the area. Most settlements in Thulamela are rural and few have developed a local economic base. There is, however, both commercial farming and smallholder farming and some work is offered by nature reserves. Van Averbeke (2012) reports that traditional agriculture in South Africa has been disturbed by military and political subjugation of African tribes during the nineteenth century, followed by land dispossession, segregation and forced removals to restricted areas of the country in the twentieth century.

The homelands were characterised by high rural population densities, small allotments of arable land and shared rangeland to the extent that the overcrowding made it difficult for smallholders to make a living from the land. The effect was a diversification of livelihoods, with men migrating elsewhere for work, with the mines being a typical example. From 1970, some local employment was created in education, government administration and business. From the 1990s onwards, rural homesteads have increasingly relied on state pensions and child support grants. Like the rest of the study areas, a minority of people in Thulamela earn their livelihood through farming. There are, however, commercial farms and a number of long-standing smallholder irrigation schemes which, along with domestic water use, are the most significant water uses in Thulamela.

Msunduzi, situated on either side of the N3 highway 67 kilometres from Durban, has both light and heavy industry and agriculture. The location of the municipality is on an agro-industrial corridor stretching from Durban to Estcourt and on a major tourist route to Durban in one direction and the Drakensberg in the other. Since it is the capital of KwaZulu-Natal, there are employment opportunities in government, and the municipality is also known for producing aluminium, timber and dairy products. The farming communities in neighbouring municipalities are linked to the municipality through available services such as banking, government-related transaction facilities, and even the social amenities. On a typical working day, the population of the City of Pietermaritzburg is at least doubled since residents from surrounding municipalities come in for work and to access services (Msunduzi, 2012a). As such, the water demand in Msunduzi is higher than would be the case if calculated solely on its resident population.

Letsemeng is almost entirely commercial farmland (9 730 km^2 out of 10 180 km^2), with five small towns dotted in between which offer services and small industry needed by the rural areas. Crops farmed include maize, wheat, lucerne, potatoes, groundnuts, viticulture and animal feed. There is also extensive livestock farming with sheep, goats and some game farms. The commercial farms, however, employ only a small number of the local population and few opportunities exist for work-seekers. There are nevertheless a few wine-makers, grain packaging factories, abattoirs and mining activities in Letsemeng. A reasonably large diamond mine in Koffiefontein dating back to 1870 still functions and provides some employment. There are also a few wildlife reserves, including the relatively large Kalkfonten Nature Reserve.

The main economic activities in Madibeng are mining, agriculture and tourism, with platinum, chrome, vanadium, lead, marble, granite and slate being produced in the area (Bojanala, 2010). Wide-scale platinum mining is a recent development in this area, which has generated much employment and attracted the migrants of communities from other provinces, and especially the Eastern Cape. Commercial farming of maize, sunflower, citrus fruits, paprika, cotton, wheat, soy, lucerne and vegetables thrives, along with plant nurseries in the south of the municipality. In the northern area of Madibeng are farms growing wheat and soy on a large scale. The Hartbeespoort Dam is a tourist attraction which has spawned many service businesses in the hospitality industry and crafts and leisure activities, as well as attracting new investments in a housing boom around the dam. A high level of poverty is evident in the densely populated rural and semi-urban settlements, where the level of unemployment which has been prevalent over the years continues to be high. Although homestead food gardens are not common, water uses in Madibeng include commercial agriculture, mining, industries and domestic use.

7.4 The current climate in the case study areas

The case study areas are very different in terms of annual rainfall and winter minimum temperatures, while maximum temperatures have significantly lower differences. Table 7 below shows the winter and summer temperature range for the district municipalities and the current annual rainfall for key towns in the case study areas.

Table 7: Climate of case study areas (SAWS, 2011).

	Thulamela LM Vhembe DM	Msunduzi LM uMgungundlovu DM	Letsemeng LM Xhariep DM	Madibeng LM Bojanala DM
Winter temperature range	10°C to 23°C	6°C to 23°C	1°C to 20°C	3°C to 22°C
Summer temperature range	20°C to 32°C	19°C to 31°C	17°C to 33°C	17°C to 31°C
Current annual rainfall	608 mm	840 mm	274 mm	685 mm

Thulamela is generally hot even in winter where the minimum temperature averages 10°C. Figure 14 below shows that the average minimum temperature in some months is as high as 20°C.

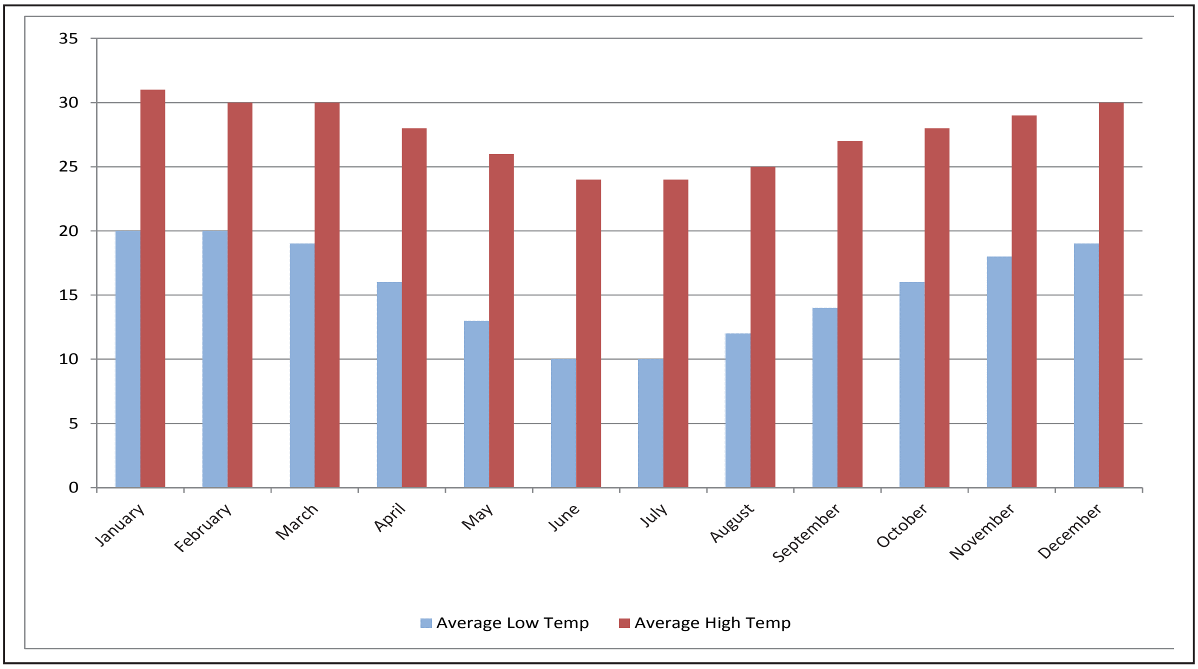


Figure 14: Thulamela temperature based on records in Thohoyandou

Rainfall is highest in Msunduzi with levels as high as 1 200 mm in the mountainous areas to the north-east, and as low as 750 mm in the lower flatter terrain to the south-east (Figure 15).

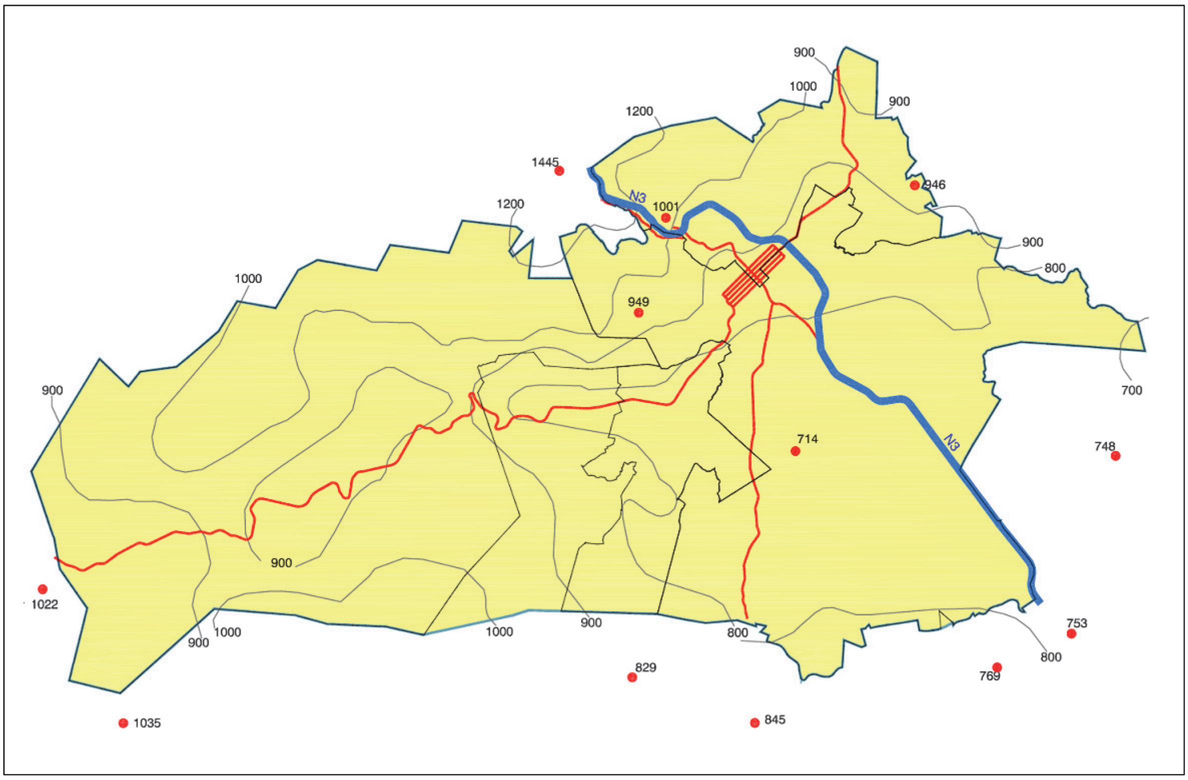


Figure 15: Mean annual rainfall in Msunduzi Local Municipality (Msunduzi, 2006b)

Letsemeng is a low rainfall area, with the Mean Annual Precipitation (MAP) for most of the area being below 300 mm. Rainfall in Letsemeng is associated with the summer season, starting in September and usually ending in April. The rainfall pattern as illustrated for Jacobsdal in Figure 16 below is characteristic of this area. The generally flat terrain, devoid of large mountains, tends to reduce the intensity of the precipitation events, which are usually orographic in nature.

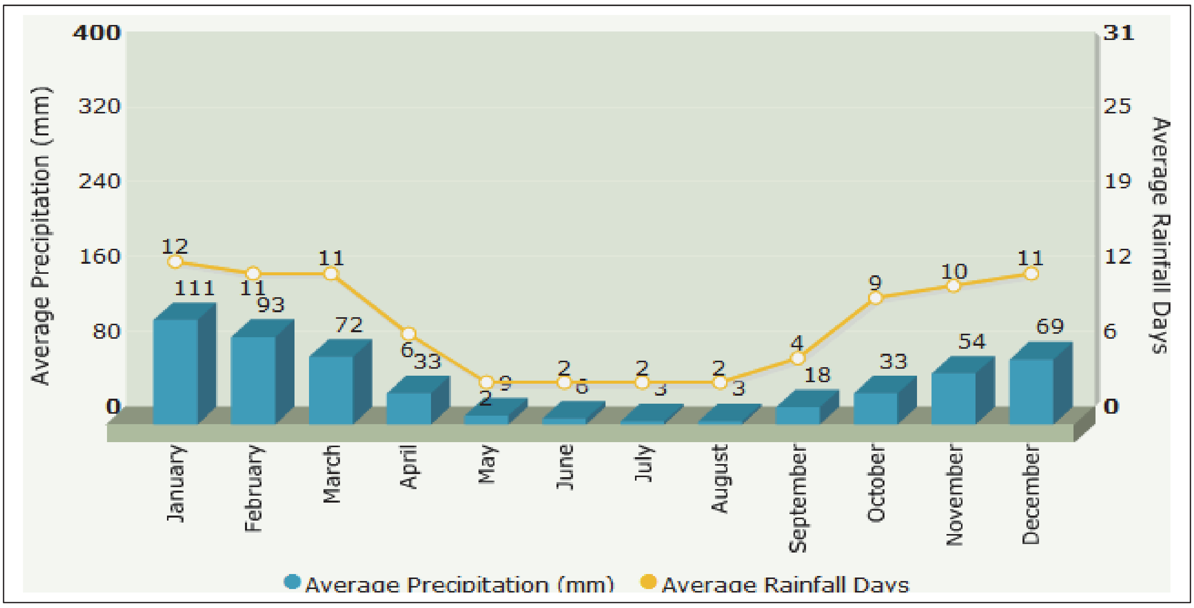


Figure 16: Rainfall and rain days in Jacobsdal, a town in Letsemeng (based on SAWS, 2011)

Although rainfall is low, this area benefits from large inflows or water transfers from the Orange River system and as a result the low rainfall in the area has little effect on water access for some water users, including farmers. Indeed, some farmers pointed out during the period of field-based questionnaires that rainfall in their areas was difficult to work with since they plan their water usage solely on the available water from the Kalkfontein and Vanderkloof Dams. Open water evaporation is relatively high in Letsemeng due to the flat topography, which generates windy conditions, in addition to the generally high summer temperatures. The high average temperature in Jacobsdal, a town in Letsemeng, is illustrated in Figure 17 below.

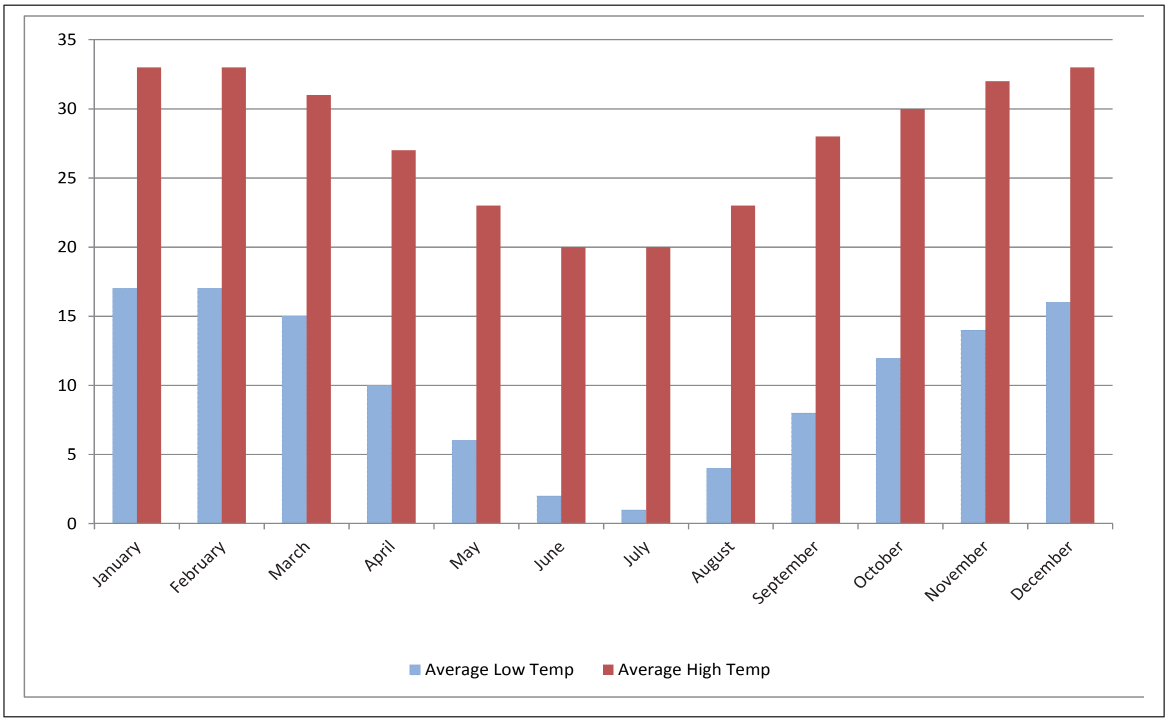


Figure 17: Average high and low temperatures in Jacobsdal, a town in Letsemeng (based on SAWS, 2011)

Madibeng Local Municipality receives an average of 600 mm rainfall in the west, increasing to 700 mm in the eastern parts. Figure 18 below shows the rainfall distribution in the whole of the Crocodile West -Marico catchment, where Madibeng is located in the eastern half of the catchment area. In the past 50 years, rainy days in September and October have been increasing, but the principal characteristic has been high inter-annual variability in rainfall quantities and distributions (Thomas et al., 2007).

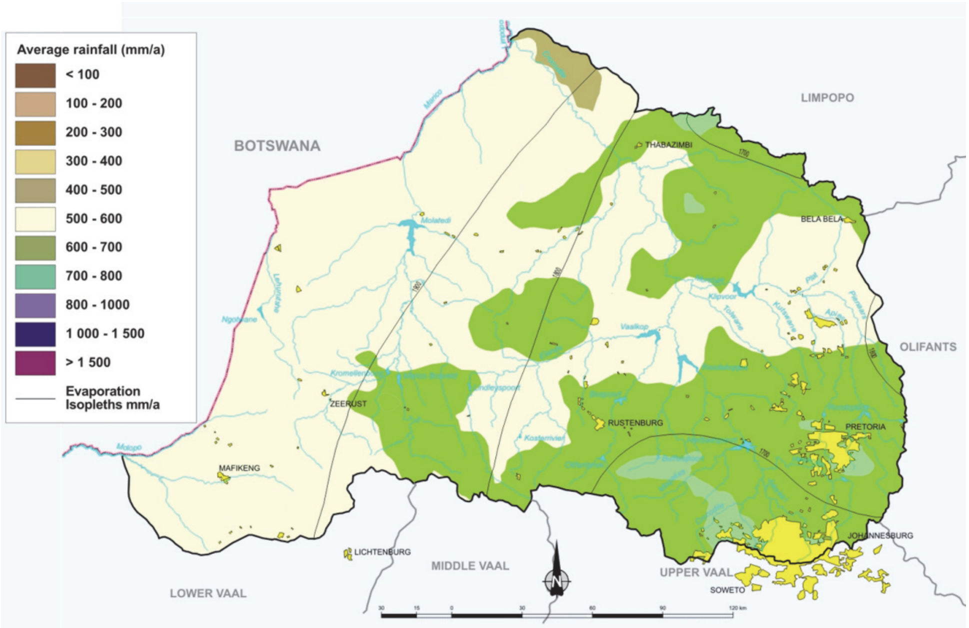


Figure 18: Rainfall and evaporation in Madibeng

7.5 Water resources and hydrology

7.5.1 Water resources and hydrology in Thulamela

The water system of immediate importance for Thulamela is the Luvuvhu River, whose catchment forms part of the larger Limpopo system which flows into Mozambique before discharging into the sea. The Luvuvhu River and some of its tributaries rise on the southern side of the Soutpansberg Mountains east of Makhado between 1 000 m and 1 400 m above mean sea level. Further eastwards, the Latonyanda, Dzindi, Mutshindudi and Mutale tributaries join the Luvuvhu, all originating from within the mountain ranges east of the Entabeni and Vondo forestry areas (DWAF, 2001). The Luvuvhu River traverses the Kruger National Park and joins the Limpopo River on the Mozambique border. The yield in the Luvuvhu water system and availability of water to users of surface water in this area are closely linked to the Letaba River system due to water transfers between these systems (Figure 19).

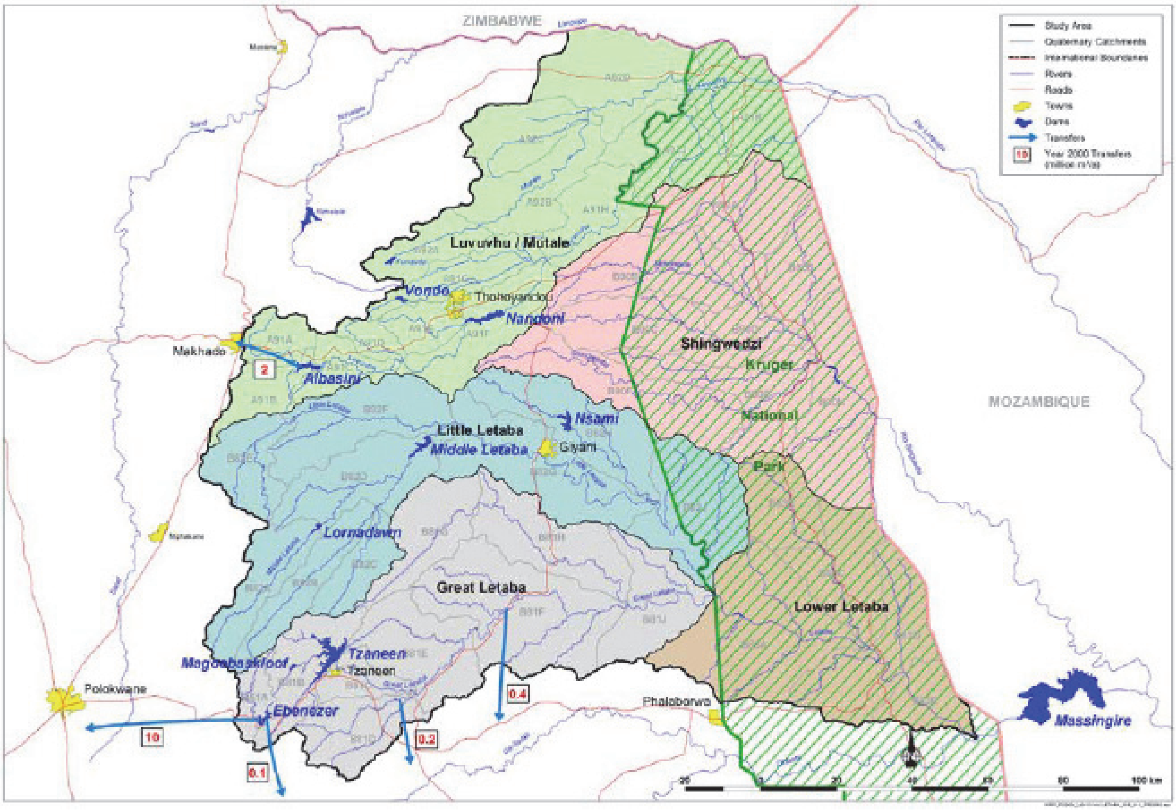


Figure 19: Luvuvu/Letaba water system (DWAF, 2004b)

The main dams are the Albasini, Nandoni and Vondo Dams, while dams in the Luvuvhu River catchment include the Albasin Dam and the smaller Mambedi, Tshakhuma and Damani Dams. The Vondo and Phiphidi Dams lie in the Mutshindudi River, and the more recent Nandoni Dam is located between Thohoyandou and Malamulele, with a catchment that stretches from Makhado in the west to Malamulele in the east. The Luvuvhu Catchment is 5 941 km², with a mean annual precipitation (MAP) of 608 mm (Figure 20 below). The catchment generates a Mean Annual Runoff (MAR) of 519 million m³, but with a huge range from 85 million to 1 900 million m³, depending on rainfall (DWAF, 2004b). Thulamela has average monthly temperatures of nine degrees in June and July and 33 degrees in January. Potential evaporation increases gradually from 1 400 mm per annum in the west to 1 900 mm per annum in the east, with about 60% of the evaporation occurring during the six months from October to March (DWAF 2001).

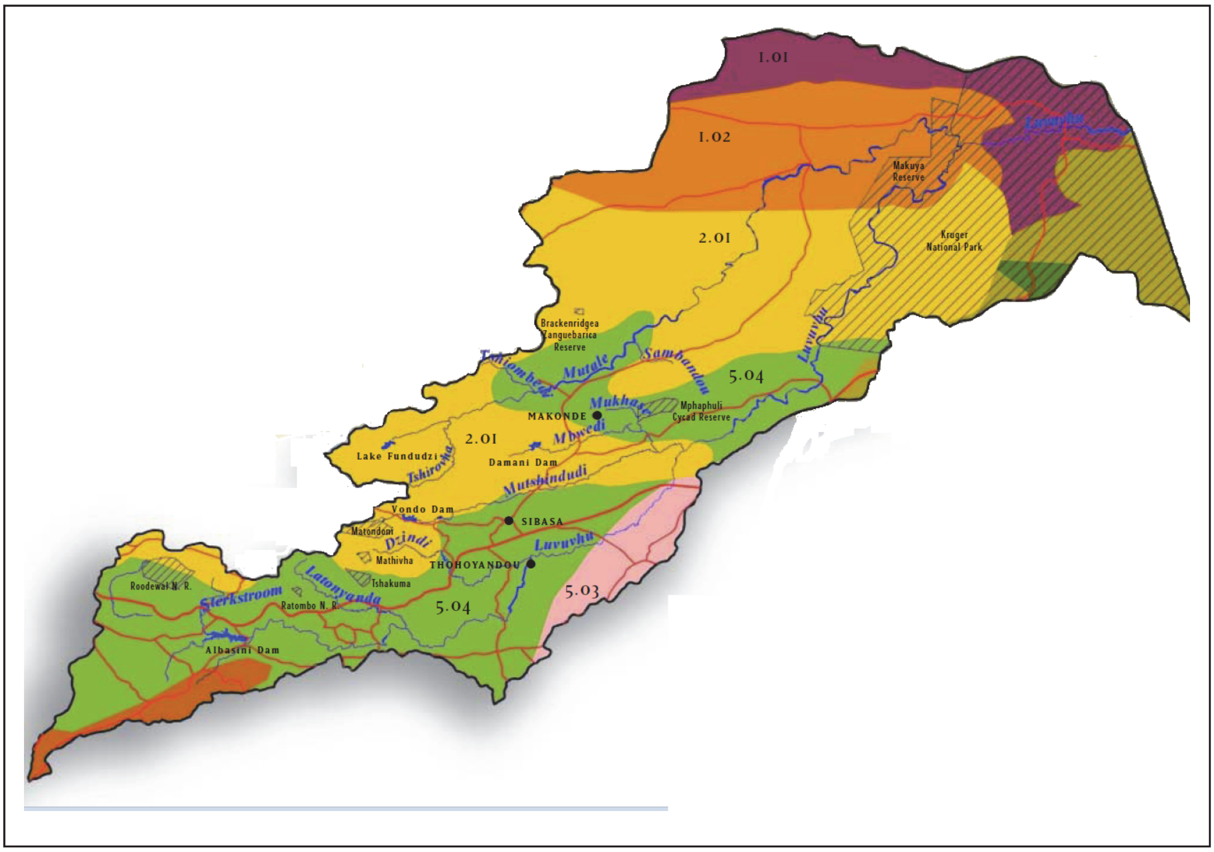


Figure 20: Luvuvhu catchment system (DWAF, 2001)

The addition of the Nandoni Dam has increased water yield in the Luvhuvu catchment area. The yield in this catchment has increased by 62 million m³ per annum. With the construction of Nandoni Dam, the Luvuvhu catchment is no longer fully committed as it now has an excess yield of 37 million m^3 (DWAF, 2004b), and thus possible developments are planned in the catchment to utilise the remaining yield. Many rural communities do not have access to reticulated surface water but are dependent on groundwater.

A large area of the Luvuvhu catchment is under poorly regulated subsistence farming which can lead to overgrazing and exposed soil. Commercial logging and the constant cutting of trees for firewood also expose soil to erosion (DWAF 2001). As a result, the Luvuvhu River system suffers from high levels of siltation, with the rivers in and around Thulamela having very high levels of silt. At the same time, they also suffer from the addition of pollutants from waste water treatments and the contents of pit latrines which end up in the river system. The high temperatures and low rainfall tend to increase the concentration of pollutants (VDM, 2007).

There are good groundwater reserves in areas close to Thohoyandou, and Figure 21 below shows that in these areas the groundwater levels were predominantly high despite low rainfall in the area during the period August 2010 to August 2011 (DWA, 2011a). The water is currently used by farmers, although there is also one groundwater scheme in Thulamela, known as the Tshifudi groundwater scheme, where water is used for domestic supply.

DWAF (2006) stated that there were strong indications that the surface water from the catchment areas of the Albasin Dam and the groundwater could be linked in such a way that abstraction from groundwater will reduce the surface water yield. There is evidence that over-exploitation of the groundwater resource occurs at some locations around the Albasin Dam, in the vicinity of

Thohoyandou and at Gidiana. Without records on the usage of groundwater, however, the yield of this water system, although important to Thulamela, remains uncertain.

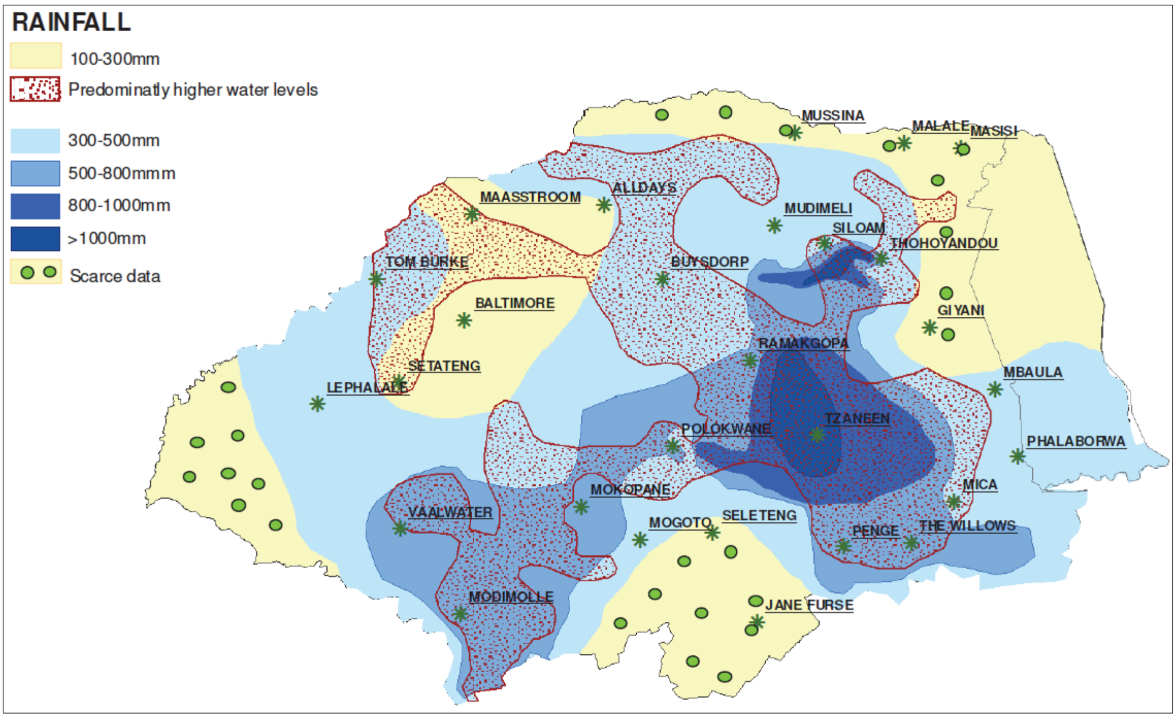


Figure 21: Patterns in groundwater level behaviour versus total rainfall received: August 2010 to August 2011 (DWA, 2011a)

The quality of groundwater in the WMA, particularly in the mountainous areas, is generally good, with water of high mineral content occurring in some of the drier parts. There are, however, no records of significant pollution of the groundwater. Community members in areas to the north of Thohoyandou reported that since some of their wells are poorly constructed, pollution is caused by surface water which drains into these wells. As a result of pollution from runoff some wells are no longer in use.

7.5.2 Water resources and hydrology in Msunduzi

Msunduzi lies in KwaZulu-Natal, a relatively wetter province of South Africa where 27% of South Africa's natural MAR of 49 x 10^9 m³ occurs annually (DWAF, 2002). The Mooi, uMgeni and uThugela catchments are the main water sources available to Msunduzi and surrounding areas.

Rainfall in the catchment areas for rivers that serve Msunduzi ranges between a low of 700 mm to 970 mm at the headwaters (uMgeni, 2011). The prevailing weather patterns are predominantly orographic, where warm moist air moves in over the continent from the Indian Ocean, rises up the escarpment, cools down and creates rainfall. With this type of rainfall process, rain shadows occur in the interior valley basins of the major rivers where the annual rainfall can drop to below 700 mm.

Msunduzi itself is in the middle of both the Msunduzi and Mgeni River systems. The water transfer scheme from Mooi River in the uThukela Basin is located upstream of the abstraction points for Msunduzi. The uMgeni River and its main tributary, the Msunduzi River, have a combined catchment area in excess of 1 300 km². The topography is hilly, especially in the areas around Msunduzi and further downstream, and this creates fast flows and occasional waterfalls, with much soil erosion during flooding events.

Msunduzi relies on water supplied from Midmar Dam on the uMgeni River, and is located upstream of the larger eThekwini Metro, which also obtains water from the same uMgeni River System (Midmar, Albert Falls, Nagle and Inanda Dams). The high water demand in Msunduzi, eThekwini and surrounding areas has led to the development of water augmentation schemes to transfer water from the Mooi and uThukela River systems (Figure 22).

Figure 22: KwaZulu-Natal river systems and location of Msunduzi (uMgeni, 2011)

Phase 2 of the Mooi-Mgeni Transfer Scheme (MMTS-2), which includes the building of Spring Grove Dam on the Mooi River, will provide an additional 60 million m³ (TCTA, 2011). The yield at Midmar Dam, at a 99% assurance of supply, and after taking into account MMTS-2, will be 476 Mℓ/day. This, however, is already projected to be lower than the total demand by the year 2018. There are thus plans to extend water yield in other catchments which supply the eThekwini Metropolitan Municipality, and to reduce the water demand on the upper uMgeni River System, at the same time freeing up more water for Msunduzi. Figure 23 below provides an illustration of growth in water demand for the eThekwini, uMgungundlovu and Msunduzi municipal areas.

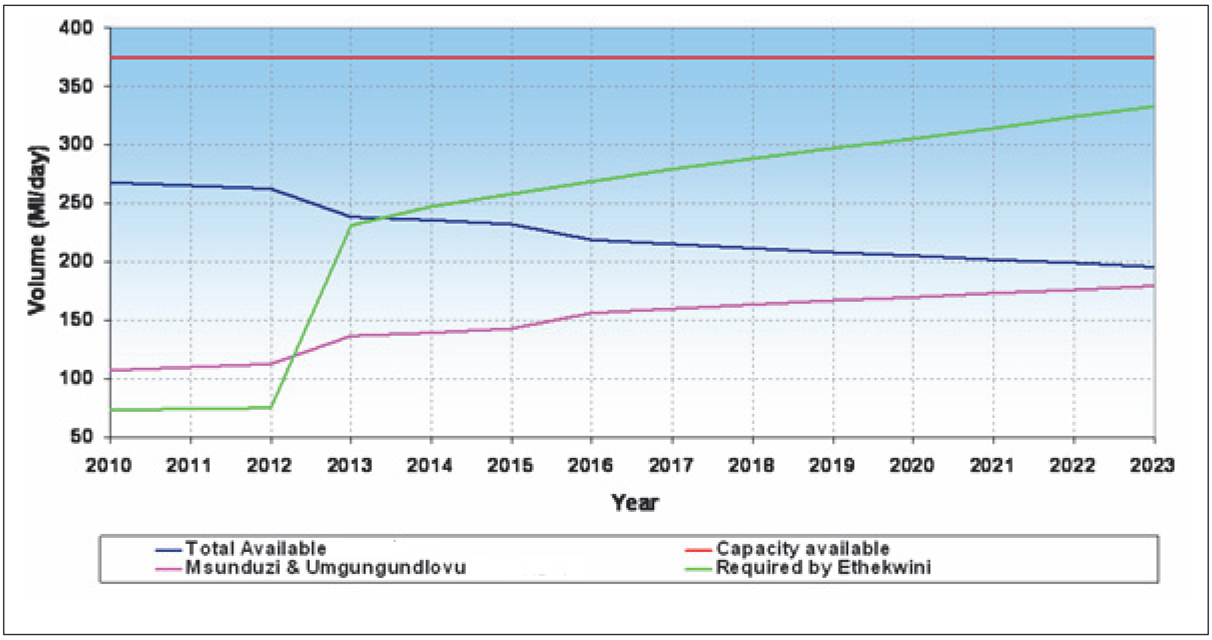


Figure 23: Available water supply in Msunduzi, uMmgungundlovu and eThekwini (uMgeni, 2011)

Planned future water development for the eThekwini and Msunduzi areas is the Mkomazi-Mgeni Transfer Scheme Phase 1, which consists mainly of the Smithfield Dam with a yield of 147 Mm^3 per annum. Designs for the Smithfield Dam have been completed and it is planned to start construction in 2013. The DWA reconciliation strategy report (DWA, 2009c), however, advised that it will take ten years to develop and implement this scheme from design. As such, there is a high likelihood of water shortages being experienced in the area by 2018 unless other steps are taken to balance supply and demand.

DWA (2009b) reported that the water quality in the Msunduzi River downstream of Henley Dam is seriously affected by sewer infrastructure problems such as broken and blocked sewers, and wash-aways of sewer lines. The area is inhabited by 11 000 people in informal settlements, and excessive ingress of rainwater into the sewer system, resulting in surcharges hydraulically overloading the Darvill Waste Water Treatment Plant (WWTP). Pit latrines, also extensively used in this area, are not always adequately installed and protected from storm water ingress, with the result that some pit latrine contents become mobilised during storm events and cause further pollution. The Msunduzi River, which passes through the city centre in Pietermaritzburg, feeds into the uMgeni River just below Nagle Dam. The impact of pollution from the inhabited catchment area and the additional nutrient point loading from the Darvill WWTP is most evident in Inanda Dam on the uMgeni River.

The water quality of the uMgeni River is relatively good all the way until the confluence with the Msunduzi River, where the water quality in the middle and lower Msunduzi River is very poor, with a high faecal coliform content and nutrient over-enrichment. There are significant health risks if this water is used for drinking and contact recreation. The Msunduzi River is the venue of a major international water sporting event, the Duzi Canoe Marathon, and is already known to have caused health problems attributed to the water quality. The water quality problems in the Msunduzi and uMgeni Rivers resulted in the formation of a Section 21 trust called the Duzi-uMgeni Conservation Trust (DUCT). This Section 21 trust was formed to champion the environmental health of the Msunduzi and uMgeni Rivers, and thus reduce the threat to the annual Duzi Canoe Marathon. The trust focuses on eight water quality issues: faecal pollution, industrial pollution, solid waste pollution, invasive alien vegetation, bilharzia, soil erosion and unregulated sand-winning operations, as well as a poorly operated dam which does not release the environmental flows (Mvula Trust, 2011).

The water quality of the Inanda Dam on the uMgeni River is very poor. In recent dam monitoring programmes, it was observed that the water in the Inanda Dam has excessively high total algae and blue-green algae counts (DWA, 2009c). Alien plants such as water hyacinth clog the water surface and deplete oxygen, foster mosquitoes, disrupt the river's self-purification processes and may lead to a loss of aquatic species, with an associated loss in resource use and value. It is also expensive to purify water polluted by water hyacinths.

7.5.3 Water resources and hydrology in Letsemeng

Although rainfall is low in Letsemeng, this area benefits from large inflows or water transfers from the Orange-River system. Thus, the low rainfall has little effect on water access for many users, including irrigation farmers. The commercial farmers who benefit from irrigation schemes pointed out that they do not necessarily need rainfall in their areas as they schedule their water usage on water available from the Kalkfontein and Vanderkloof Dams. Water supplies from these two sources have addressed the needs of farmers without fail for several decades. In general terms irrigation water demand is met 100% of the time on irrigation farms connected to the Riet and Orange-Riet Canals.

Letsemeng's bulk surface water supplies are obtained from the Orange, Modder and Riet Rivers, as illustrated in the map in Figure 24 below. The surface water flows in this area are dominated by large controlled water transfers from the Orange River System. Although the yield from the Modder and Riet Rivers has already been fully committed, the yield of the Orange River System exceeds existing water commitments.

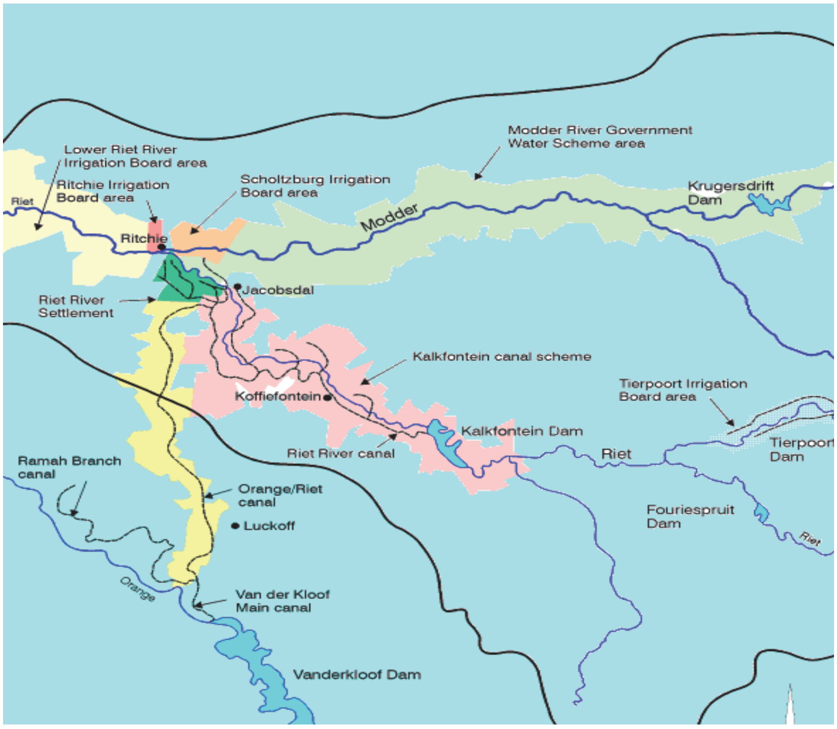


Figure 24: Water access in Letsemeng is dominated by the Modder, Riet and Orange Rivers (DWAF, 2004c)

At this point, there is at least a further 340 million m^3 of water yield not utilised in the Orange River System. Taking into account the existing water transfer system from Vanderkloof Dam to Letsemeng, this local municipality depends on six local water catchments as shown in Tables 8 and 9 below.

Table 8: Reconciliation of water requirements and availability in the Senqu-Orange water system (million m^3/a) (DWAF, 2004c)

Component/ Sub-area	**Local** yield	**Transfers** in	Local requirements	Transfers out	Balance
Senqu Lesotho	**523**	**0**	**23**	**491**	**9**
Caledon Lesotho	**31**	**0**	**40**	**0**	**(9)**
Caledon RSA	**178**	**0**	**105**	**59**	**14**
Kraai	**44**	**0**	**103**	**0**	**(59)**
Riet/Modder	**137**	**242**	**351**	**29**	**(1)**
Vanderkloof	**3 534**	**0**	**346**	**2809**	**379**
Total for WMA	**4 447**	**2**	**968**	**3 148**	**333**

Table 9: Natural Mean Annual Runoff (MAR) and ecological reserve (million m^3/a) (GTZ, 2007)

COMPONENT	NATURAL MAR	ECOLOGICAL RESERVE
Senqu Lesotho	**4 012**	**933**
Caledon Lesotho	**753**	**92**
Caledon RSA	**650**	**90**
Kraai	**956**	**158**
Riet/Modder	**407**	**45**
Vanderkloof	**203**	**31**
Total at Vanderkloof	**6 981**	**1 349**

In the long run, Letsemeng, like many other areas that benefit from the Orange River system, will have access to even more water as the various planned phases of the Lesotho Highlands Water Project (LHWP) are completed. The second phase of the LHWP will result in the construction of Mashai Dam on the Senqu River in Lesotho (GTZ, 2007). The Senqu River in fact becomes the Orange River when it crosses into South Africa from Lesotho. The projects planned for the various phases of the LHWP are shown in Figure 25 below.

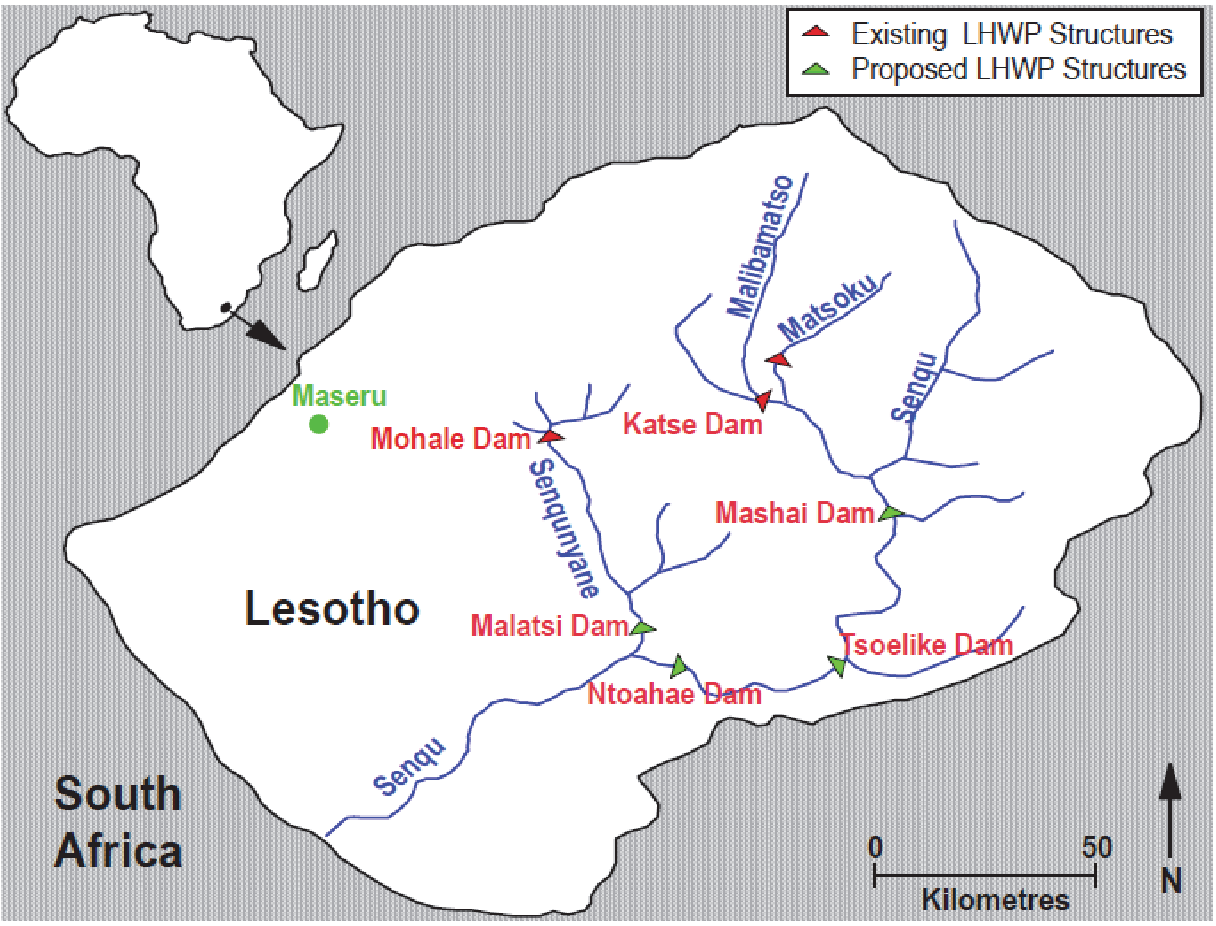


Figure 25: Senqu River System in Lesotho showing LHWP planned and developed water infrastructure (IUCN, 2003)

Two important dams characterising the Letsemeng area are the Kalkfontein Dam (258.2 million m^3) and Vanderkloof Dam (3 200 million m^3). Vanderkloof Dam is located at the border of the Free State and Northern Cape, while Kalkfontein Dam is more central and close to the town of Koffiefontein, where the municipality obtains water from the dam. The Riet River Canal takes water from Kalkfontein Dam to a raw water storage reservoir close to the water treatment works in Koffiefontein. The main water resource infrastructure in the area is the Vanderkloof Dam and the network of canals which convey water from Vanderkloof and Kalkfontein to the farming areas in the Modder-Riet area. An additional raw water source for the area is the Koffiefontein mine which releases excess water from its underground mining operations into the Riet River.

Letsemeng's generally flat terrain tends to create windy conditions. As a result, the area has a high evaporation potential exacerbated by the dry atmosphere, clear skies and high daytime temperatures. The extensive surfaces of the large canals are exposed to the sun, and the high evaporation rates result in heavy water loss in the bulk water conveyance systems. As a result, the water supplied from the dams is significantly more than that demanded by users. In Letsemeng, the potential evapotranspiration is 2 000 mm. Out of the 242 million m^3 per annum of water conveyed through the Orange-Riet Canal, approximately one third is lost to evaporation.

Water quality

The main source of surface water for Letsemeng, the Orange River water system, contains return flows from a number of farms in the Vaal System, as well as effluent from industry and waste water treatment facilities. These pollutants are partially diluted by the water from the more pristine Lesotho Highlands catchments, which have very sparse settlements and therefore negligible pollution. The large dams on the Orange River act as pollution sinks. The nutrients are generally lower in the Vanderkloof Dam with mean Total Nitrates (TN) and Total Phosphates (TP) concentrations of 0.61 mg/ℓ and 0.052 mg/ℓ respectively, while at Roodepoort further upstream of the Gariep Dam, the concentrations of TN and TP are 1.57 mg/ℓ and 0.130 mg/ℓ respectively (DWA, 2009d).

Viljoen and Armour (2002) state that water quality in the Vaal and Orange Rivers is deteriorating. This normally occurs naturally in the dry seasons and when flows decrease, with the quality improving again during periods of good rain. The main problem identified in relation to economic use of surface water is salinity. Irrigation was observed to be the main cause of the increasing salinity, and the overall effect is that continued use of saline water causes soil to degrade as salts accumulate. In addition to the higher costs of using the water for irrigation, costs of treating the water for domestic use in the various communities that rely on the Orange River system also increase. Viljoen and Armour (2002) also observed that as the soil becomes saline the water-draining properties decline and the soil become more susceptible to waterlogging. Farmers' yields for certain crops deteriorate with increasing salt content in the soil and in due course some crops become economically unviable in the environment created by saline water.

Groundwater

According to the DWA WARMS database, the total volume of groundwater usage in the Orange River Basin is 89.3 million m^3 per yr. This represents only 10% of the groundwater harvest potential in this area (DWAF, 2004c). Communities in Letsemeng which are not connected to the canals from the Vanderkloof or Kalkfontein Dams, rely on groundwater, while the municipality also uses borehole water to supply a small number of domestic users in Koffiefontein.

In Petrusburg and surrounding areas, the abstraction of groundwater is well above the available harvest potential, causing shortages to occur in the dry season. The groundwater abstraction rate in Petrusburg reached 15 million m^3 per year by 2004 (DWAF, 2004c). The use of groundwater is affected by a lack of information on availability and potential yield at various points, and it has been reported that boreholes in the southern Free State are prone to fail (DWAF, 2004c). This is blamed on poor prospecting methods and weak groundwater management practices.

Groundwater in areas surrounding Jacobsdal has high salinity and nutrient levels due to seepage from irrigated areas and the natural soil salinity (DWAF, 2004c). The elevated salinity levels in the Jacobsdal area are aggravated by the closed nature of the groundwater system, which does not allow for flushing out of the accumulating salts. Water quality in Petrusburg is not a major problem, with the exception of a few boreholes that were poorly located too close to cemeteries. The local municipality of Letsemeng stated that little or no groundwater monitoring is taking place in the area (Letsemeng, 2011a).

7.5.4 Water resources and hydrology in Madibeng

The runoff potential in Madibeng is estimated to be an average of 7% of precipitation, which is lower than the national average (NWDACE, 2008), meaning that the area would never be able to meet its water needs from its own water resources. It is the beneficiary, however, of major water transfers totalling at least 300 million m^3 of water from the Vaal River system. Water is also transferred out of the WMA to Botswana and the Limpopo WMA. In fact, an estimated 549 million m^3 per annum flows out, with 96% going to the Limpopo River (NWDACE, 2008).

The main trunk of the Crocodile River, which has its source in the Witwatersrand mountain range, runs from south to north through the local municipality of Madibeng. Many rivers feed into the Crocodile River along its course through the municipality, while the Magalies, Leeuwspruit and Swartspruit Rivers feed into the Hartbeespoort Dam. The Magalies River is drying up due to intensive irrigation taking place upstream in the Tarlton area outside Krugersdorp, while water which should be flowing into the Magalies River is draining into the dolomitic areas which cover vast areas of the North West province (Durand, 2007).

Of the four large dams located in the municipality, namely the Hartbeespoort, Rooikoppies, Vaalkop and Klipvoor Dams, the most important is the Hartbeespoort Dam. This large dam has a gross full supply capacity of 195.2 million m^3 and a yield of 158 million m^3 (Madibeng, 2010) which serves the domestic, industrial and agricultural sectors.

Madibeng Local Municipality falls in hydrological areas A21F, A21J and A21K of the Crocodile (West) – Marico WMA, which covers a total catchment area of 47 565 km^2 (NWDACE, 2008), stretching from Gauteng through the North West Province and into Limpopo. The catchment generates 20% of the area's Gross Domestic Product (GDP) and serves 5.5 million people (DWA 2011b). There are nine major storage dams in the catchment with limited scope for additional dams. The naturalised MAR in the Crocodile West catchment area is about 646 million m^3 per annum, with an exploitable groundwater resource of about 125 million m^3 per annum (NWDACE, 2008). Water use in the catchment exceeds the water available from local sources more than fourfold (DWA, 2010a). The WMA is heavily dependent on water from the Upper Vaal and Olifants WMAs, with the most significant transfer being by Rand Water from the Upper Vaal WMA. The largest inter-basin transfer in South Africa occurs when Johannesburg's Northern Waste Water Works discharges effluent into the Jukskei River, which ultimately flows into the Crocodile West River. The use of such return flows is increasing and steadily adding to the available water.

The North West Department of Agriculture, Conservation and Environment estimated in their Environment Outlook Report of 2008 (NWDACE, 2008) that municipal water use would grow by 1% per year, that industry, mining and power would grow at 2.5% per year, and irrigated agriculture and forestry water use would remain the same. Generally, the urban demand is expected to increase in Madibeng, though the growth is less steep after 2030. Figure 26 below indicates the anticipated water balance from 2005 to 2030, assuming high growth and increasing return flows. Different scenarios for demand management are indicated, with the figure demonstrating a positive water balance. In this area, increased use of water in Gauteng will result in increased effluent and other return flows into the Crocodile River system. Additionally, provision of purified water from Rand Water into Madibeng and other areas in the North West province is expected to increase. The effluent from Gauteng and the supply of purified water from Rand Water represent a transfer of water from the Vaal River System into the Crocodile River, although not all runoff in this area remains in the area for local use. Compared to the Crocodile and Marico area's natural MAR of 855 million m^3/a originating in the WMA, an estimated 549 million m^3/a still flows out of the area, with 96 per cent going to the Limpopo River (DWA, 2011b).

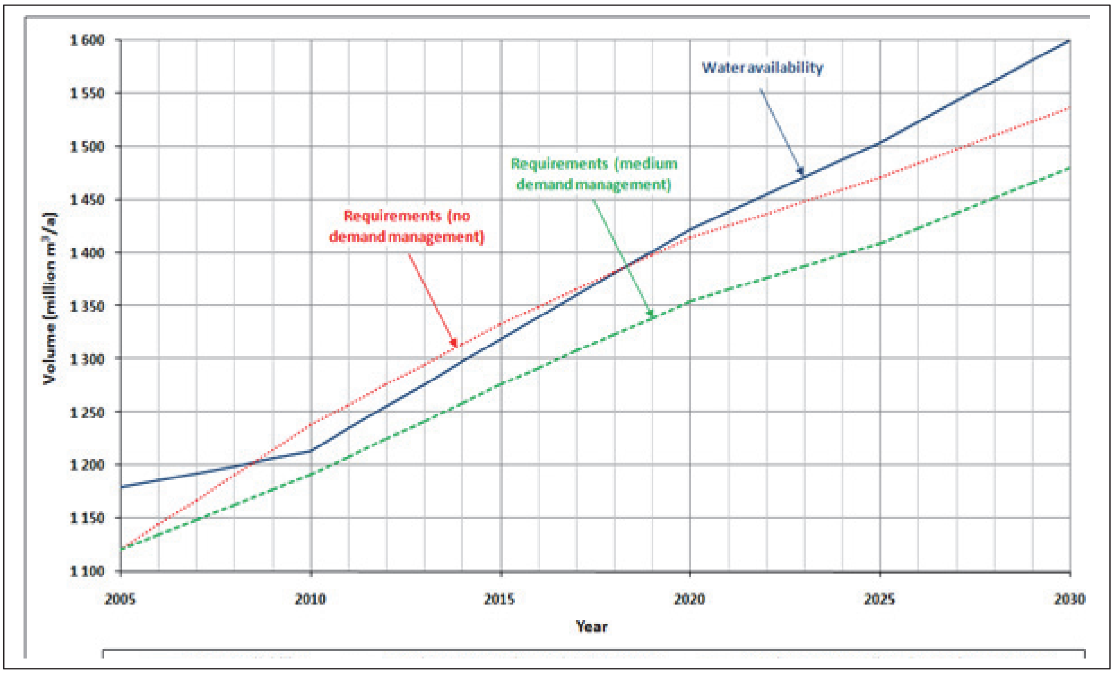


Figure 26: Crocodile River water balance (DWA 2011b)

Water Quality

Hartbeespoort Dam, a major source of water in Madibeng, has been affected by continued degradation of water quality since the early 1970s (Thornton and McMillan, 1988). The Madibeng's Water Safety and Security Plan (Madibeng, 2010) lists the problems causing pollution within the catchment of the dam as follows:

- Direct discharge of raw and partially treated sewage effluent from wastewater treatment works upstream of the dam;
- storm water filling sewer reticulation network manholes causing overflow into the catchment;
- surface water runoff causing pesticides, fertilisers, litter, animal waste, oil spills from roads, etc. to enter the dam;
- adverse modification and destruction of the wetlands, river banks, river bed and natural river course;
- pollution from leachates coming from mining activities and waste disposal sites;
- oil spills and other direct pollution from recreational activities within the dam;
- sediment transported into the dam;
- industrial effluent; and
- agricultural return flows.

The resultant problems include eutrophication, toxic algal blooms, a pungent smell, water hyacinths, increasing salinity and phosphate load, and high loads of e-coli. Some of the problems, which also affect other rivers and dams in the municipality, are affected by temperature and are worse in the hot summer months. DWA conducts monitoring of the water resource quality, when levels of calcium, chloride, fluoride, magnesium, ammonia, nitrate and nitrite, sulphate, potassium, and ortho-phosphate are monitored, as well as electrical conductivity and upper pH. Levels are classified from ideal to unacceptable. Those elements that are at an unacceptable level at many monitoring points are ammonia, ortho-phosphate and high pH (DWA, 2011c).

Groundwater

The areas most reliant on groundwater for domestic use are the rural areas to the north of Madibeng. Unfortunately groundwater use is not metered and therefore the abstraction volumes are not known (DWA, 2010a), while Madibeng does not maintain a register of groundwater users. There are 1 600 known boreholes within Madibeng, but the total number used for domestic purposes is not known. Magalies Water operates 192 supply boreholes in 32 villages and, based on equipped boreholes and borehole yields, the domestic demand is estimated to be 1.6 million m^3 per annum. A volume of 0.640 million m^3 per annum has been registered for agricultural supply. Since projections indicate that the population of the area will decrease with time, it is estimated that there is sufficient water for current and future use.

Groundwater in other areas of the municipality also supplies mines, industry, agriculture and domestic users. Most domestic users in the south of the municipality, however, live in settlements which are supplied by formal water schemes drawing on surface water resources. Nevertheless it emerged from this study that groundwater is a vital back-up supply in areas suffering the disadvantages of poor water supply from the formal water schemes.

7.6 Conclusion

The picture that emerges from the case study areas is as follows:

Thulamela is the most underdeveloped area, and communities in this area have the fewest resources, with very few employment opportunities for their rural populations. The area suffers from the multiple deprivations characterising former homelands (Noble and Wright, 2012), with many communities not even having access to water due to a lack of the infrastructure necessary to bring water to the people. The available water yield, however, is adequate for the needs of communities in Thulamela. Following the development of Nandoni Dam, there is now excess yield in the water system amounting to 37 million m^3, according to the catchment strategy report (DWAF, 2004d).

In Msunduzi a large proportion of habitants are concentrated in Pietermaritzburg, the capital of KwaZulu-Natal. Of the four case study areas, Msunduzi has the lowest unemployment rates. The high rainfall of up to 1 000 mm in the upper areas can support sectors such as forestry and rain-fed sugar cane. Although it has an extensively developed water resources infrastructure, Msunduzi water provision is still below the unrestricted demand. Msunduzi shares the water provision system with the much larger metropolitan area of eThekwini, whose demand is more than five times that of Msunduzi. Water demand in Msunduzi already exceeds supply, while the uMgeni Catchment, in which Msunduzi is located, has been fully developed to the extent that any further increase in yield will be possible only if water is transferred from other catchments (uMgeni, 2011).

Of the average daily water sales of 1 129 Mℓ/d, eThekwini receives 77.1% while Msunduzi's portion is only 15.1%. Water provision in Msunduzi and eThekwini is not driven by demand but rather restricted by the available supply (uMgeni, 2011). Demand management, loss controls, debt collection regimes, pricing and retarded growth are some of the mechanisms used to reduce water demand to the levels of available water. uMgeni (2011) also reported that the MMT-2 and Smithfield

Dam water projects are expected to improve water provision and allow for much-needed wide-scale developments, including new high water use industries.

Letsemeng, where the biggest water user is commercial farming, is currently well resourced due to water transfers from the Orange River System and extensive development of bulk water conveyance infrastructure such as the canals which criss-cross the municipal areas to reach many irrigation farmlands. The history of the country has led to the farmland and water rights being largely owned by a few white commercial farmers. The area is otherwise undeveloped and offers few employment opportunities, while the population is small and decreasing. Out of the population of 38 628, 800 farmers use 99% of the water and own a similarly high proportion of the land in Letsemeng, while communities in farming areas and a few informal settlements have only very restricted access to water. Water access problems are associated with the absence of infrastructure rather than the availability of water resources.

Water uses in Madibeng include mining and associated industries, agriculture and domestic use. Madibeng has sufficient water resources due to transfers into the Crocodile (West) – Marico WMA from the Upper Vaal and Olifants WMAs. Water access problems are characterised by high pollution levels, limited water distribution and reticulation infrastructure, as well as a poorly functioning municipality with a major skills shortage.

8 Water access, uses and needs in the case study areas

8.1 Introduction

Community level questionnaires on how residents perceive and then respond to their own present and future water situation and needs provided information for the study baseline to ascertain water access, uses and needs. In this section, water uses, water supply, levels of service, water quality and water needs are discussed for each case study area.

While community members were able to articulate their problems relating to water access and how they were responding, they did not necessarily know why water access problems existed or whether there were currently plans to address identified problems. Ward councillors supplied supporting information and additional perspectives, with further information being gained from relevant institution officials, or from associated documentation such as water service plans and IDPs. Additionally, such sources helped to quantify some of the issues that community members described.

8.2 State of water service in Thulamela

8.2.1 Water resource infrastructure

The water resources infrastructure in Thulamela is owned by three institutions. Most of the dams and their bulk water pumping systems are owned by the Department of Water Affairs. The bulk infrastructure fed by the dams, amounting to approximately 20% of the total water assets, belongs to the district municipality, whilst the retail infrastructure of about 80% is under the control of the Thulamela Local Municipality. According to the 2012/13 IDP report (Thulamela, 2012), all water matters were being handled by the district municipality.

The water service infrastructure in the Vhembe district is generally inadequate for the needs of their community. The population of Thulamela is growing fast, leading to existing water resource infrastructure failing to cope with demands for water (Thulamela, 2008b). The district has a total of 11 dams, and borehole yields are reportedly low (Vhembe, 2010). During consultations with community members of the Thulamela municipal area in November 2011, members expressed dissatisfaction with the fact that there were new dams around them not being utilised, resulting in continued water shortages. On completion, the newly constructed Nandoni Dam will supply water to both the Thulamela and the Mutale Local Municipalities (Vhembe, 2010).

According to reports, water services are indeed being delivered to most areas in Thulamela, albeit with numerous backlogs. These water supplies, however, are below RDP standards. As a result, the highest priority on the Thulamela IDP review list of priorities for the 2008/9 period was set as water services, facilities and infrastructure development (Thulamela, 2008a). COGTA (2011) also reports that there are many water projects underway in Thulamela and that, of the nine projects under their jurisdiction, four are reportedly complete.

8.2.1.1 Metering

Very few establishments and houses in Thulamela have water meters since they were installed only in the Central Business District (CBD) areas of Thohoyandou, Sibasa and Malamulele, as well as a few other new areas. The IDP review of 2007/8 (Thulamela, 2008a) proposed the installation of pre-paid meters to household taps in order to save water. After some meters were installed, a few residents resorted to illegal connections or to deliberately defaulting on their payments, expressing dissatisfaction with municipal services (Thulamela, 2008a). The municipality recently requested tenders for the installation of meters at the water storage reservoirs in Thulamela. Delays in appointing suitable contractors to carry out the work, however, mean that this project is likely to take some time. Without such meters, the good management of water supplies is impossible since volumes of water usage and losses are not known.

8.2.1.2 Water uses and location of users

Water is used mainly for domestic, agricultural, manufacturing and institutional purposes. The IDP review (Thulamela, 2008a) notes that the misuse of purified water, such as for watering gardens, by some community members, contributes to major water shortage challenges. In cases with rampant illegal connections, shortages of water and loss of pressure in the system continue to affect the level of water access by the majority of users. Domestic water users are concentrated in Thohoyandou, where the water provided is well below demand due to inadequate water storage and surrounding residential settlements. The reservoirs supplying the town can only store sufficient water to last half a day. The result is that most users run out of water by mid-afternoon. Other water users who benefit from the municipal services are scattered in the rural areas of Thulamela. Water in these rural settlements comes from boreholes, wells and rivers, or from deliveries made by municipal trucks.

8.2.1.3 Served areas and state of water access

STATS SA (2007) puts the number of community members with access to piped water of any form at 88.5%. The figures in Table 10 below are not based on distance from the house or dwelling of the community member. At least 50% of those living in Thulamela rely on water points outside their dwellings. The numbers of community members who access water outside their households are dominated by municipal residents who have no access to water, according to the strict definition of the term. Most of these community members have access to water at sources well beyond 200 metres from their households, in some instances even having to pay neighbours for this water.

Table 10: Access to water and sanitation in Thulamela (Vhembe, 2009)

Population in Thulamela	683 852
No. of households	133 565
No. of settlements	335
Water services above RDP	270 086
Water services below RDP	413 766
Sanitation services above RDP	197 864
Sanitation below RDP	485 988

8.2.2 Service provision capacity

The fact that the municipality bulk water supply infrastructure is not adequate poses a major challenge, with a further challenge being posed by t the poor state of most infrastructure. Most of infrastructure is old and unable to cope with the ever-increasing number of people (Thulamela, 2012). Water is provided from boreholes in the following areas: Mavunde, Sambandou, Mahuwi, Shanzha Tshitavha, Tswera and Mangaya. Table 11 below provides information on the state of water access at the end of 2008 in Thulamela.

Table 11: State of water access in Thulamela (Thulamela, 2008b)

TYPE OF SERVICE	NUMBER OF HOUSEHOLDS
Piped water (dwelling or yard)	5 860
Within 200 metres	20 799
More than 200 metres	36 053
Borehole	3 662
Spring	4 550
Rain water tank	154
Dam, pool, stagnant water	659
River	4 097
Other	5 420

The municipality's annual target is to service at least 3 415 households. At the current rate of new services installation, the municipality reported that it would provide water services to all inhabitants by 2023. The 2012/2013 IDP report for Thulamela (Thulamela, 2012), however, indicated that the increasing population is making it difficult for the municipality to meet water service delivery targets. A further challenge is posed by the fact that, while installing new water conveyance systems, old systems need to be upgraded and extended (Thulamela, 2008b). Most taps in rural and urban peripheral communities intended for the provision of free basic water at times run dry for many weeks at a time.

8.2.2.1 Financial capacity

External funding dominates the Thulamela budget, with funding from government grants and financial support from the Development Bank of Southern Africa (Thulamela, 2012) being prominent. The local municipality has plans for several new infrastructure projects, including the installation of 6 000 household water connections within a period of five years (Thulamela, 2008a). These new connections are planned to ensure that water provision exceeds the minimum RDP levels. Adequate external funding, however, including that from government grants, is necessary to ensure the completion of all new developments. Nevertheless, these new developments will not generate sufficient revenue for maintenance or for future developments, particularly as the large indigent population of the municipality also places a heavy burden on its financial capacity. These communities receive services free and do not make any contribution towards the upkeep of the supply system.

The balance sheet of Thulamela shows that the municipality does not pay for bulk water provision provided by the Department of Water Affairs, while the financial report for 2011 does not include information on expenses towards water purchases.

8.2.2.2 Human resources capacity

Thulamela has many vacancies in the technical sections of the municipal establishment (Thulamela, 2012), and relies on technical and financial staff members seconded by the Development Bank of Southern Africa. Customer service in Thulamela is poor since no municipal staff are available for handling customer issues (Aurecon, 2009). Most community members responded to the questionnaires on water access administered by Hydrosoft in 2011 by complaining that they never receive responses to their queries regarding water or other municipal services.

8.2.3 Service providers and community dynamics

Communication from Thulamela Local Municipality is to all appearances more active during budget consultations, since these involve most stakeholders. Chiefs and headmen from all wards are called in to participate in the budget consultation necessary for the writing of the IDP reviews (Thulamela, 2012). Although most community members are either unwilling or unable to attend these meetings, the municipality nevertheless reaches a wide audience when it communicates to the community through the three radio stations available in the area, namely Phalaphala FM, Munghanalonene FM and Univen Radio. The three radio stations use the two local languages, Tsonga and Venda, as their communication medium.

In the questionnaires administered as part of this project in July and September 2011, some community members of Thulamela expressed the opinion that the municipal authorities do not have a good working relationship with the community as water service providers. The majority of the respondents to questionnaire interviews held with community members of Thulamela in September 2011 indicated that there was no information-sharing between communities and municipal authorities about their water problems. Community members indicated that communication improved only around election time, when authorities tried to garner the community's support. They also stated that personnel who represent them on issues such as water access and use were mostly the chiefs or ward councillors.

Frequent water shortages also strain relations between the municipality and residents. The municipality has no capacity to provide emergency water supplies to those who do not have water throughout the day. The only available water distribution vehicles are used to supply community members residing in rural areas with no water, including river water, sources.

8.2.4 Role of community in their water access now and in the future

The role of the community with respect to water access now and in the future cannot be separated from the legacy of apartheid. During the apartheid era, the Venda area was a homeland and black people had few means with which to develop water infrastructure. A sense of ownership denied to them in this period continues to affect how they acquire and use resources. As Lahiff (1997) points out, much of South Africa's poverty is concentrated in the former homelands.

The community of Thulamela remains heavily reliant on the local municipality for their daily supply of water. A questionnaire survey completed in September 2011 revealed that very few rural households have boreholes or take steps themselves to provide for water access. Most community members replied to a question on what they would do in times of water shortages. A number of community members said that they would either go somewhere to look for water, or ask help from neighbours, even if it meant having to pay. The community's bid for access to water is thus subject to numerous limitations, including a lack of ownership or the capacity to obtain their own boreholes without the necessary resources. Because most residents obtain their water from street taps, they do not see themselves taking ownership of the means to provide water access. Even their indigenous knowledge on how to obtain water from individually dug wells is not useful, particularly in an area where groundwater is scarce and surface water has to be retrieved on a rights basis. Based on the Thulamela community's response to the questionnaires on vulnerability to water access, one can clearly visualise a community whose future access to water is solely reliant on institutional support.

8.2.5 Institutional water access support mechanisms at household level

While households in Thulamela struggle to access water, those involved in the Needs Analysis survey in November 2011 provided some indication of the kind of support required from the municipality, and this is summarised below:

- Rainwater harvesting equipment;
- development of new water schemes;
- the need for available dams to cater for water requirements;
- water purifiers and water tanks;
- education on water abstraction and use strategies for climate change-impacted environments;
- a strong and well-resourced municipality which can adequately contend with their service needs;
- more bulk water storage systems; the present storage systems are inadequate and poorly equipped. For example, there are no inflow and outflow measurement systems;
- water tankers to supply water during breakdown of services or shortages (currently a few places where there is a permanent water shortage are supplied using tankers); and
- direct support in development of private boreholes.

8.3 State of water service in Msunduzi

8.3.1 Water resource infrastructure

8.3.1.1 Water purification and distribution

The Msunduzi Local Municipality relies on two water treatment works operated by uMgeni Water, namely the Midmar Water Treatment Works, located in uMngeni Local Municipality, and the D.V Harris Water Treatment Works, located to the east of Pietermaritzburg in Msunduzi. The two treatment works not only serve Msunduzi, but also uMgungundlovu District Municipality and eThekwini Metropolitan Municipality. Msunduzi Local Municipality uses 164.9 Mℓ/day (58%) of the total water demand of 284 Mℓ/day, with the remaining 42% being utilised by eThekwini Municipality (28%) and uMgungundlovu District Municipality (14%) (uMgeni, 2011).

The Msunduzi Local Municipality has a high percentage of non-revenue water consisting of unbilled authorised consumption, other unauthorised consumption and water losses. Non-revenue water in Msunduzi has increased from 17 615 000 kℓ to approximately 29 326 000 kℓ in 2011/12 financial year (Msunduzi, 2012a). The volume of non-revenue water is increasing at a faster rate than the rate of increase in total water supplied. In the 2011/2012 financial year, the total non-revenue water was forecast to reach 47.1% of the total water supplied in the local municipality, as outlined in Table 12 below.

Table 12: Non-revenue water in Msunduzi Local Municipality (Msunduzi, 2012c)

Water Balance Component	**Financial Year**							
	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12 Projected
Non-revenue water (NRW) by volume	36.3%	40.7%	37.3%	42.4%	23.4%	38.6%	40.9%	47.1%
Inefficiency of use	29.4%	32.1%	24.7%	28.0%	13.1%	24.6%	26.5%	31.5%
Total no. of connections in the municipality	46 942	49 421	51 351	52 337	53 902	55 167	54 443	57 007
Average total supply (kl/day)	129 637	137 618	129 404	141 871	140 544	146 319	152 763	170 445
Average water sales (kl/day)	82 631	81 622	81 142	81 728	107 715	89 808	90 256	90 098
Length of reticulation (km)	2 037	2 037	2 037	2 037	2 037	2 037	2 037	2 037
Total water losses per connection	1 001	1 133	786	999	463	882	1 003	275

The Msunduzi Local Municipality also estimates that water use through unauthorised water connections will cost the municipality at least 5 726 000 kℓ in the financial year 2011/12. Unauthorised water consumption is shown in Figure 27 below, while the area covered by the municipality is shown in Figure 28.

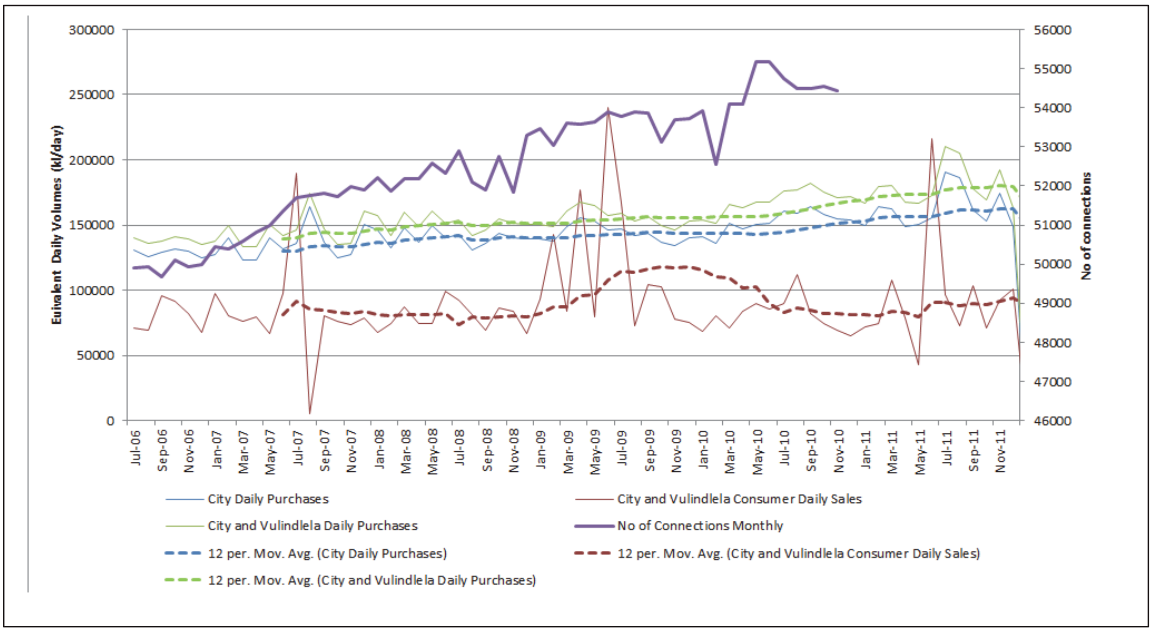


Figure 27: Msunduzi Local Municipality Equivalent Daily System Input Volumes and Billed Authorised Consumption Volumes for July 2006 to November 2011

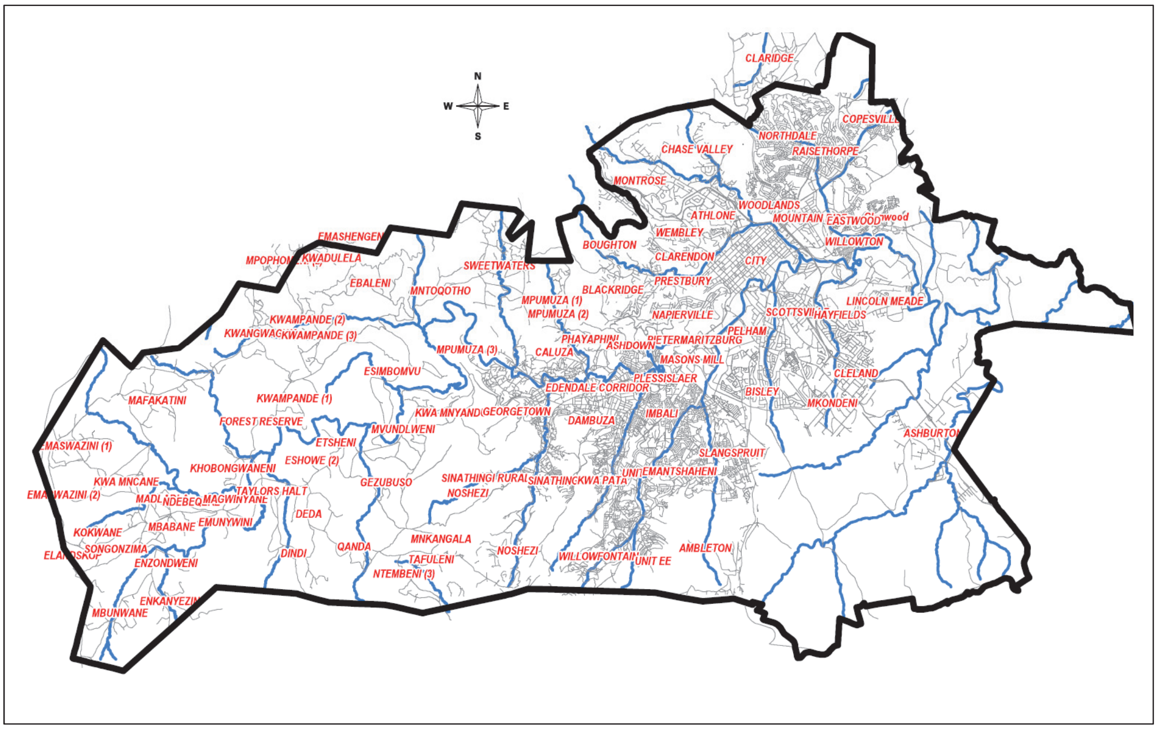


Figure 28: Msunduzi Local Municipality's Area of Water Supply

8.3.1.2 Metering

In collaboration with the DBSA, Msunduzi Local Municipality is implementing a remote metering system for water supply measurements in certain communities (Msunduzi, 2006a). A major objective of the project is to change the current culture of misuse and wastage of water in indigent communities receiving free basic services. This culture of water wastage is believed to have been created through the policy of providing water with no monetary value to the consumer. The absence of mechanisms to measure water usage and ensure that users do not exceed free basic water allocations aggravates the tendency to waste water.

8.3.1.3 Water uses and location of users

The 2009 water reconciliation study conducted in Msunduzi by the Department of Water Affairs used a water demand figure for the year 2006 of 51 million cubic metres per annum. Three scenarios of demand increase were considered, resulting in the three sets of demand projections shown in Figure 29 below. Scenario A relates to an instance of high population projection, B low population and C medium population. A population growth rate of 2.16% was used for Msunduzi. The uMgeni water demand projection in 2011 (Umgeni, 2011) used a figure of 3,5% for water demand increase for unrestricted increases, and 2% in instances when planned demand management and water conservation are accounted for. In the uMgeni Water Infrastructure Master Plan, the demand for water in Msunduzi reached 58.9 million m^3 per year in 2011, thus exceeding the earlier projection by some 3 million m^3.

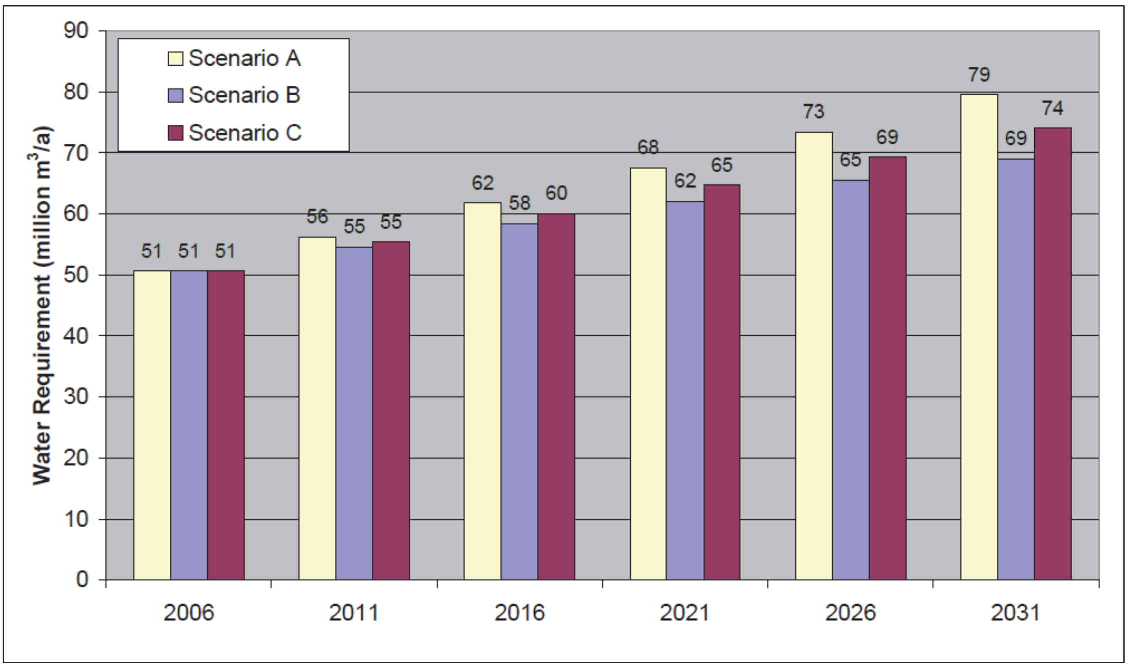
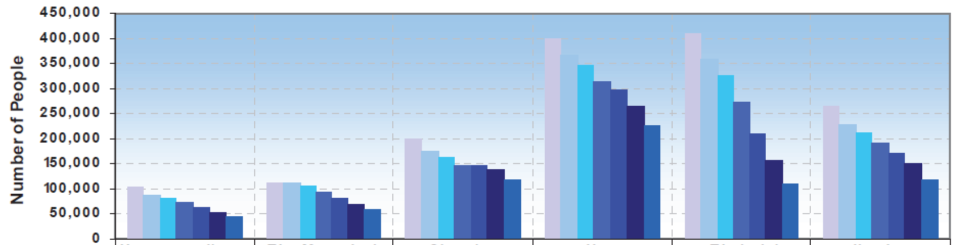


Figure 29: Msunduzi water demand projections for three possible scenarios (uMgeni, 2011)

8.3.1.4 Served areas and state of water access

Msunduzi has a population of 620 000, of whom 54 881 people, constituting about 13 578 households, have water access classified as being below the RDP level of 25 ℓ per person per day (DWA, 2012d). The DWA Water Services Information System (DWA, 2011d) also reported that 2 416 residents of Msunduzi have no water infrastructure at all. The municipality has set the target to clear these backlogs by 2014 (uMgeni, 2011). The water services backlog for Msunduzi is illustrated in Figure 30 below, where it can be clearly observed that the municipalities of Msunduzi and eThekwini, despite being classified as the highest performing municipalities, have major water services backlog problems.



	Umgungundlovu	The Msunduzi	Sisonke	Ugu	eThekwini	Ilembe
2004	102,017	111,580	200,726	400,717	410,426	266,550
2005	87,569	112,686	174,260	364,971	360,642	228,524
2006	81,182	104,851	161,667	345,666	325,686	213,898
2007	71,088	92,485	148,226	313,205	272,218	189,969
2008	63,409	81,987	147,097	296,861	209,669	172,032
2009	53,412	70,275	137,056	267,024	157,044	149,840
2010	44,946	59,391	117,568	224,618	110,754	119,118

Figure 30: Number of people with access to water below RDP levels as per the WS NIS (uMgeni, 2011)

8.3.2 Water service institutions

Msunduzi Local Municipality

The Water Services Act of 1997 (Republic of South Africa, 1997) redefined the roles of metropolitans, district municipalities and some local municipalities such as Msunduzi. This legislation designated Msunduzi Local Municipality as a Water Service Authority, responsible for supplying water to all communities, industries and other users in the local municipal area. Furthermore, with the exception of infrastructure owned by other stakeholders, such as treatment plants belonging to uMgeni Water, it is charged with maintaining the water service infrastructure in the area.

uMgeni Water

In terms of the Water Services Act (Act 108 of 1997), uMgeni Water is a Water Service Provider (WSP) responsible for supplying bulk water to its customers in terms of the water requirement forecasts presented to the water board. The relationship between uMgeni Water and the Msunduzi Local Municipality is further influenced by several other linkages and programmes where the two entities have to work together. While uMgeni Water treats and supplies bulk water to Msunduzi, it also buys back some of that water from Msunduzi for supply to iLembe District Municipality and some western parts of the eThekwini Metropolitan Municipality. uMgeni Water manages water supplies to 37 small towns in iLembe District (uMgeni, 2011).

Department of Water Affairs

The Department of Water Affairs is an important water service institution to all local municipalities. Besides being the custodian of the water and owning the major dams in these areas, the Department also drills boreholes and provides borehole water services to communities not connected to existing municipal reticulation systems or the uMgeni Water system (DWA, 2009c). The Department of Water Affairs also owns the bulk water pumping infrastructure at Midmar and Albert Falls Dams. All daily operations, such as pumping water from the dams, is the responsibility of uMgeni Water. The DWA, however, continues to maintain and replace pumping equipment as required at no additional cost to Msunduzi Local Municipality or uMgeni Water.

8.3.2.1 Quantity supplied versus demand

The main restriction to water supply in Msunduzi is the infrastructure since the water supply coverage does not reach all water users in such a way as to ensure equity in service provision. For example, uMgeni (2011) reported that 2 416 residents of Msunduzi have no access to any water infrastructure. During the administration of questionnaires in Msunduzi, some community members in areas such as iMbali and Edendale complained that while they have access to piped water, the water pressure was low in some areas, resulting in water shortages. The municipality also plans to intensify water loss controls through water pressure management. This programme may reduce water access to some communities, especially those at high elevation in medium and low income settlements.

8.3.2.2 Financial capacity

The Msunduzi Local Municipality's municipal revenue sources are dominated by property rates, service charges and government grants and subsidies. The property rates were recorded as R420 030 161 in 2010, increasing to R448 256 813 in 2011. Service charges, the main source of financial income to the municipality, increased from R1 159 300 660 in 2010 to R1 449 716 955 in 2011. Government grant and subsidies increased from R355 033 160 to R385 629 804. All other revenue sources are less than R50 000 000 in total per year for both 2010 and 2011. The breakdown of service charges is shown in Table 13 below (Msunduzi, 2012b).

Table 13: Breakdown of service charges (Msunduzi, 2012b)

Service Charge	2011	2010
Sales of electricity	1 011 458 928	816 172 839
Sale of water	270 106 949	213 633 343
Solid waste	65 558 726	53 287 411
Sewerage and sanitation charge	102 592 352	76 207 067
	1 449 716 955	**1 159 300 660**

Revenue from sales of billed water contributes a little more than 18% of the total revenue from service charges for the municipality. The costs associated with the bulk purchases of water are as shown in Table 14 below.

Table 14: Msunduzi LM's bulk purchases

Service	2011 (R)	2010 (R)
Electricity	729 325 043	568 236 145
Water	265 040 887	236 743 218
Total	**994 365 930**	**804 979 363**

Although the provision of water services generates revenue for the municipality, it remains unprofitable and unsustainable without external inputs such as the annual grants and subsidies from government. It is believed that an additional R249 million could be added to the municipality's revenue if all non-revenue water was billed and paid for. This could potentially turn around the municipality's finances, described in the financial report for the municipality 2010/11 financial year (Msunduzi, 2012b).

The 2010/11 financial report for the municipality (Msunduzi, 2012b) reported that:

The Msunduzi Municipality during the previous reporting period experienced serious financial challenges which have necessitated Provincial Government intervention in terms of section 139 (1) (b) of the Constitution during the third quarter of 2009/10. The financial crisis was the result of poor controls, rampant corruption amongst senior staff, failure to prepare the mid-year adjustments budget and the 2010/11 budget in good time, and other issues relating to poor internal control and procedures, which has placed tremendous pressure on the municipality's liquidity ratio and financial sustainability.

The mayor and several other heads in the municipality have since been replaced, with several control measures being instituted in the municipality. These measures include:

- Effective supply chain management and a new procurement system;
- new and strict policy on indigent water users;
- revised overtime policy to reduce unnecessary expenditure;
- a comprehensive debt collection strategy;
- new meters for water and electricity to reduce thefts and inaccurate billing, and;
- revised tariff structures to align service sales rates to purchase rates.

8.3.2.3 Human resources capacity

The Msunduzi Local Municipality is a large organisation which attracts good technical personnel. Msunduzi is currently going through a post-establishment process which seeks to streamline the functions and authority of personnel, while establishing a new employment structure (Msunduzi, 2012a).

8.3.3 Service providers and community dynamics

8.3.3.1 Relationship with the community

The Msunduzi Local Municipality has received positive feedback from the more affluent communities within its jurisdiction, such as Athlone, Scottsville and Hilton. They reported that their water services were uninterrupted and of good quality. A few concerns were raised, however, regarding the billing of water services in these neighbourhoods. Some water consumers were concerned that their bills were excessively high compared to those of their neighbours. Nevertheless, most water users said that they were not interested in meeting with municipal personnel or discussing their water provision concerns with the municipality.

Community members from areas such as Esgodini, KwaMpande, Swapo Informal, KwaPata, Machibisi and France complained of potable water shortages. They further indicated that they frequently contacted the municipality regarding their water problems, but felt that they were not receiving good service.

The municipality provides water to some communities with no access to piped water, or who experience water shortages, such as those in Swapo and Copesville. It was observed that water provided to standing tanks was wasted through damaged valves or other equipment left open all the time. In Swapo, one pipe close to the Greytown road, where community members fetch water or do their laundry, seems to have been left running uninterrupted, as observed on many visits made by this author to the area in the period from 2009 and 2011.

8.3.3.2 How do users and institutions handle service delivery shortcomings?

Water services shortcomings in Msunduzi did not seem to be worse than other case study areas. Some shortages, however, were noted to be due to low water pressure in some areas, the absence of reticulation infrastructure in a very few settlements, and breakdowns. During the research period, there were no instances where communities mobilised to demonstrate against water shortage, and none was reported by communities forming part of the field work.

The Msunduzi Local Municipality is embarking on several initiatives that could reduce water delivery shortcomings (Msunduzi, 2012a). These include:

Reducing water shortages through infrastructure development:

- Extension to the reticulation system;
- new reservoirs; and
- new bulk water conveyance systems.

Temporary and emergency responses:

- Use of water tankers;
- use of temporary storage in communities during shortages; and
- standpipes.

Extending water availability through improved operational processes

- Water pressure management to reduce leakages; and
- improving revenue collection by reducing non-revenue water, revising indigent policy, implementing new rate collection procedures, and changing water tariffs.

8.3.4 Knowledge of climate change and readiness for adaptation

The yield assessments for uMgeni Water were completed using some scenarios where climate change was included in the simulations of projected yield changes. The uMgeni Water planning report (uMgeni, 2011) reported that there were numerous complexities associated with modelling the natural climate of the future and relating it to target areas. uMgeni Water, responsible for bulk water provision in the Msunduzi Local Municipality, has already used up to ten different climate change models to determine the impacts of climate change on the key water systems and yield at the important dams in the area.

The climate impact investigations generally showed that yield is expected to increase in the uMgeni catchment and other key water systems where the main water storage dams are located. The storage dams considered were Midmar, Albert Falls, Nagle and Inanda (uMgeni 2011). The climate impact simulations were done using both statistical and deterministic models. While the deterministic models were responsible for the few projections where decreases in yield were found to be most likely, the statistical models simulated large increases in runoff in the intermediate and long-term periods (2046 to 2100). uMgeni Water has taken all possible steps to ensure that the recent planning strategy report (uMgeni, 2011) is adequately advised by the available knowledge on climate change. Further climate change simulations are reported to be on-going.

The Msunduzi Local Municipality is developing a "Climate Change Response Strategy and Plan". To date, a draft Inception Report and Status Quo Report have been completed. The municipality has also prepared a Strategic Environmental Management Plan, which contains a number of "Action Plans", one of which relates to climate change (Bartholomew, 2012).

8.4 State of water service in Letsemeng

8.4.1 Water resource Infrastructure

The population distribution and nature of settlements in Letsemeng dictate how water is obtained, purified and distributed. The towns are far apart, with Koffiefontein being the largest town (Stats SA, 2011), with a population of 13 224 residents. As a result, there are separate small water treatment plants serving each town with no connection between water provision systems in the five towns.

While Koffiefontein Water Treatment Works' capacity of 6 Mℓ/day is currently adequate, the quality of purified water is not consistently maintained since the plant occasionally has inadequate chlorine on site. As a result, the addition of residual chlorine is not consistently practised. All three settling plants are poorly roofed, resulting in continuous mixing which reduces the efficiency of settling. Furthermore, this has negative effects on the quality of the drinking water. Finally, records were not maintained at this plant (DWA, 2011e) during the period of this study in 2011. This is a threat to proper water service and the maintenance of water quality.

Jacobsdal, a town of more than 8 000 inhabitants, has a single water treatment facility available, with good access to an adequate raw water supply from the Orange-Riet Canal system. The water is transferred from the canal to two raw water dams. The raw water dams, which are located close to cattle feedlots, are exposed to faecal pollution from the feedlots during the rainy season, thus negatively affecting water quality. This WTW, which consists of old facilities in a dilapidated state working alongside new waterworks, suffers from the inherent problem of poor maintenance of consistently good water quality standards. Silt removal, backwashing and differences in filtering pressure all tend to complicate the system for the Grade 0 operators manning the facilities.

In Luckhoff, water is supplied from Vanderkloof Dam through the Orange/Riet Canal to two raw water storage tanks, from where water is pumped to the WTW. The WTW has a capacity of 4.6 million litres per day, which serves the population of just above 6 000 inhabitants. Although this plant operates at full capacity with no allowance for any additional water requirements, the operations of the facility are poorly organised (Letsemeng, 2011b). One such example is that the operators are not permanent and do not work formal shifts, even though the plant has to be operated 24 hours a day. Furthermore, Luckhoff WTW has no water quality testing equipment to conduct operational monitoring. As such, the WTW does not comply with the minimum requirements stipulated in South African National Standard for Drinking Water (SANS 241), (DWA, 2012). Additionally, there is no provision for record-keeping via logbooks at these works. The plant controllers and superintendents cannot check the operational processes or determine potential quality problems.

Petrusburg and surrounding areas rely on groundwater from a large dolomitic aquifer. The abstraction of groundwater in this area is well above the available harvest potential. As a result, shortages are experienced in the dry season in Petrusburg, Bolokang and surrounding areas. The groundwater abstraction rate in Petrusburg in 2004 (DWAF, 2004c) was reported as up to 15 million m^3/yr. The use of groundwater in Petrusburg is negatively influenced by the risk inherent in a lack of knowledge concerning availability and potential yield.

Unscientific methods of prospecting for groundwater have resulted in several boreholes of poor yield being drilled in many locations in and near Petrusburg, with further reports noting that the failure of boreholes in the southern Free State, which includes the whole of Letsemeng, is a very common experience (DWA, 2004c). The latter problem was blamed on poor prospecting methods and weak groundwater management practices. The risk of groundwater contamination is very high in Petrusburg, with at least three boreholes being located close to two cemeteries. In fact, the borehole referred to as PMBH05 is situated right on the edge of a cemetery (Sedibeng, 2009). A further water quality threat to groundwater in Petrusburg is poor sanitation and the widespread use of pit latrines. In the DWA Blue Drop findings (DWA, 2011e), the disinfection of water, especially that from boreholes, is observed to be below required minimum standards.

8.4.1.1 Metering

The water treatment facilities have water measurement facilities only at the intake points, and there is little water measurement done in the water conveyance systems, including the reservoir inlet and outlet. The absence of metering and records of bulk water distribution makes it difficult to determine losses and efficiency of the water distribution network (Letsemeng, 2012). A visit to the municipal offices in Koffiefontein revealed that the municipality is planning future water meter installation projects.

8.4.1.2 Served areas and water users

The municipality defines its water users as those communities in the five main towns. Communities of farmers and other locations outside the five towns are not covered in the IDP report, with no allowance made by way of other water provision plans of the municipality.

Out of the 10 180.71 km^2 which make up the area of Letsemeng Local Municipality, 9 730.22 km^2 consists of farms (Letemeng, 2011a). These farms have their own private domestic water provision systems in addition to relying on water from Kalkfontein and Vanderkloof Dams. One of the main canals is the Orange-Riet Canal, which supplies water to a large number of farmers over a distance of more than 100 km from the Vanderkloof Dam. At full capacity, the Orange-Riet Canal can transfer 370 million m^3/a (WRC, 2004). The annual water requirement of irrigators supplied by the canal is 186.8 million m^3. Altogether, the canal serves 371 farmers (including farmers in Ritchie), with a total of 17 000 ha of cropland being irrigated in the process.

8.4.1.3 Planned future water provision and adequacy

Raw water supplies in Letsemeng are adequate for those communities connected to the Orange River System through a series of canals and pipes. The Orange River has an unallocated yield of more than 300 million cubic metres (DWAF, 2004c), and plans are afoot to allocate this available yield to agricultural developments.

There are many gaps in water conveyance within the municipality creating shortages for a number of community members. Planned major improvements include the extension of water provision from the Orange-Riet to disadvantaged communities who continue to lack water provision despite their farms being located next to major bulk water provision systems. Examples of such communities are the many farmers in Oppermansgronde. The Orange-Riet Balancing Dam S1 project, currently under construction, includes outlet pipes to supply farmers included in the Oppermansgronde Government Scheme (DWA, 2009e).

The Orange-Riet WUA also has plans to develop hydropower at the two large diameter outlet pipes located just before the pumps for the Orange-Riet Canal water. This development will result in the reduction of water use costs and farmers will benefit by paying less for their water. The planned Hydropower is expected to ensure uninterrupted bulk water provision for many farmers (ORWUA, 2013).

8.4.2 Water service institutions

The main water institutions in Letsemeng are:

a) Letsemeng Local Municipality: The local municipality is legally responsible for ensuring that all residents of Letsemeng have access to basic water and all other domestic water services;
b) Department of Water Affairs: The department owns and manages the major water infrastructure such as the dams and canals, and also supports the municipality in ensuring that all its community members have access to adequate water of suitable quality. To a large extent, the municipality reports to the Department of Water Affairs on water issues. The municipal processes, infrastructure and services are also monitored by the department. In addition to other funding streams, the department provides financial support for the implementation of water provision infrastructure;

c) Bloem Water: This water board was established in 1981 with the mandate to provide water services to the southern and central areas of the Free State, including Letsemeng. In terms of the Public Finance Management Act, Act 1 of 1999, Bloem Water is a Schedule 3B entity, a National Government Business Enterprise which reports to parliament via its executive authority. Bloem Water, however, does not provide water to Letsemeng, but merely technical support in various water purification and distribution functions;
d) Orange-Riet WUA: This Water User Association provides water to 371 commercial farmers, while operating and maintaining the Orange-Riet Bulk Water Supply Canal. A few farm-based diamond mines and small towns also obtain their water from the Orange-Riet Canal; and
e) Lower Riet River Irrigation Board: The board provides water to farmers in the north-eastern parts of Letsemeng as well as to those few who fall under the Pixley ka Seme District Municipality of the Northern Cape.
f) Eskom: Eskom is a major stakeholder in the responsibility of water distribution in Letsemeng. Having been involved in financing the raising of Gariep and Vanderkloof Dams, Eskom has continued to play a role in bulk water delivery through partnerships with the irrigation water user institutions and the Department of Water Affairs. Eskom has two hydropower stations with an overall full load capacity of 600 Mw, consisting of 240 Mw at Vanderkloof and the balance at Gariep Dam. Some of the power generated from the hydropower stations is used for the six large electric water pumps with energy needs ranging from 650 kw to 2 000 kw (Eskom, 2010). The fact that these hydropower schemes produce power at half the cost incurred by coal-powered stations made it possible for Eskom and DWA to agree on half the energy prices that would otherwise be due by farmers on regular tariffs.

8.4.3 Service provision capacity

8.4.3.1 Financial capacity

The budget for Lestsemeng is dominated by the Municipal Infrastructure Grants. In total, projects with a value of R61 million were funded through the Municipal Infrastructure Grants in 2010, with revenue from rates contributing up to R27 million per year (Letsemeng, 2011a), including water provision projects with a value of R16 million. With the municipality claiming to have utilised all the available funding in its budget, important projects such as extending the surface water supplies to Petrusburg are still not part of the business plan and local municipality budget.

8.4.3.2 Human resources capacity

The Letsemeng Local Municipality currently has several vacancies, including two critical Section 57 vacancies for a Chief Financial Officer (CFO) and a Cooperative Service Manager. To help mitigate the situation, the municipality is receiving support for the role of a CFO from a DBSA employee assigned to the task. Bloem Water also provides water purification expertise to assist the municipality in effectively utilising its potable and waste water treatment facilities.

Although there are currently processes in place to build capacity, these are mostly for lower-end positions, and include, for example, the training and hiring of female candidates for involvement in a programme aimed at eradicating the bucket system. Other candidates are being trained in maintenance-related expertise such as plumbing, building and water maintenance.

8.4.4 Service providers and community dynamics

8.4.4.1 Relationship with the community

A recent field-based Hydrosoft water assessment of community vulnerability to water access, based on inputs from members in the vicinity of Letsemeng, established that they were generally satisfied with the municipality's efforts. Later investigations in the dry season, however, showed varied responses from community members. Those in Petrusburg, for example, who were relying on groundwater, were very dissatisfied and chose to maintain protracted service delivery protests, blocking the highway between Kimberley and Bloemfontein for lengthy periods in Petrusburg. The relationship between the municipality and its communities in respect of water provision tends to deteriorate rapidly when communities suffer water shortages.

8.4.5 Role of community in their water access both now and in the future

Most of the communities in Letsemeng reside in urban areas which are characterised by a very high reliance on a municipality with few facilities for alternative water supplies. Apart from farmers, most community members rely on the Letsemeng Local Municipality for all their water access. In addition to municipal water services, a few community members use rainwater harvesting and private boreholes. The low rainfall of below 300 mm MAP limits what communities can achieve to secure their own water access systems. In Petrusburg, the area with the worst water access problems, community members in the town area generally have several private boreholes, most of which were drilled decades ago and use wind power. Figure 31 below shows typical boreholes around Petrusburg.

Figure 31. Private wind-powered boreholes and rainwater harvesting supplement municipal water services in Letsemeng

8.5 State of water service in Madibeng

8.5.1 Water resource infrastructure

8.5.1.1 Water schemes and conveyance

According to Madibeng's Water Service Development Plan of 2011 (Madibeng, 2011), their water supply system includes 37 water schemes, 88 reservoirs, 75 pump stations, and 1 289 km of bulk pipeline. The infrastructure was logged in a detailed Water Supply Network Rehabilitation and Master Plan Detailed Report completed in 2006 by Utility Informatics. The master plan did not cover the Fafung and Dikgophaneng groundwater schemes to the north, and states that there are many rural schemes about which little is known and which they were not able to include in the plan due to inadequate funding (Madibeng, 2011). The master plan also does not include information regarding water infrastructure operated by private industries and mines.

There are two large agricultural irrigation schemes within the municipality. The Hartbeespoort Irrigation Scheme takes 80% of the water abstracted from the dam to supply 480 km of irrigation canals for agriculture, and some mines. The Crocodile River Irrigation Scheme draws water from the Vaalkop and Rooikoppies Dams. This scheme does not have a canal system, however, and as such, water is abstracted directly from the Crocodile River, supplying 16 000 hectares of agricultural land.

One of the most significant inter-quaternary transfers of water in Madibeng involves a canal with a design capacity of 4 m^3/s which conveys water from Hartbeespoort Dam to Vaalkop Dam, from where the water is distributed to the various consumers supplied by Magalies Water. There are also several other canals within Madibeng by means of which water is transferred from Hartbeespoort Dam and the Crocodile River to farming communities (DWAF, 2008b).

It was estimated that return flows accounted for about 30% of the available surface water resources within the Crocodile (West) River Catchment, which corresponds to 30% of Hartbeespoort Dam's firm yield of 155.7 million m^3. These return flows are in fact water brought to the Gauteng region from the Orange River and connected water systems (DWAF, 2008b). The return flows constitute a very large water transfer from other catchments to the Crocodile West River.

Rand Water has two major pipelines which convey water from Ga-Rankuwa to Brits and surrounding areas, and from Brakfontein in Johannesburg to the Hartbeespoort Dam Scheme (Rand Water, 2009).

8.5.1.2 Metering

The 2006 water supply network rehabilitation and master plan for the MLM records 67 bulk meter chambers, with only 39% having measuring devices and available readings. The North-East Water Scheme has no metered consumption either for bulk or household water. Demand is estimated to be 2.7 Mℓ/day. Since this is not monitored in any way, it is not possible to assess any losses (Madibeng, 2006).

In the area of the Hartbeespoort Dam, there has been an unexpectedly large and rapid increase in residential development complexes in recent years. During these expansions, the municipality did not have the capacity to install individual household meters. The municipality arranged with the developers that they would put in a bulk supply meter for the whole development, and the residents would pay management, who would then pay Madibeng. According to the 2010 Water Safety Plan (Madibeng, 2010), registration, monitoring and metering of groundwater use in the Dikgophaneng and Fafung supply areas in the north are very limited. The plan further states that about 10% of the connections supplied by MLM are unmetered, or are meters that are not read. Madibeng (2011) reports that the number of unauthorised connections is unknown, but is estimated to be in the region of 14 000 households (19% of serviced households). Currently, there is a programme to include 16 000 meters in the system. In some instances, there are meters on the ground, but these are no longer easily accessible (Madibeng, 2011).

In the Hartbeespoort Irrigation Scheme, there are no water meters. Each farm, however, has a fixed listing of the number of hectares that come with the property, and the quota of water per listed hectare is set at 6 200 cubic metres of water annually. The farmer arranges the time the water is received, normally in accordance with his or her needs. The irrigation board employs staff to lock and unlock the sluice gates in order to manage the flow of water to the different farms.

8.5.1.3 Water uses and location of users

Mining covering 2% of the Madibeng area takes place primarily along the Merensky Reef, which stretches from the south of Brits west into the Rustenburg Municipality. The area is the world's largest chrome producer and includes the richest platinum group metals reserve (DWA, 2010a). There are approximately 13 mines in the municipality.

The mines use water from a number of sources, including:

- Rand Water via the Sandspruit Western Water Scheme;
- MLM, which supplies Lonmin, International Ferro Metals and Afplats;
- the Hartbeespoort Dam Irrigation Board;
- smaller rivers – volumes unknown; and
- groundwater. For example, the Crocodile Mine draws from its own aquifer and has its own treatment package plant.

Up to 80% of the water from the Hartbeespoort Dam is used as irrigation water for agriculture, and the other 20% is used by the domestic, industrial, and commercial sectors (Madibeng, 2010). Intensive farming on the 13 000 hectares of irrigated farmland downstream of the dam produces wheat, soy, mealies, vegetables and citrus. To the north, there are more extensive farms on the 16 000 hectares of the Crocodile Irrigation Scheme, with many other farmers also relying on groundwater.

8.5.1.4 Served areas and state of water access

The data in Table 15 below is taken from the reconciliation strategies for the Hartbeespoort Dam supply area, the Sandspruit Rand Water supply scheme and the Dikgophaneng and Fafung supply schemes in the rural north (DWA, 2010a and DWA, 2009f). The data indicates that the level of service in the Hartbeespoort Dam area is markedly higher than in the rest of the municipality, with levels of service being very similar in the other three supply schemes. At first sight it is surprising that the levels of service in the north, with its dispersed rural settlements, seem to be so comparable to other areas (Table 15). It is acknowledged, however, that data for the northern areas relating to population and services is of a low confidence level (DWA, 2010a).

Table 15: Levels of service in Madibeng Local Municipality supply schemes (DWA, 2010a)

Service level	Above RDP		RDP	Below RDP	
	House connection	**Yard connection**	**Communal supply (<200m)**	**Communal supply (<200m)**	**None / own resources /supply > 500 m**
Hartbeespoort scheme	51.9%	37.2%	9.2%	0.4%	1.3%
Brits scheme	32.6%	23.4%	12.3%	7.3%	24.4%
Sandspruit Rand Water supply scheme	33.5%	24.1%	13%	6.9%	22.5%
Dikgophaneng and Fafung supply schemes	32.4%	23.3%	11.1%	7.7%	25.5%

The DWA reconciliation studies data given in Table 15 above suggest that more than 50% of households are supplied at above RDP level. These figures do not correspond well with the overall figures given in Madibeng (2011), which reports that only 34% of households have a house or yard connection, with 51% relying on a standpipe of RDP standard. The DWA figures correspond more closely with the data collected by Hydrosoft in 2011, though only a relatively small sample of areas was visited in the research study.

8.5.1.5 Planned future water provision and adequacy

It is anticipated that water demand will increase for domestic, mining and industrial use in the south of the Madibeng Local Municipality. To cope with this scenario various plans are under consideration to increase the supply of bulk water. There is currently no plan, however, to increase the capacity of the Hartbeespoort Water Treatment Plant. Instead, the supply of bulk water from Rand Water has been increased, with a new pipeline currently being commissioned.

There are plans to increase the Brits Water Treatment Works bulk treated water supply from 60 Mℓ/day to 96 Mℓ/day, with a further option being to augment the supply from Rand Water (Madibeng, 2011). The Hartbeespoort reconciliation study (DWA, 2010a) recommends augmenting the Hartbeespoort scheme with excess water treated at the Brits WTW, which was also an option discussed in the 2006 master plan. Generally, the argument put forward in favour of this option is that MLM can produce water from its own treatment plants cheaper than buying it from Rand Water. Plans to increase the use of waste water to supply industry and some mines are also under consideration, and are likely to be taken forward in the future.

Mines within the MLM and further west into Rustenburg are seeking to secure additional water. A pipeline known as the Bakwena Bulk Supply Pipeline, which will take water west from the Hartbeespoort Dam, is currently under consideration. The option of having an industrial supply pipeline, as well as a potable water pipeline, is also being considered (Madibeng, 2011).

The Sandspruit Rand Water supply scheme, supplying the west and north east, supplies bulk treated water via a 2.9 million m^3/a pipeline. From this, 1.68 million m^3/a (55%) are available for domestic use and the rest is allocated to mining and agricultural needs. Although this pipeline would have been inadequate in relation to need, Rand Water has recently installed an 18.25 million m^3/a pipeline, which will supersede the current supply once it is completed (DWA, 2009f).

Water demand in the north, where there are few employment opportunities, is projected to decrease. Nevertheless, there is a need to upgrade the water service, which is largely dependent on groundwater. Given an anticipated decline in population, a careful cost-benefit analysis needs to be carried out in respect of the various options. These include:

- Increasing the supply from the Klipvoor Dam;
- putting in systems and infrastructure to treat the groundwater to bring it up to potable standard; and
- taking bulk water from the Brits treatment works to the north of the municipality.

The first option would require analysis of the capacity of the Klipvoor Dam to satisfy both agriculture and increased domestic water consumption. The second option leans to a more decentralised water scheme with a number of small treatment plants. The capacity of groundwater and its protection from pollution by sewage and agriculture would need to be fully assessed. The third option is a centralised solution where water supplies are serviced by one centralised treatment plant with bulk pipelines radiating out to the serviced areas.

8.5.2 Water service providers

Although the MLM is the Water Service Authority for the municipal area and holds the responsibility for water services, there are also a number of other water service providers. These are:

Rand Water: This is the largest water utility in South Africa, providing bulk potable water to Madibeng as well as many other areas and serving up to 11 million people. Water provision from Rand Water ensures that some of the areas in Madibeng have the highest quality water. DWA's Blue Drop report of 2010 states that Rand Water's water treatment facilities 'are managed according to world class standards' (DWA 2010b).

Madibeng Local Municipality (MLM): The MLM treats raw water in its two water treatment plants, providing bulk water for domestic, mining and industrial use. It also manages the majority of the reticulation services and waste water treatment services in the municipality, along with a number of boreholes.

Magalies Water: This organisation is a state-owned water board established in 1969 mainly to supply the needs of the platinum mines in the Rustenburg and Thabazimbi areas. It is contracted by MLM to manage and maintain 192 boreholes in 32 villages to the north of the municipality. It also abstracts water from the Klipvoor Dam before purifying it in three small water treatment works. These services place Magalies Water in the unusual role of a water utility providing retail services in Madibeng.

Irrigation Boards: The two irrigation boards are the Hartbeespoort Irrigation Board (HIB), which supplies water to agriculture and mines, and the Crocodile River Irrigation Board, which supplies agricultural water. Both schemes are well managed and the small sample of farmers interviewed by Hydrosoft in 2011 had no complaints about the schemes. Both schemes, however, are experiencing increases in water salinity and worsening water pollution levels.

8.5.2.1 Quantity supplied versus demand

Sandspruit Water Supply Scheme

In 2010 the Sandspruit water scheme found itself with a deficit which was increasing every year as the bulk Rand Water pipeline was inadequate to meet the demand. This 2.92 million m^3/a capacity pipeline has, however, been replaced by an 18.25 million m^3/a pipeline, which means that there is now sufficient water to meet current and future demands (DWA, 2010a).

The Brits scheme

The Brits scheme has sufficient raw water for its current and future needs as useable return flows are expected to increase due to additional transfers from the Upper Vaal WMA. Water re-use within the municipality does not currently occur, but plans are in place to supply treated sewage effluent to two mines at a rate of 3.65 million m^3/a (DWA, 2010a). This supply could be extended to other mines as the sewage works are expanded, which will add further to the available supply. It is intended to upgrade the Brits WTW to keep up with demand.

8.5.2.2 Dikgophaneng and Fafung supply schemes

Water in these areas is supplied by Magalies Water from both groundwater and surface water sources, with the indications being that there will be excess supply in the long run. However, DWA (2010a) assigns a low confidence rating to information for the study area as there are no existing records of actual supply volumes. Magalies Water is expected to improve the available information on water abstraction to ensure more reliable assessments of current and future use.

8.5.2.3 Financial Capacity

Although Madibeng serves as the local government and water service authority, there are indications that the municipality is facing challenges in carrying out its functions. Examples are:

- In 2009, the municipality was placed on the National Treasury's list of financially distressed municipalities and its audit outcome was of an adverse nature (COGTA, 2009);
- the municipality was put under administration in 2010; and
- charges of mismanagement and corruption have been laid against municipal officials.

While the municipality was under administration, capital expenditure was stalled, and projects to upgrade services were delayed. However, some of these blockages in service delivery were addressed after the municipality received approval to fast track some projects and implement them despite penalties imposed for past financial shortcoming *(*Republic of South Africa, 2013).

According to Madibeng (2011), non-revenue water is 71%, which is much higher than the national level of 35% for municipal systems (DWA, 2011b). Failure to monitor water usage and bills is more serious as the level of service provision is advanced to higher levels, since higher levels of service cost the municipality more to install and result in higher household water consumption. There are areas of Brits and Hartbeespoort in more affluent neighbourhoods which are unmetered or have fixed tariffs where the municipality could recover more from correct application of water tariffs. The DWA (2010a) breaks down non-revenue water as shown in Table 16, based on data from the 2006 master plan for Madibeng Local Municipality.

Table 16: Non-revenue water in Madibeng Local Municipality, Source: DWA (2010c).

Non-revenue water	Million m³/a	Percentage
Leakage and unauthorised connections	5.9	28.6%
Commercial losses	6.5	31.4%
Debt recovery losses	2.1	10.0%
Total	**14.5**	**70.0%**

Commercial losses in Table 16 above refer to inadequate metering of water consumption, either because meters were never installed, or are old, missing, not working, or cannot be read. In some areas of municipal spending, expenditure exceeds combined income from revenue and the portion of the equitable share that it is allocated.

8.5.2.4 Human resources capacity

In 2010, 101 of 159 positions were filled, meaning 58 were left vacant. Three of the five senior posts directly below the Water and Sanitation Manager were not filled, leaving only three out of fifteen key players in posts to manage the water network (Madibeng, 2010). There was no treatment technologist to head the purification services, no superintendent and only three instead of eight process controllers. Furthermore, out of 11 key staff members required for electro-mechanical maintenance only one, a millwright, was available. Staffing, therefore, was considered insufficient to provide the required service delivery. The Water Safety Plan of 2010 (Madibeng, 2010) concludes with the following recommendations (among others):

- Appoint sufficient staff to fill vacant posts within the Water and Sanitation Department without delay; and
- Provide the necessary training for new and existing staff, and fast-track application to the DBSA for qualified staff to be deployed, and to provide long-term support.

8.5.3 Service providers and community dynamics

8.5.3.1 Relationship with community

The Madibeng local municipality communicates with the citizens of Madibeng through newspapers and radio stations such as Letlhabile Community Radio Station. As observed during the field visits to the area in 2011, there is also a bi-monthly municipal news bulletin produced in English and distributed by councillors and at community centres. Furthermore, stakeholder consultative forums have also been established in Madibeng. These provide a facility for sharing of information in an attempt to defuse the frustration leading to community protests in the municipality (Republic of South Africa, 2013).

8.5.3.2 How do users and institutions handle service delivery shortcomings?

Hydrosoft carried out research in 2011 in which 109 household representatives were interviewed about their water access and use. Almost all the respondents, when asked who they contacted when they had a problem relating to water, identified the ward councillor or a traditional leader as the appropriate person.

Some residents have been illegally connecting to available water pipes to address what they see as poor service delivery. This takes place in areas without installed meters or where meter reading and billing ceased some years ago. Since water is regarded as being free of charge in these areas, many households allowed neighbours to make illegal connections.

During the vulnerability study, contact was made with the Hartbeespoort Inhabitants' Forum. In 2010, a public meeting was called around the issue of the raw sewage that could be seen flowing into the Hartbeespoort Dam. The meeting was attended by 500 people, clearly demonstrating that concern was widespread, and a committee was elected to take the issues forward. Thus, the Hartbeespoort Inhabitants' Forum was formed, with many branches, including an infrastructure committee, which have taken it upon themselves to become involved by partnering with institutions such as the municipality and the Department of Water Affairs (DWA) to solve the issues facing their community.

8.5.3.3 The role of communities in their water access both now and in the future

The MLM is facing serious water challenges, some of which are created by water users. For example, industrial, agricultural and household consumers contribute to water problems through:

- Industries and agriculture discharging pollutants into water courses;
- individuals dropping litter, plastic and other solid waste into or on the banks of water courses, or on the streets where it is washed into storm water drains;
- damage to shorelines;
- damage to natural water courses;
- using water wastefully. For example, irrigating in the full sun and allowing hosepipes to run;
- damaging water installations and treatment works and stealing from them;
- vandalising meters;
- taking water through illegal connections and;
- non-payment of water bills.

8.6 Conclusion

Thulamela suffers from multiple deprivation factors as a legacy of apartheid, and these are undermining socio-economic growth. Water access is but one of those factors. The chief constraint is not water resources, but rather underdeveloped infrastructure to supply bulk and reticulation water. In this municipality, water access is a challenge for a high percentage of the population. To supplement the poor water provision from the municipality, many rural communities are dependent on those few neighbours who have boreholes and are willing to provide them with water at a reasonable cost. The current state of water provision and the state of infrastructure in Thulamela determines the potential of the municipality to deal with climate change, including the support of communities in adapting to those impacts.

Msunduzi seems to have the highest levels of service delivery in terms of sufficient quantity supplied to the greatest percentage of the population. Interaction with water users and the blue drop records showed that Msunduzi also has the best water quality by comparison with the other three case study areas. The current capacity of water provision in the municipality of Msunduzi, however, is still not adequate and is expected to worsen over time. Early development of the large planned additional water sources and water conveyance systems to supplement water availability in the uMgeni System, or to reduce the need to use water from this system, are key to long-term adequate water access.

Letsemeng, despite its low rainfall, has well-developed bulk water supplies and surface reticulation which adequately serve the extensive commercial farming needs and small domestic needs in the area. The municipality, however, is not managing the water treatment plants effectively, and as a result water quality is not assured. A typical example is Petrusburg, which relies on groundwater and is experiencing periodic water shortages. Letsemeng's future water provision and community access to water depends on the sustainability of water transfers from the Orange River system to Letsemeng communities.

Despite Madibeng having adequate water resources, widespread water infrastructure problems create water access difficulties for many communities using water for domestic use. The municipality is overwhelmed by service backlogs, a maintenance backlog and a backlog in upgrading infrastructure to keep pace with development and population growth. Nevertheless, farmers who participate in water schemes feel that their needs are adequately met. A major problem exists in that water sources within Madibeng suffer from very high levels of pollution. Water provision from Rand Water, and its sustainability in the long term, will reduce the burden of water provision on the otherwise poorly functioning local municipality.

9 Climate change impact mapping

9.1 Introduction

The information currently used as the prevailing knowledge on climate change impacts is derived from the fourth IPCC report (IPCC, 2007b). Advances have been achieved at each IPCC reporting stage in respect of the data used, the knowledge of the participating stakeholders in each working group and improvements in the tools used. Further improvements are also expected in the next release of IPCC results in late 2013 following recent revision of the IPCC terms of reference on processes, procedures and reviewers. The changes were meant to ensure that the next IPCC reports address all identified issues and also take advantage of the best available knowledge (IPCC, 2012a).

Evidence of climate change impacts have been reported in many parts of the world on a wide spectrum of both the natural and the human environment (IPCC, 2007a). While climate change is considered as a global phenomenon, its impacts are felt at regional and local levels, which are the scales where adaptation is expected to take place. It is therefore necessary to identify the impacts of climate change on localised scales in order to develop relevant adaptation strategies.

9.2 Impacts on hydrology

Water resources are among the most important natural resources affected by climate change as different hydrological processes are altered. On a global scale, changes in sea levels and surface temperatures due to climate change will result in the areas covered by ice caps changing in size, along with changes in the distribution and magnitude of precipitations. Additionally, it is expected that evaporation will increase as a result of increased temperatures in most parts of the world (Houghton, 2005). These changes will lead to major alterations in runoff generation and stream flow, which will result in greater variability in water resource availability as well as negative implications for water quality (Kundzewicz et al., 2007).

Water resources at regional and sub-regional levels are expected to be affected in different ways, with some areas experiencing an increase in water resources and others a reduction. The main hydrological processes affected by climate change are precipitation, snow melt, evaporation, stream flow and groundwater recharge. Even on a local scale, some areas are expected to experience changes in temporal distribution of available water resources.

9.2.1 Climate change impacts on hydrology: Global cases

Climate change tends to amplify seasonal variation in precipitation and temperature parameters. In Ireland, climate change predicted for the period 2021 to 2060 will cause an increase in winter stream flow while resulting in a decrease in summer stream flow, mainly due to an increase in winter precipitation and a decrease in summer (Steele-Dunne et al., 2008). This compares favourably with predicted changes in Norway for the period 2007 to 2010, with melting snow contributing immensely to increased winter stream flows (Beldring et al., 2008). In all areas where stream flow is generated from snow in addition to precipitation, a general increase is expected. This is also the case in northwest China where the Zamu River, with a catchment containing a mountainous glacier area in an arid region, is expected to experience an increase in spring stream flow due to ice melt as the temperature increases (Wang et al., 2008). Groundwater recharge in most areas is expected to be affected by climate change. Herrera-Pantoja and Hiscock (2008) reported that by the end of the 21st century, future climate change will have caused a reduction of between 7% and 40% in potential groundwater recharge in some parts of Great Britain. These predicted climate change impacts demonstrate the importance of downscaling the climate change scenarios. The relevant impact at a local scale can then be obtained and the appropriate adaptation measures identified.

9.2.2 Climate change impacts on hydrology: Africa

The IPCC (2007b) reported that climate change predictions for Africa are showing that precipitation is projected to decrease in most sub-regions of Africa such as the Mediterranean, north of Sahara, the winter rainfall areas and the western margins of southern Africa. The East African and Equatorial African sub-regions are the only areas generally expected to experience an increase in precipitation. The areas projected to experience a decrease are also those areas that experience the most variable climatic conditions in the world, especially in terms of the seasonal and decadal time scale (UNFCCC, 2007).The IPCC's working group II (Boko et al., 2007), reported that in an analysis of six climate models (HadCM3, ECHAM4-OPYC, CSIRO-Mk2, CGCM2, GFDL_r30 and CCSR/NIES2) and the SRES scenarios (Arnell, 2006 in Boko et al., 2007), a probable increase in the number of people who would be likely to experience water stress by 2055 in northern and southern Africa was observed (Figure 32).

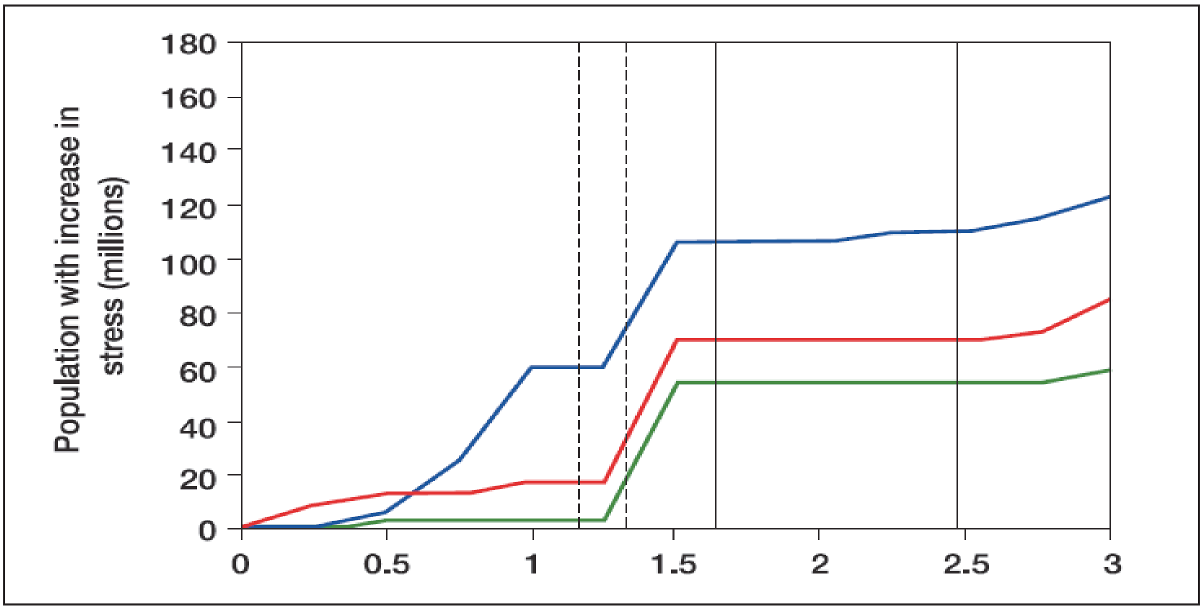


Figure 32: Number of people (millions) with an increase in water stress (Arnell, 2006 in Boko et al., 2007).

9.2.3 Climate change impacts on hydrology: South Africa

There is general consensus that the temperature will continue to rise as the climate changes (IPCC, 2007a). In South Africa, climate change is also projected to cause increased precipitation in areas that receive orographic rainfall, especially in the central areas, but also the north-east and eastern coastal areas. The rest of the country, however, comprising most of the interior and the western coastal part of the country, which largely receive convective rainfall, could experience a decrease in precipitation (EDRC, 2003, Lumsden et al., 2009). Impact of climate change on runoff is also expected to vary in response to changing rainfall. Findings made using deterministic climate models and Agricultural Catchments Research Unit (ACRU) projected that areas that with predicated increased precipitation in the eastern region of the country will also have high runoff (Lumsden et al., 2009).

The hydrological climate change impacts on precipitation, evaporation, stream flow and groundwater recharge are resulting in increased water demand, and in particular crop water demand, all of which has a negative impact on water access and use.

9.3 Extreme weather events

Climate change is causing an intensification of extreme weather events such as heat waves, floods and droughts (Benston and Stephenson, 2004). The effects are interrelated and will tend to aggravate other conditions in the future. For example, an increase in high temperatures in the cold climatic regions will increase the amount of snow melting, which will in turn generate floods and ultimately higher sea levels. Joubert and Mason (1996) and Iglesias et al. (2007) also observed that climate change will result in extreme precipitation events both in magnitude and frequency. An extreme increase in precipitation increases will result in increases of extreme flow regimes which will cause flooding, especially flash floods, while an extreme decrease will cause droughts (Joubert and Mason, 1996; Iglesias et al., 2007).

Extreme weather events attributed to climate change are already being noticed (IPCC, 2007a). IPPC (2012b) also describe a system of complex climatic feedbacks and compound events that are not always correctly understood and articulated. In IPCC (2012b), examples are given to describe extreme events which precondition the physical impacts of successor events, as well as events that occur as a result of other climate events and result in complex feedback loops. These feedback loops and compound events are said to be poorly understood and/or represented in current climate knowledge basis and models. Feedbacks and compound events are known to play an important role in either damping or enhancing extremes in several climate variables (IPCC, 2012b).

Adger et al. (2003) reviewed different climate change scenarios for Africa from various models and concluded that Greenhouse Gas-induced global warming is set to continue and even escalate into the next century. Effects of climate change on precipitation are expected to result in an increase in occurrence of extreme droughts in many parts of Africa (Iglesias et al., 2007). Inland and drier areas of the southern African region are expected to be affected by increased occurrences of extreme drought conditions, while generally wetter conditions will affect other areas. The predictions made from various models at this stage are not conclusive as there are many poorly accounted-for variables associated with the model data, accuracy of model processes and a whole range of other variables associated with local conditions. As a result, accurate information on extreme weather events attributed to climate change is still to be produced.

It is predicted that southern Africa will also continue to experience increases in droughts and floods attributed to El Niño/La Niña-Southern Oscillation effect as the temperature increases over the Indian Ocean. Joubert and Mason (1996) predicted an increase in frequency of droughts in some parts of Mozambique due to the increased atmospheric temperatures. The Limpopo River Basin, north of South Africa, and southern Mozambique experienced one of the worst floods known in southern Africa in 1999/2000 (Toulmin, 2009). This flood destroyed some water and sanitation facilities and affected about 1 million people (Douglas et al., 2008). These flooding events were attributed to the combined effect of La Niña and climate change.

9.4 Impacts on livelihoods

9.4.1 Impact on rural livelihoods

In developing countries most rural people's livelihoods depend on activities that are directly linked to climate, such as rain-fed agriculture, livestock rearing, market gardening, etc. Most of these people are classified as poor and already suffer from poor water access. These communities are also poorly served by institutions and less equipped to represent themselves on service delivery issues. A large proportion of the South African population already lives in poverty, and climate change will alter the very environment that they are currently failing to cope with. Table 17 below shows the poverty levels as determined by the Human Sciences Research Council (HSRC) in 2004. The HSRC observed that since 1996, the numbers of people living in poverty had not changed by noticeable margins. Observations were also made that those who already live in poverty were sinking deeper into poverty.

Table 17: Poverty indicators by province (HSRC, 2004)

Province	Number of poor persons (million)	% of population in poverty	Poverty gap (R billion)	Share of poverty gap
Eastern Cape	4.6	72%	14.8	18.2%
Free State	1.8	68%	5.9	7.2%
Gauteng	3.7	42%	12.1	14.9%
KwaZulu-Natal	5.7	61%	18.3	22.5%
Limpopo	4.1	77%	11.5	14.1%
Mpumalanga	1.8	57%	7.1	8.7%
North West	1.9	52%	6.1	7.5%
Northern Cape	0.5	61%	1.5	1.8%
Western Cape	1.4	32%	4.1	5.0%
South Africa	**25.7**	**57%**	**81.3**	**100.0%**

Communities affected by poverty tend to resort to diversification of livelihood activities. Reasons for this include seasonality of opportunities, especially in the agriculture-related sector, inputs and markets, risk of failure, fluctuations in the labour market for both availability and value of wages, and credit market failures that may affect their plans in their livelihood occupation (Ellis, 2000). Climate change is already increasing the probability of failure of some of the rural livelihood activities. Problems associated with working in a changing climate are already being felt as farmers fail to determine the best times to start planting various crops.

9.4.2 Impact on urban livelihoods

A large proportion of the urban community in South Africa lives in areas with few available services, including water provision systems. The influx of people into urban areas, as well as the dynamics of where they end up living, is also a major source of problems in respect of water access and how responsible authorities can make the necessary provisions to address this problem (Setswe, 2010). Setswe (2010) also reported that the major cities were experiencing an influx of people from rural areas in search of employment and a better livelihood. Setswe (2010) observed that approximately 80% of recent population growth in the Cape metropolitan area was occurring in townships. Communities in these townships already experience poor access to water, and provision of services is increasingly difficult due to unplanned settlement patterns.

The locations of the major cities in South Africa are such that available water resources are directly threatened by pollution. In the cases of Johannesburg, Pretoria and Cape Town, groundwater is also contaminated by pollutants from waste disposal, effluent flows and past mining activities. The implications of pollution on water access are dire, especially for communities living in informal settlements. In South Africa, Stats SA (2010) reported that at least 13% of the population live in informal shack dwellings.

Most urban community members depend on the local municipality, water board or other such institutions for access to water. The level of service provided by these institutions has a direct effect on the community livelihood, as well as the ability of community members to access and use water. Availability of water and access to it is also a factor of the ability of community households to pay for the water provision service. Mukheibir (2007) observed that poor access to water could also be due to political or economic policies. The implications of the shortcomings associated with the human element in water provision for urban areas tend to amplify the negative impacts of climate change.

9.5 Social impacts

Within limits of uncertainties, Mendelsohn et al. (2000) estimated that Africa’s economy will suffer the most from the impacts of climate change. The effect of climate change on the economy, agriculture and extreme events within the context of a developing continent implies that many socio-economic spheres of life will be affected by climate change.

9.5.1 Loss of employment

An area that has received little attention with regard to climate change is the latter’s impact on job opportunities. Climate change will slow down economic activity through reduced activity in various sectors including, of course, the water sector. In addition to the wide-ranging impacts on water activities, agriculture and other associated industries, Vicuna and Dracup (2007) showed that impacts in the energy sector will also affect employment. Loss of employment will have a direct impact on water access for those affected, and on their dependents. In most urban areas, where the majority of employed people reside, water is available at a cost. These costs cannot be met by the unemployed.

9.5.2 Health

The impacts of climate change on the health of vulnerable communities will be of such magnitudes that some countries will not be able to cope (UNFCCC, 2007; Unmusig and Cramer, 2008). Climate conditions were singled out as one of the causes of the emergence of some arboviruses in areas outside their usual endemic environments (Gould and Higgs, 2009). Climate change is already causing some areas to become more conducive to certain disease-carrying vectors, thereby exposing people to higher risks. According to the World Health Organisation, at least 30 diseases have either emerged, or re-emerged since 1975 (WHO, 1997). Factors contributing to the emergence or re-emergence of vector-borne diseases include environmental changes such as climate change (McMichael, 2004). In South Africa and other southern African countries affected by malaria, the increase in the number of months suitable for *plasmodium falciparum* malaria transmission will affect some areas (Tanser et al., 2003). The Rift Valley fever virus (RVFV), an arbovirus which is widely spread across central Africa, could expand to other regions (Gould and Higgs, 2009).

The effects of climate change will further weaken communities' and households' ability to cope, predisposing them to HIV vulnerability, risk behaviours and infection. In cases where climate leads to insufficient access to water supply and sanitation services, diseases like HIV/AIDS (Bolton and Talman, 2010) and cholera are exacerbated. The HIV/AIDS pandemic also reduces household labour capacity and hence the ability to fetch water from long distances and the capacity to develop new and improved sources of water, thereby exacerbating the negative impacts of climate change.

9.5.3 Demographic changes and migration

Reuveny (2007) cited a number of cases where environmental problems, including floods and droughts, led to migration. Some cited cases include Bangladesh, USA, Mauritania, Ethiopia, Somalia and Rwanda. In Bangladesh, for example, frequent droughts and floods since the 1950s have led to the migration of more than 12 million people. In Mauritania, drought and land degradation caused migration of about 69 000 people to Senegal. It is evident, therefore, that the anticipated increase in drought occurrence will lead to migration.

Droughts in sub-Saharan Africa have led to famine, which in turn accelerates rural to urban migration, leading to over-populated urban areas that often do not have adequate capacity to supply water, sanitation and energy (Magadza, 2000). The 1984/85 drought in Ethiopia led to the internal movement of about 600 000 people from the drought-stricken areas (Reuveny 2007). In South Africa, Setswe (2010) reported that in just five years from 1999-2003, more than 3 million people migrated from rural to urban areas. According to the Stats SA mid-year demographic estimates for 2009, at least 60% of the population in South Africa is now living in urban areas.

9.5.4 Social inequalities

Climate change could increase the level of social inequality as it tends to hit the poorest the hardest. The economic imbalances in South Africa are still high owing to decades of apartheid policies that segregated various non-white communities, and in particular, Black South Africans. In South Africa, the differences in needs between communities are worse than most countries since the country is categorised as having one the highest inequalities in respect of access to resources. For South Africa, the Gini coefficient on gross income, a measure of income disparities, grew from 0.63 in 1993 to 0.70 in 2005. By comparison to this startling fact, in countries like Japan and Sweden, where income levels are most equal, the Gini index is below 0.25 (UN, 2012).

The majority of disadvantaged groups are still living in poor and vulnerable environments. Adaptation initiatives for the rich are not necessarily suitable for poor communities. The different groups have competing needs which affect allocation of resources by responsible authorities such as a municipality. This tends to complicate developments in water access and use. The poor and vulnerable communities are usually underserviced due to a variety of localised issues, and will need basic services, whilst the more affluent communities seek maintenance or improvements in available infrastructure. Added to the complications of the real needs on the ground are political interests, as well as interests by other active movements which tend to work with communities to shift the processes of decision-making by taking advantage of the differences prevailing in communities.

9.6 Knowledge base on climate change impacts at the disposal of communities

While communities may be affected by climate change in certain aspects, such as reduced access to water and loss of livelihoods, they possess traditional and local knowledge on how to cope with the negative impacts of climate change. This knowledge base can provide important guidelines for planners and policy-makers on what programmes need to be implemented in these communities in order to be most effective. Communities are key role-players in climate change adaptation since they contribute local and indigenous knowledge on adaptation solutions (Reidlinger and Berkes, 2001). Community adaptation to climate change can only be achieved if it is built on initiatives already under way in the communities (Blanco, 2006). For generations communities have recognised changes in their climate indicators and devised ways of responding to these changes. By comparison with urban communities, rural communities have a greater knowledge base for climate change adaptation due to their direct reliance on livelihood activities based on the use of natural resources. By contrast, in urban areas water is provided through infrastructure owned by other stakeholders, such as municipal institutions. Most urban communities need only to pay for the water services in the expectation that the water authority will fulfil their side of the bargain by providing this service.

9.6.1 Knowledge base for rural and farming communities

Community knowledge based on climate change and adaptation relates to issues surrounding the predominant livelihood activities of each group. In rural areas, two main stakeholders, namely subsistence and commercial farmers, are active. These groups have knowledge bases evolved over many years (Berkes et al., 2000). The commercial farming community is a large depository of climate data as they keep their own records, including in many instances hourly and daily weather data (IWMI, 2008). The availability of important historical information in farming communities is illustrated in the most comprehensive South African daily rainfall data ever compiled, using thousands of records from commercial farms in addition to the regular data from ARC, DWA and SAWS (Lynch, 2003). The knowledge in the farming community can be used to design sustainable climate adaptation practices which will make farming possible in the face of climate change and increased variability.

9.6.2 Knowledge base for urban communities

In urban areas, the knowledge system tends to be dominated by formal institutions since they have the responsibility of supplying water to communities. Nevertheless, certain individuals at community level in urban areas have their own knowledge systems for adaptation to climate variability such as droughts. Mukheibir and Sparks (2005) indicated that currently community members and municipalities in the Northern Cape use both supply and demand management strategies for adaptation to climate variability. The supply management strategies include, amongst others, conjunctive use of groundwater and surface water, artificial groundwater recharge, water storage, rainwater harvesting and desalination. Some communities have implemented rainwater harvesting for domestic water supply. In addition to this practice, some communities store municipal water in large containers on their premises. When municipal water supply is poor, the storage is used, thus reducing the impact of a possible water shortage. In general, the knowledge base in urban areas has been translated into regulations, by-laws, municipal plans and the development of infrastructure, all of which are documented and disseminated to urban communities. Community members must comply with the provisions and in so doing, improve water access to all. Legal penalties may be applied if some of the provisions, such as those relating to pollution and water theft, are flouted.

9.7 Sources of impact data and regionalisation

This study has used data from General Circulation Models in mapping of climate change impacts. Such General Circulation Models are all Cartesian grid-point models (Figure 6) (O'Keef and Kueter (2004). These can be run at a variety of horizontal and vertical resolutions: e.g., 8°×10°, 4°×5°, or 2°×2.5° in the horizontal (latitude × longitude) and nine-layer, 18-layer, 23-layer, and 31-layer in the vertical. In the horizontal, these scales translate to minimum scales of the order of 500 km.

Scaling down from large global scales to regional models allowed the research team to draw more representative and meaningful conclusions for selected study areas. The assessment of climate change impacts in the selected study areas was based on CSIRO-CCAM (Conformal Cubic Atmospheric Model) (Figure 33, McGregor and Dix, 2001), a Regional Climate Model (RCM) which is dynamically downscaled. The use of the CCAM data was selected based on available data sets and a need to interpret findings based on tested approaches which provide better representation for the southern African region. Most GCMs use two key drivers for predicting the climate in the southern hemisphere. These are the Tropical Convergence Zone and the El Niño – Southern Oscillation (Jia-Lin, 2007; Cai, Sullivan and Cowan, 2009).

The limitations in the knowledge and understanding of the drivers of the African climate reduce the efficiency of the available models in predicting climate change for Africa, including South African areas. The La Niña and El Niño patterns which used to have a three- to seven-year cycle have been observed of late to be changing and are less predictable. The implications are that the accuracy of several GCM predictions is negatively affected. There is no evidence that other GCMs represent the climate drivers for the southern African region better than the CCAM model. The investigations of available climate datasets revealed that the achievement of objectives for investigating vulnerabilities and adaptation at local community level is not necessarily improved by the use of other datasets with little previous application for southern Africa. The limited understanding associated with the current climate predictions is also highlighted by Jia-Lin (2007), who discusses the errors due to feedback and a double-Intertropical Convergence Zone (ITCZ) problem in the CGCMs.

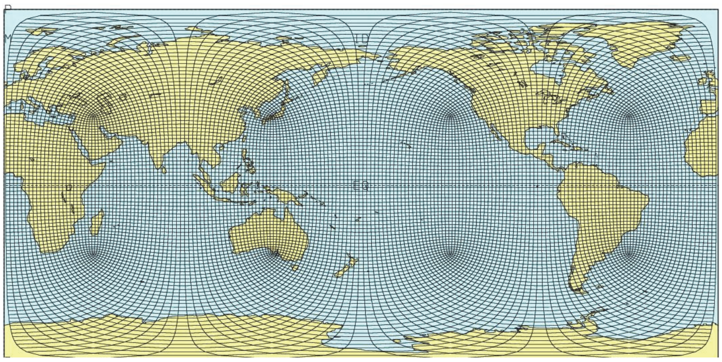


Figure 33: Illustration of the Conformal Cubic Atmospheric Model (McGregor and Dix, 2001)

For the prediction of impacts at local scales for South Africa, the CCAM was applied in a modest stretched-grid mode providing a resolution of about 0.5 degrees or approximately 55 km (X and Y axes) (Figure 34). The down-scaled data was drawn on a map with grids of 5 km. In the mapping process, further interpolation was done by the project team to produce interval boundaries at 1 km resolution, which provided a better representation in the mapping processes for the targeted case study areas.

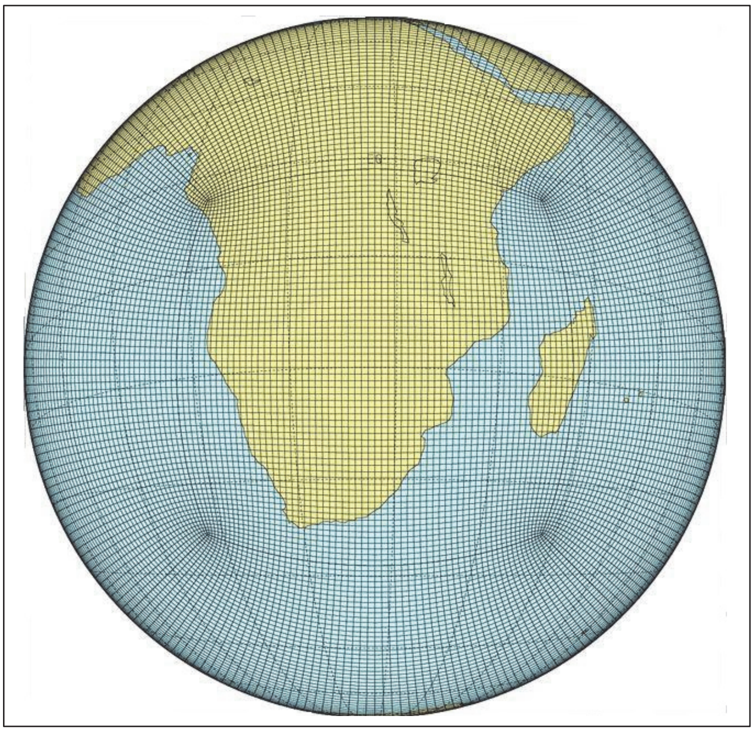


Figure 34: The modestly stretched conformal-cubic grid over southern and tropical Africa (McGregor and Dix, 2001)

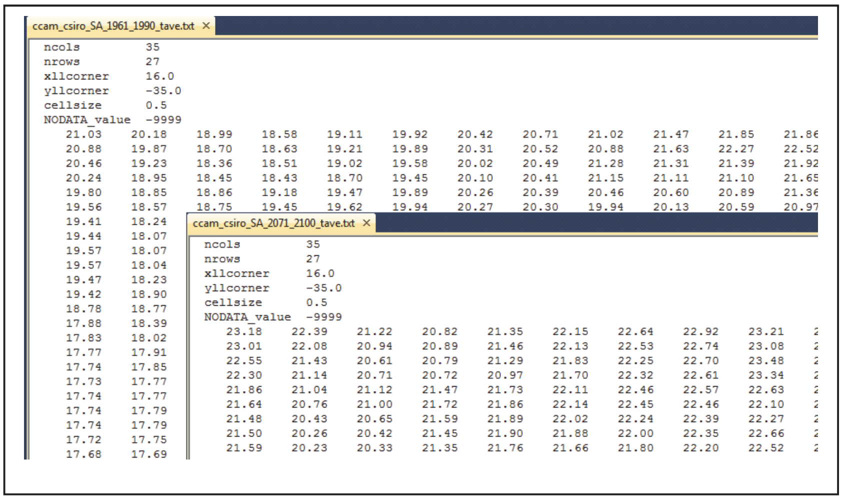


Figure 35: Two images of files showing a general temperature increase of at least 2°C from the CCAM-CSIRO Mk3.5

9.8 Impact mapping

9.8.1 Introduction

The CCAM-CSIRO Mk3.5 data (CSIR, 2011) was used to determine the nature of impacts due to climate change. For purposes of study area assessments, average temperature and average rainfall were considered. In assessing the changes, the climate data from the period 1961 to 1990 were compared with projected climate data for the period 2071 to 2100.

Over the whole of South Africa, the CCAM-CSIRO Mk3.5 climate change data showed that the temperature in the country will generally increase by about 2°C (Figure 36). Rainfall is expected to increase over most of the country, with the exception of the south and south-west coastal areas, where a decrease was predicted. This is shown in Figure 37 below. The increased rainfall in the Drakensberg mountain peaks will generate more runoff in the Vaal and Orange systems. These river systems, which originate in the Drakensberg highlands, will generate even more water and supplement current usage in the provinces of Gauteng, Free Sate, North West, Mpumalanga, Northern Cape, Eastern Cape and KwaZulu-Natal.

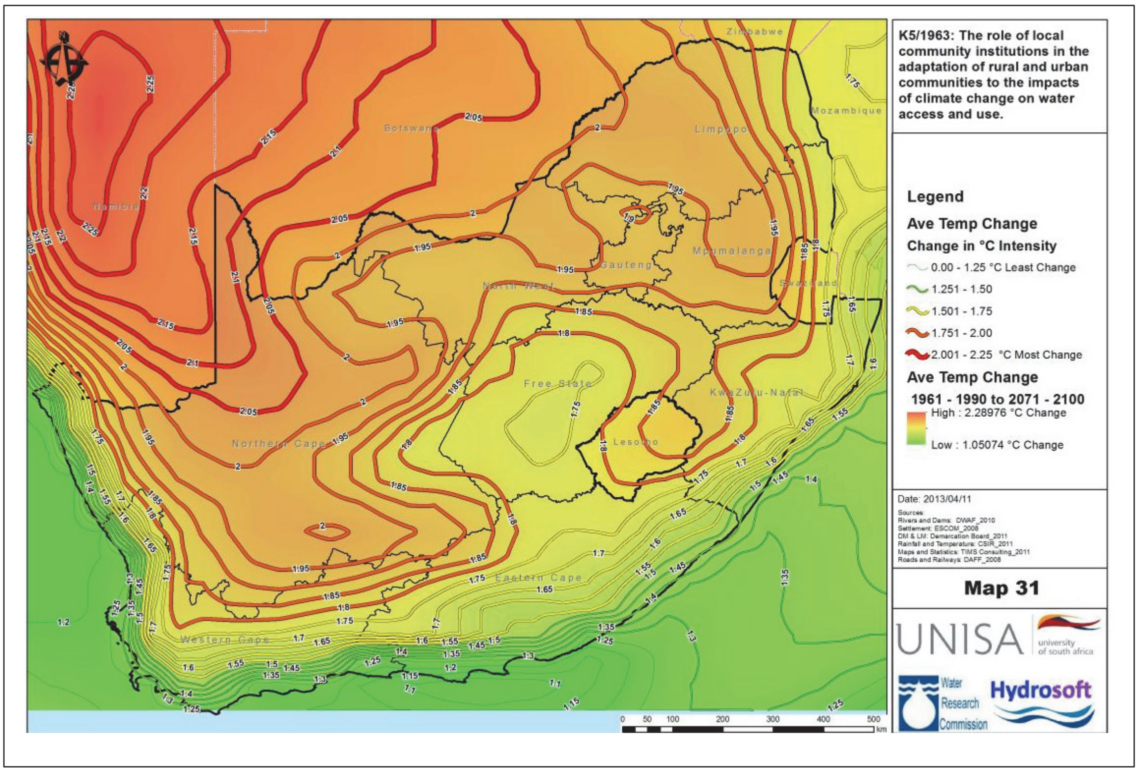


Figure 36: Average temperature increase in degrees Celsius for the period 1961-1990 to 2071-2100

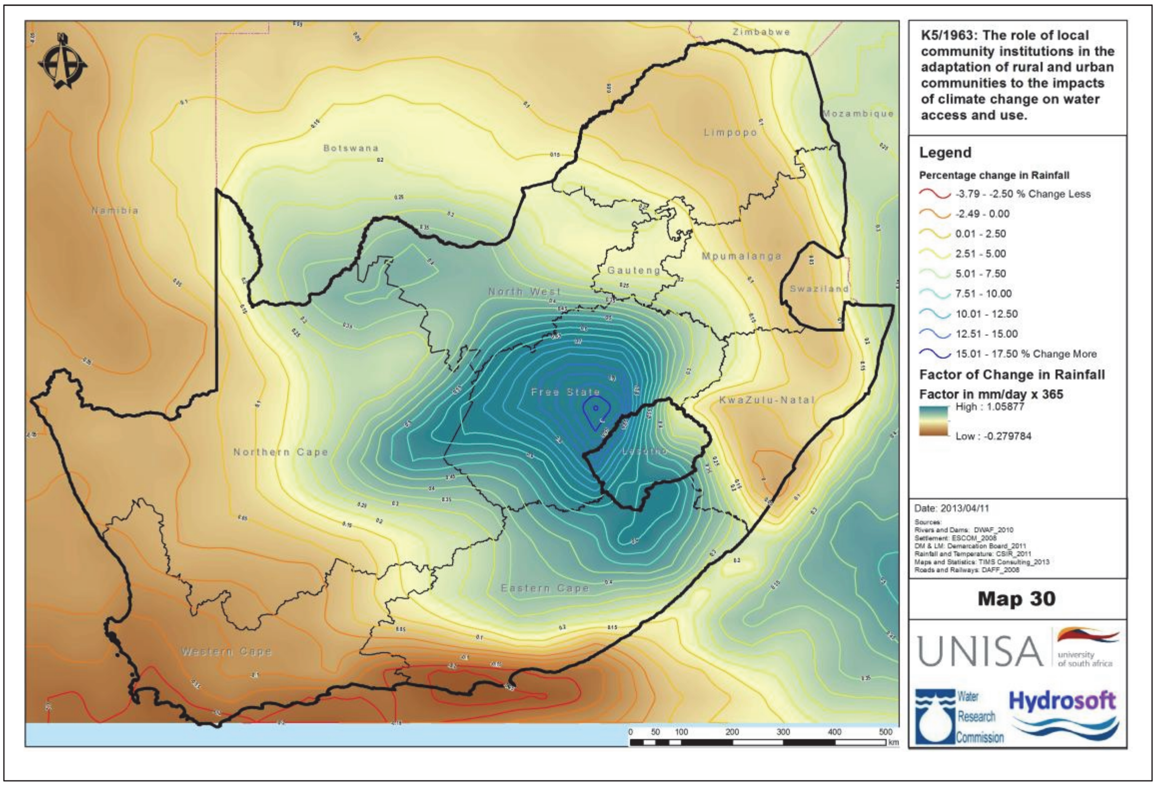


Figure 37: Percentage change in rainfall between 1961-1990 and 2070-2100 over South Africa

9.8.2 Vhembe: Thulamela

The temperature over the period investigated using the CCAM-CSIRO data set will increase by up to 2°C from the north-east to the south-west of Vhembe district. The increase will represent up to a 7% increase in average temperature for this area, with the implications to water resources being increased evapotranspiration and evaporation.

Rainfall in the Vhembe district is expected to increase by up to 12% over the period investigated. The increase in rainfall will be lowest in the south-west, where overall increase in average rainfall based on daily rainfall predictions will be approximately 6%.

9.8.3 uMgungundlovu: Msunduzi

In the uMgungundlovu District Municipality, temperatures are expected to increase from the south-eastern areas to the north-west, with temperatures increasing by as much as 2°C in the north-west. The changes are expected to be generally moderate with a common trend of slight increases along the north-westerly direction.

Changes in rainfall in the dataset seem to be affected by two factors, namely the Lesotho Highlands Project and the movement of ocean currents from the east. Somewhere in the middle of uMgungundlovu, these two factors tend to converge and create areas where there is no change in rainfall. The general trend of rainfall increase tends to suggest that the highest rainfall increases will be experienced in the west of uMgungundlovu District Municipality, where increases of up to 6% over the considered period are expected. The areas to the east, where rainfall will increase, are also the areas in which most of the rivers in this area originate. There is a good chance that the area will experience increased yield in the river systems originating in the eastern to the south-eastern parts of uMgungundlovu.

9.8.4 Xhariep: Letsemeng

The Xhariep area already experiences low average temperatures compared to the other study areas. The increase in temperature in this area is not much different from the other study areas, where temperature increases range up to 2°C. These increases, however, will take place over much lower average temperatures, in which case the percentage increase will be much higher, with up to 15% temperature increase being experienced in the cooler south-western areas.

Xhariep district is expected to experience the highest rainfall increases over the period investigated, with increases of up to 17% in the eastern areas and 7% in the west. The largest rainfall increases are expected to take place in areas which include the Lesotho Highlands Project. The implications to water resources are that the prospects for higher runoff in the headwaters of the Orange-River system are most likely in the long-term future. As such, there will be more water available for the canal system.

9.8.5 Bojanala: Madibeng

The temperature is expected to increase by up to 2°C over the whole of the Xhariep district, but with no discernible trend in the rate of increases in temperature. However, the general temperature at any one time is higher in the north-west than it is in the south-east. The cooler areas closer to Gauteng are usually 2°C to 3°C lower, based on average temperatures.

The rate of rainfall increase shows that the highest increases will be in the north-west, with increases of up to 8% projected between the 1961-1990 and the 2071-2100 periods. In the eastern areas, rainfall will be subject to a smaller average increase of approximately 6%.

10 Climate Change Adaptation Framework

10.1 Introduction

Several GIS-based techniques were considered in the development of the HCCAF, and the following guidelines set to establish the best possible approach:

- Standalone application where users do not need to load several applications;
- ability to integrate qualitative inputs, quantitative inputs, geographical references, images of locations and water access/use in one seamless tool;
- preference for tools for which users do not need to pay the high costs of securing the principal or associated software;
- allowance for open-source approaches which do not expose users to high maintenance or update costs;
- a framework that is useful at decision-making level while taking into account inputs from local communities and institutions;
- available programming expertise;
- cost-effective methods that can stand the test of time (the software should run for at least ten years without losing functionality when operating systems change); and
- the framework structure allows for ease of update (the framework comes with data for the case study areas and an inbuilt structure for completion of inputs for all other areas in the country).

The selected approach is based on a new software tool developed from original concepts as provided for in the study inception report. Delphi language was used in the development as well as an open source GIS platform accompanied by a full relational database. The best quality in this development is demonstrated by the exclusion of the expensive ESRI GIS tools, while allowing for the use of the files produced and used by most GIS tools, including ESRI GIS. As such the users will not need to purchase the ESRI software for which costs may run into several hundreds of thousands of rand for institutional users.

10.2 Vulnerability and adaptation framework concept

The processes leading to the development of the Hydrosoft Climate Change Adaptation Framework (HCCAF) in this study involved the following:

- Development of understanding of available knowledge and current practices on water access and use through a literature review study;
- an assessment of climate change impacts using simulated impacts data from GCMs, and regionalised for South Africa;
- consultations and a workshop where local knowledge from stakeholders and targeted communities was incorporated;

- assessment of vulnerabilities to climate change impacts in institutions and communities;
- assessment of water access needs in case study areas;
- establishing a baseline on water access and climate change adaptation in targeted communities;
- development of an approach that constituted the adaptation initiatives toolbox; and
- selection of the most suitable software development platform for the HCCAF.

10.3 Architecture of the adaptation framework

A bottom-up approach was used to conceptualise and investigate adaptation options. The lowest level of community discretisation, the individual household level, became the starting point in developing adaptation options, with institutions taking the high level support role as illustrated in Figure 38 below.

The water uses play a central role in the nature of adaptation relevant for each water user group. Figure 39 below illustrates that adaptation for a specific local community is a function of the nature of water use, available resources and other circumstances. Water use patterns are not fixed, however, but change over time with development. By way of illustration, in the early 2000s, a few commercial farmers in the Thulamela Local Municipality were using the bulk of the water. The domestic water requirement was 10 million m^3 per annum in 2000 while the irrigation water requirement was 100 million m^3 per annum (DWAF, 2002). This pattern of water use has changed, with more than 15% of people who were in rural areas having moved to urban areas since 2001 (Thulamela, 2012), where people use much more domestic water. The DWA National Water Resource Strategy (NWRS) (DWAF, 2002) estimated that in 2000 the water need in rural areas was 55 ℓ/c/d. As people move to urban areas, the water usage increases to well above 150 ℓ/c/d. Thus, changes in population distribution, level of community development and water usage patterns have major implications for the determination of adaptation options for water access. In 50 or 100 years' time, the water needs, the points of high water demand, and the nature of water uses will not be the same as today.

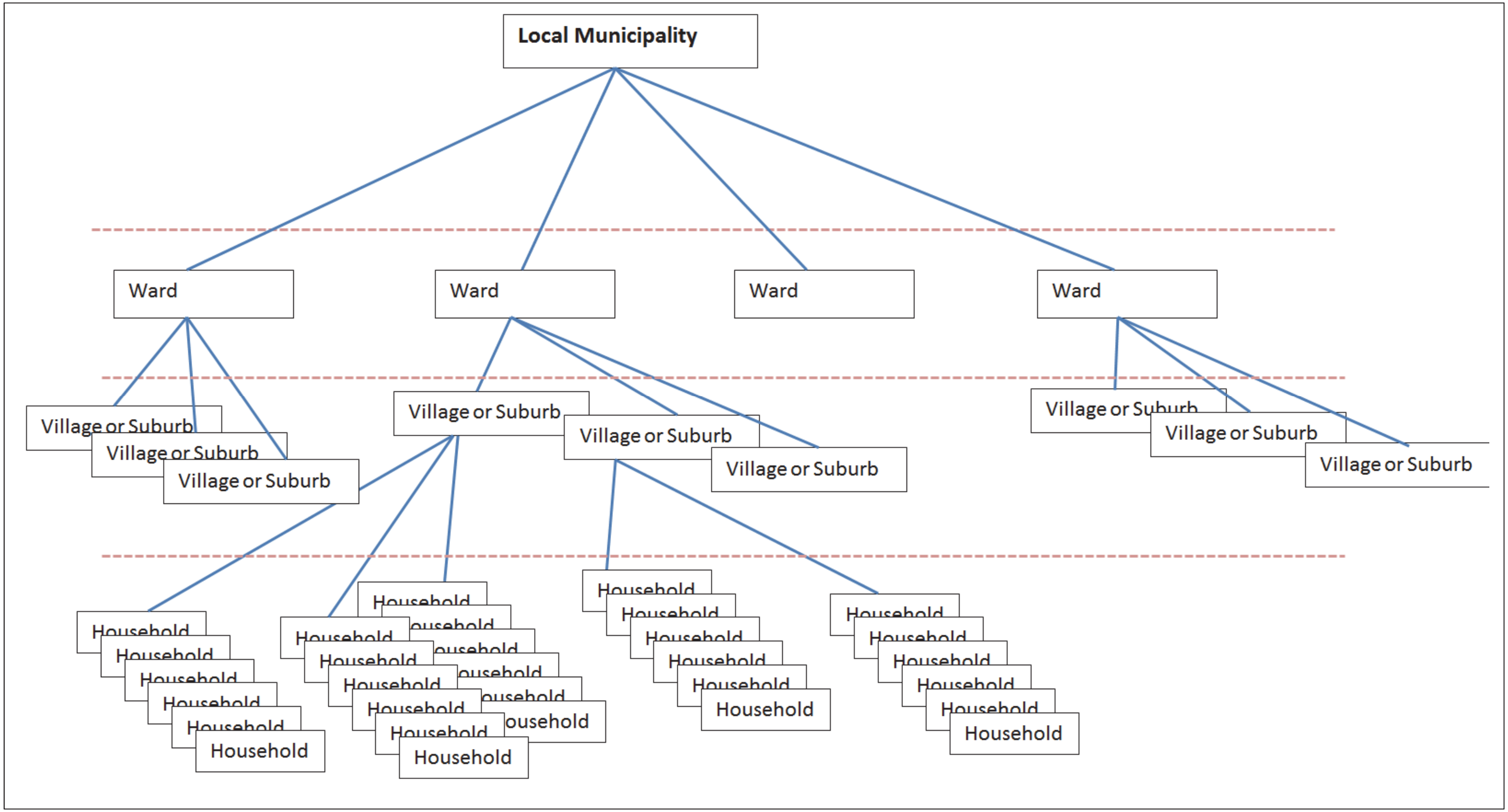


Figure 38 **Impacts and adaptation information and support path to the lowest level of spatial resolution**

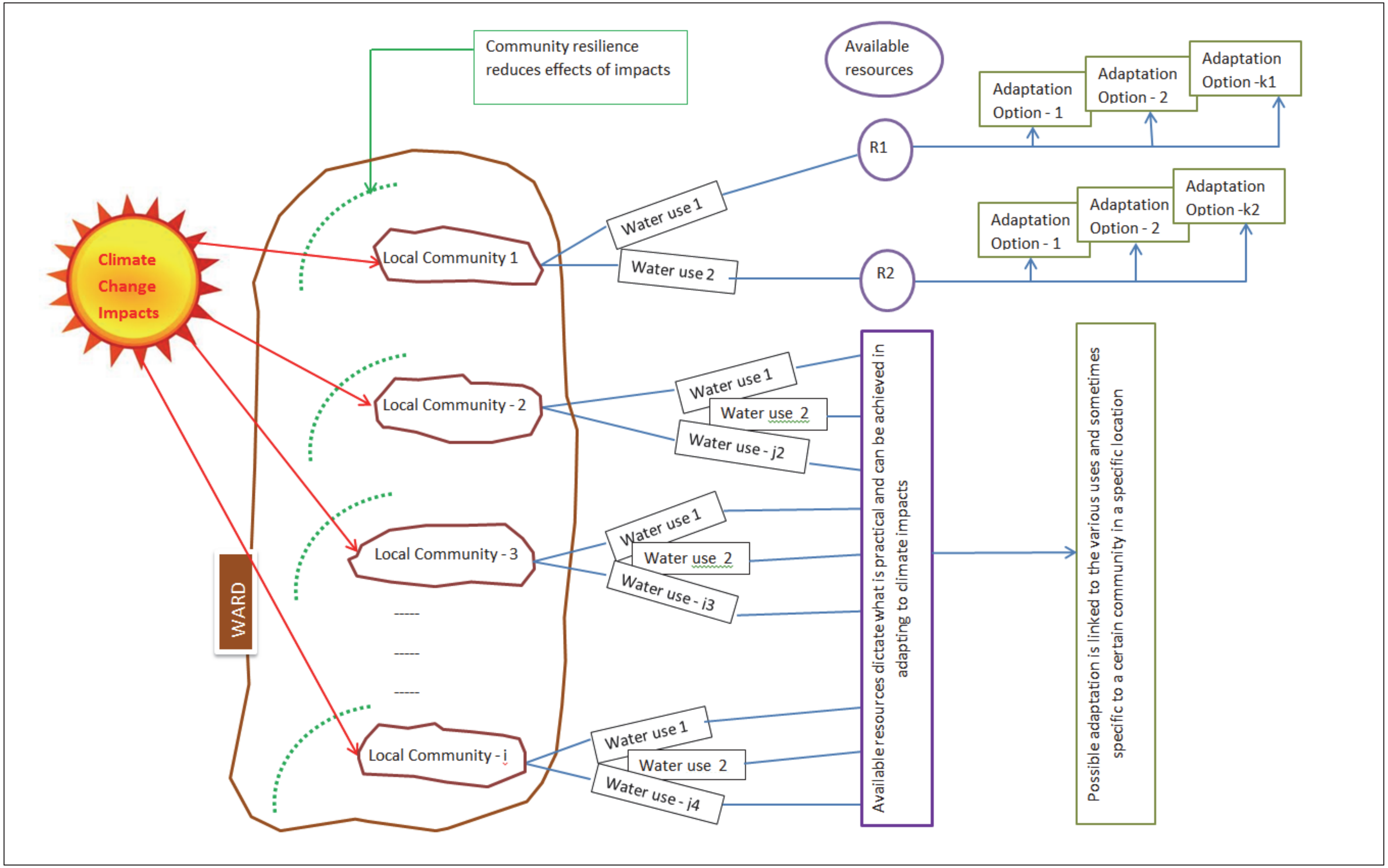


Figure 39: **Adaptation options as a function of the nature of water use and circumstances of the impacted local community**

10.4 Climate Change Adaptation Framework software

10.4.1 Defining the HCCAF system

The Climate Change Adaptation Framework was developed using an object-oriented programming platform, which also took advantage of externally built components to speed up the overall progress in programming. The adaptation framework is composed of five main components. A relational database hidden behind a GIS front-end supports the input interface, calculations toolbox and the output and reporting modules. The TatukGIS Developer Kernel, a GIS Software Development Kit for compact frameworks, was used to develop the open source GIS system (TatukGIS, 2012). The framework interactive software interfaces which integrate the Delphi Software, the GIS development Kernel and numerous other externally developed objects provide the means and methods for user input, interaction, output presentation and analysis.

The software interfaces were based on the Delphi programming language. The selection of the software language for use in the framework was based on the need to use methods already used by targeted water institutions, and especially the DWA. The DWA has guidelines on the software language preferences which are clearly articulated and include guidelines on documentation of Delphi Code. Delphi programming language is a relatively new language, having been developed by Borland Software Corporation as a descendant of Turbo Pascal in 1995, and which was later bought by Embarcadero in 2007 (Embarcadero, 2012). The preferred Delphi language is a highly scalable application which can be used to develop tools ranging from desktop single user applications up to large database tools for the internet, where users can use a variety of operating systems to access and manipulate.

Using Dephi has the further benefit of good connectivity handles for GIS objects and shape files. This is made possible by the continuous developments that are taking place at Embarcadero, where software specialists maintain the language’s relevance to new developments in various working environments, including GIS, water engineering and management. The structure of the adaptation framework is illustrated in Figure 40 below, while an illustration of the database structure used is shown in Figure 41.

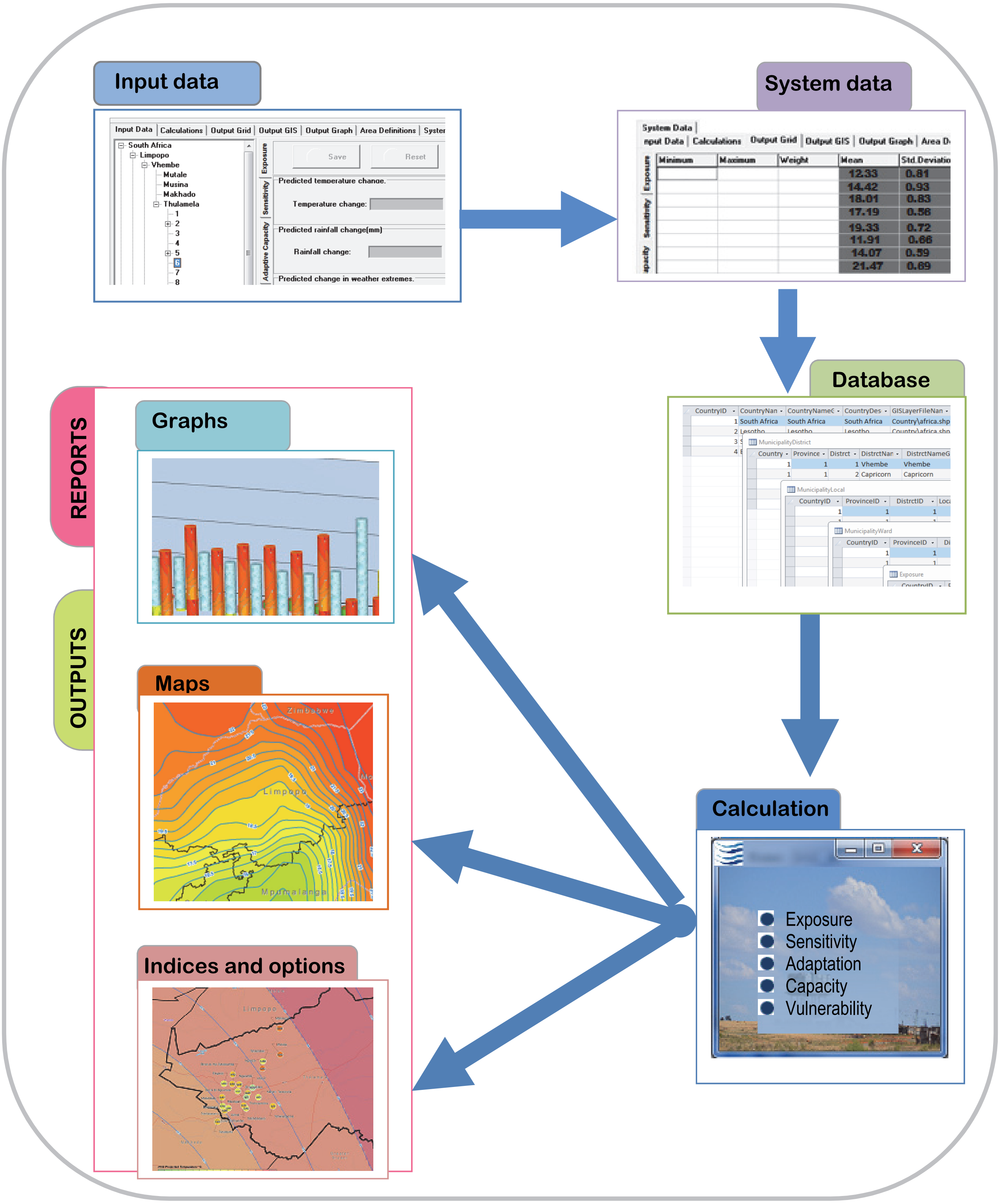


Figure 40: Structure of the Hydrosoft Climate Change Adaptation Framework

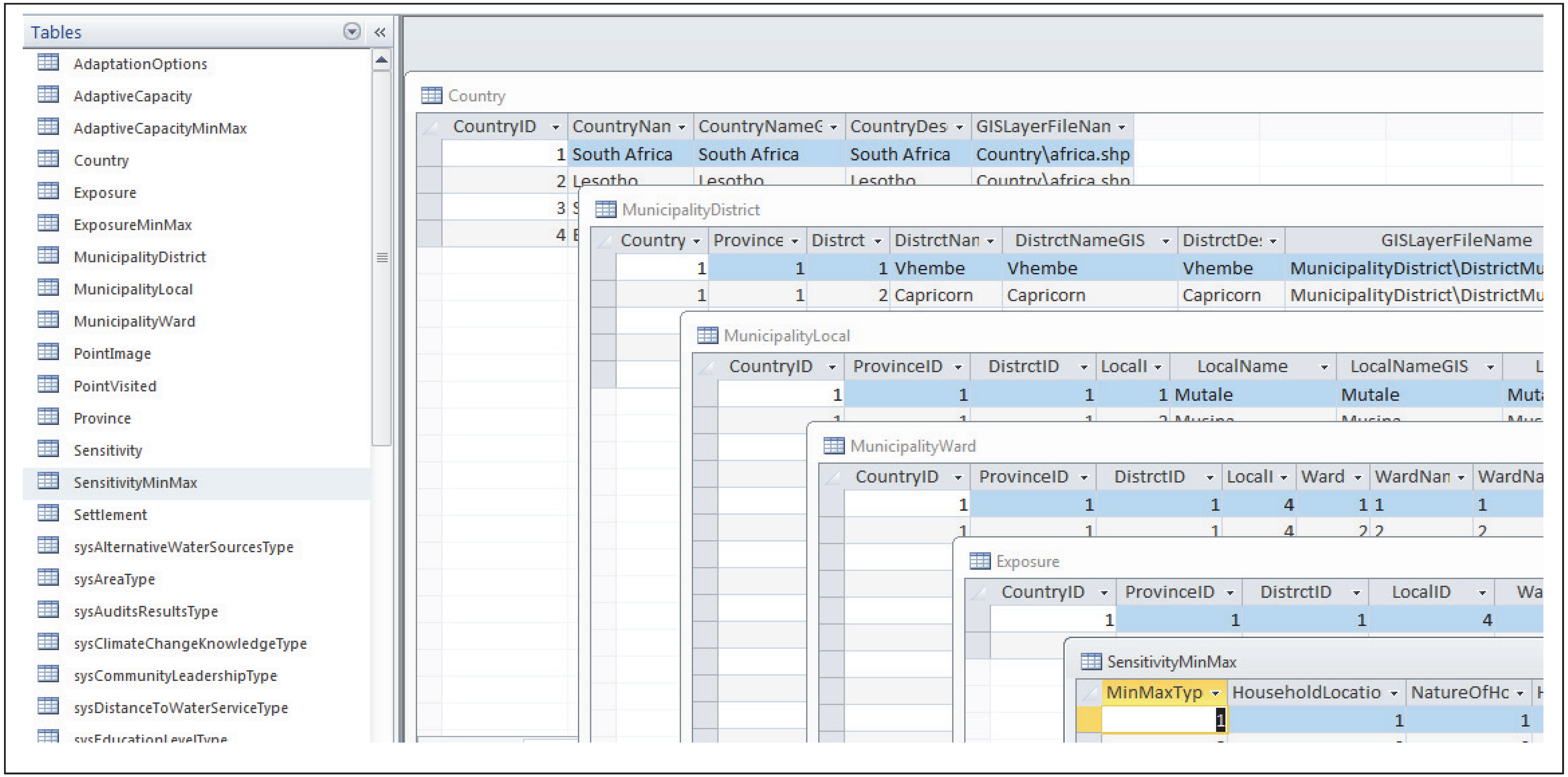


Figure 41: Illustration of the database used in the HCCAF

10.4.2 Input variables and forms

The HCCAF relies on four main categories of input variables. These inputs fall into the fallowing groups:

1. Inputs which define vulnerability;
2. GIS architecture inputs;
3. water access data, images and information; and
4. adaptation options.

10.4.2.1 Inputs which define vulnerability

In the HCCAF, vulnerability to climate change is described by three elements: exposure, sensitivity, and adaptive capacity. These are explained in Section 5.2 of this report.

10.4.2.2 GIS in HCCAF

The HCCAF runs from a GIS platform where inputs and data about settlements and wards are accessed and updated. The adaptation GIS platform structure is built in a natural hierarchy as illustrated in Figure 42 below.

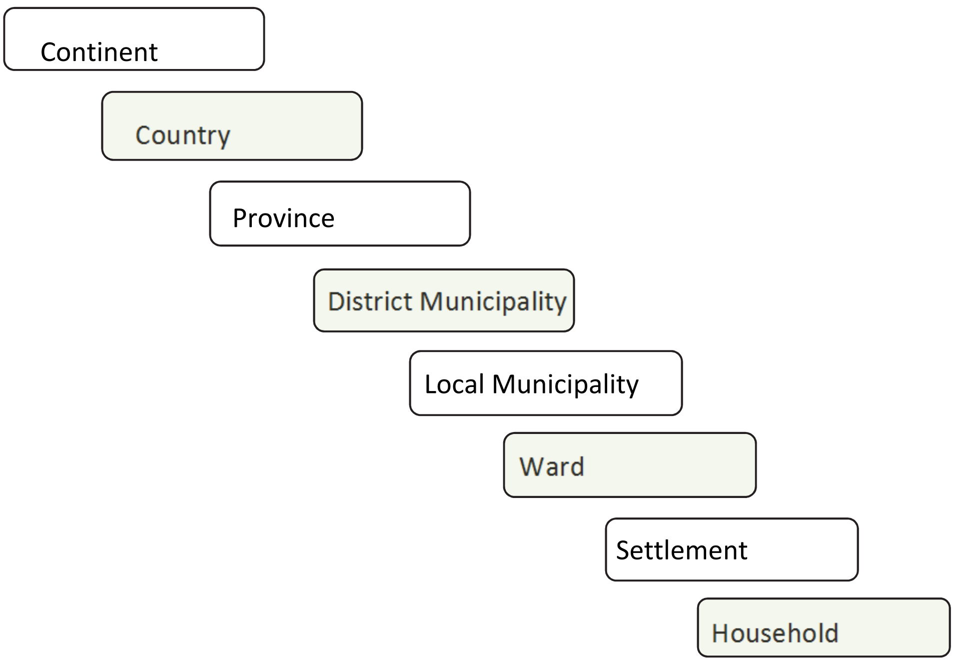


Figure 42: Structure of spatial data in HCCAF relational database

At the lowest level of the GIS representation, the household was the point where most of the data was captured. Information from other institutional role-players in community water access is included as part of the data about the specific settlements and wards which they service or which are in their area of influence. In the framework, the same hierarchy of spatial information is represented in the left pan of the GIS interfaces, as shown in Figure 43 below.

10.4.2.3 Water access information and adaptation options

Information on water access and adaptation options was derived from several sources. These included:

- Desktop studies and area photographs;
- questionnaires administered to community members;
- interviews with role-players and decision-makers;
- workshop proceedings; and
- literature studies.

The information on water access and adaptation options was initially captured for the individual settlements visited and later aggregated to provide options at ward level. The representation of adaptation options in HCCAF is as shown in Figure 43 below.

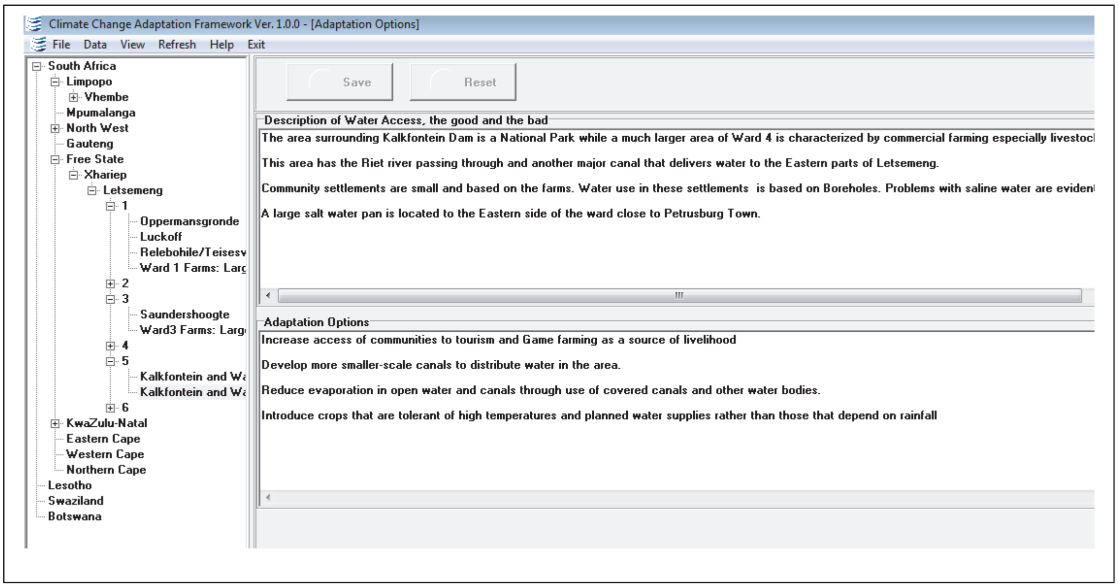


Figure 43: How water access and adaptation information were captured per settlement and ward

10.4.2.4 Use of photographs in understanding water access and adaptation

The investigations in the different local communities were accompanied by a series of photographs. The observations, which resulted in certain indicator values, were noted. The images taken provided further understanding of the nature of physical observations which characterised the various values for water access, exposure, vulnerability, sensitivity and adaptation capacity indicators. In certain areas where questionnaires were not administered, such images are expected to be used as a method for rapid assessments. As an example, the following images, taken in two locations in Thulamela and Madibeng approximately 500 km apart, show private water purchase points where water is sold by residents to their neighbours for R2 per 20 litre container. The nature of water access and vulnerability is typically the same in the two scenarios depicted in Figures 44 and 45, is the case in the images displayed in Figures 46 and 47. Major canals such as these where discharge is well above 10 m^3/s are always associated with large-scale commercial irrigation. The water users in such cases tend to use the water throughout the year and have both summer and winter crops. The major difference, however, in the two water provision systems illustrated is that the water in Madibeng is visibly a deep bluish-green with algae and is very polluted, while water in the Letsemeng system is relatively clean. All this useful information is available in the image and can be used in quantifying the indicators for determining the nature of water access.

For the purposes of populating the framework with photographic content, the researchers visited each of the wards in the case study areas and discussed the situation with the people in the area, while also capturing the coordinates of each point. The point coordinates are used when capturing the photographic content in the adaptation framework.

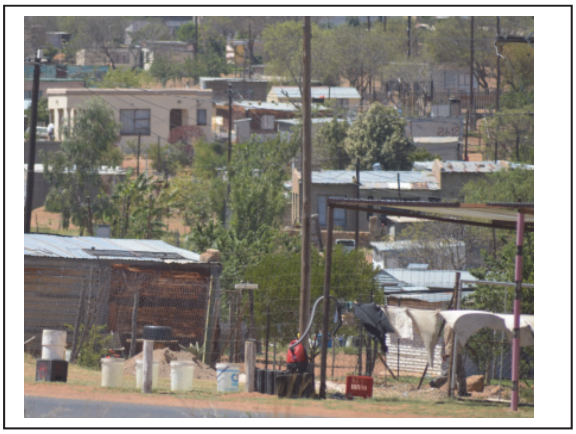


Figure 44: A water purchase point in Madibeng

Figure 45: A water purchase point in Thulamela

Figure 46: Large capacity canal in Madibeng for irrigation

Figure 47: Large capacity canal in Letsemeng for irrigation

Information from photographs lacks some of the important content, making it necessary to fill the gaps via correspondence with representatives from wards or settlements, and information gained from relevant councillors in each ward, to answer the following:

1. Confirming bulk water sources for the area;

2. information on level of water services in most of the wards – street taps, yard connections, etc.;

3. statistical information regarding households with water meters, those who are billed, those who have illegal connections and community members with no water provision;

4. description of common water access and use problems. (Quality and quantity issues);

5. understanding the source of the problem;

6. details on use of groundwater resources in the area;

7. data on farming practised in the area. If available, brief information on nature of farming and water use in farming;

8. description of water sources used by farmers. Confirming the water institutions that support water provision to the farms; and

9. description of water developments that are happening or are planned in the area. Information on who will benefit from the developments.

10.4.2.5 Municipal, ward, settlement and point data

Municipal organisational structure

District municipalities are tasked with overall responsibility for water infrastructure development, and for ensuring that the communities in their areas have access to water at government-stipulated levels. In South Africa, the targeted water access levels for all citizens are those driven by government as part of the Millennium Development Goals (MDGs). At local levels, local municipalities implement programmes and projects which benefit communities by improving water access. Improvements in water access and any institutional initiatives to do so in the light of climate change impacts have to be planned and developed as part of all municipal IDPs. In all cases where a local municipality falls under a district municipality, the IDP at district level is translated at local municipal level into specific programmes and projects.

One of the main objectives of the adaptation framework is to generate options for adaptation to climate change in specific areas which can be built into the water access and development plans of a municipality. In this study, investigations at local municipality level showed that only one out of the four local municipalities was taking climate change into account at any level of decision-making.

Municipal and ward set-up in HCCAF

In the HCCAF, inputs regarding state of water access, climate change impacts, vulnerability, sensitivity and adaptive capacity are entered for each settlement. A settlement is made up of number of households and the project research contact point in communities was through a representative of a household. The information from several households in a settlement constitutes the representation of that settlement. The information from one or more settlements in a ward provides the information for the ward. In this adaptation framework, the data from settlements is captured, followed by the data from wards and then the local municipality, followed by the district municipalities which make up the province, so that ultimately the country's data is expected to consist of data from the provinces. In Figure 48 below, Thulamela Local Municipality and the wards are shown in the HCCAF interface, according to the revised dataset produced by the municipal demarcation board in 2011 (Municipal Demarcation Board, 2011).

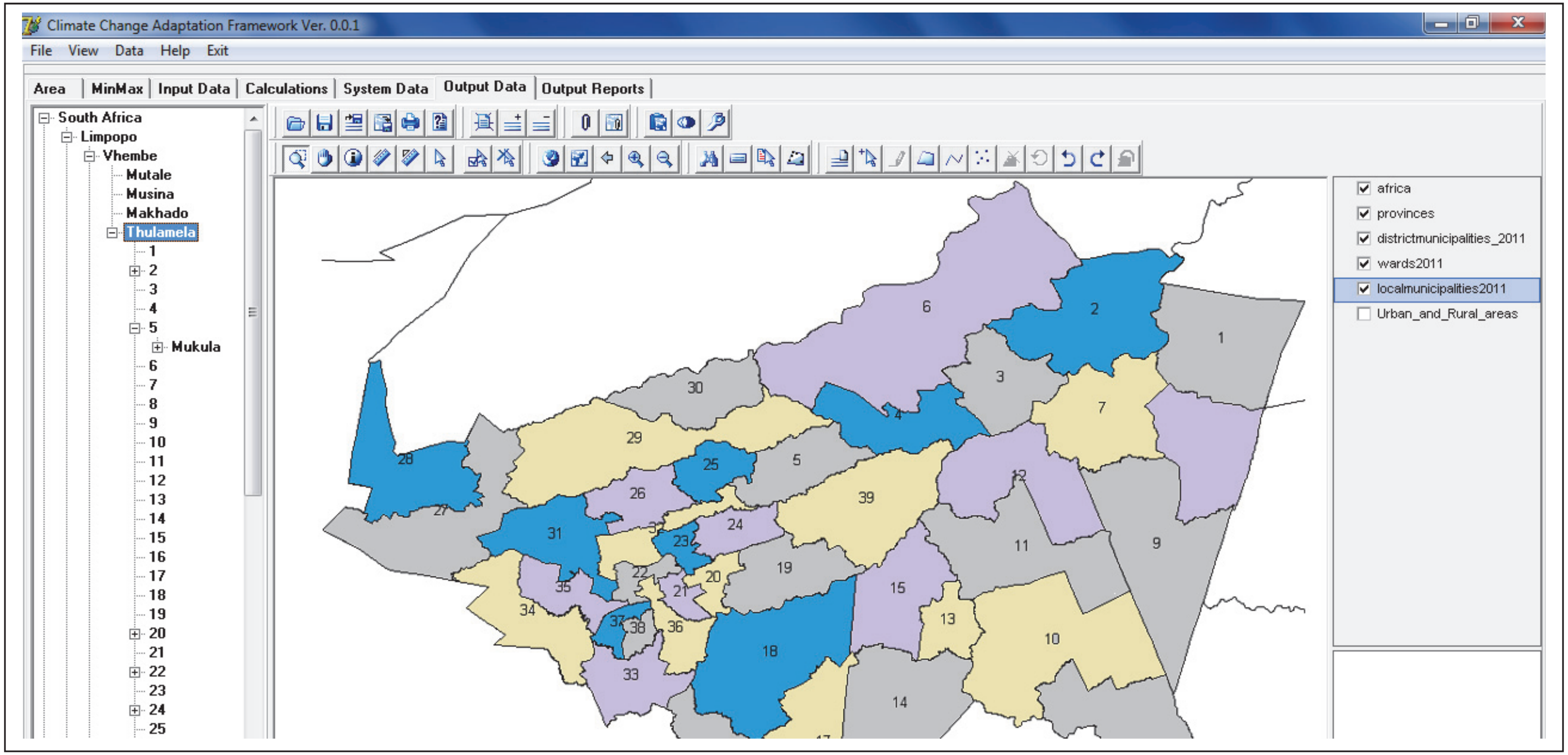


Figure 48: GIS Outputs in the Adaptation Framework

Inputs at household, settlement and ward level

Inputs at household level were captured and used to represent the nature of findings expected for a local community. The data collection entailed the administering of questionnaires at selected households in different settlements. Further data for each local community was also obtained through consultations with institutional role-players and desktop studies. The data gathered was used to quantify indicators for describing the state of water access, exposure to climate change impacts, community vulnerability to climate change impacts, sensitivity to impacts, capacity to adapt and available adaptation options. In the HCCAF, the state of water access, climate change exposure, community sensitivity and adaptation were defined using 32 indicators. The interpretation of these indicators is presented in the HCCAF and a sample of inputs is provided in Annexure 2 of this report.

10.5 Adaptation and presentation of outputs

10.5.1 Adaptation options at municipal and broader scales

The framework provides the opportunity to represent adaptation options as they apply at various scales, which include: national, provincial, municipal, ward, village, household and individual community member level. Institutions have roles to play at various scales. In South Africa, national infrastructure development programmes could be used to enhance climate-related adaptation in the field of water access and use. Adaptation programmes will have to be supported by relevant policies and an understanding of the climate changes on which the scale must be focused. The adaptation framework provides the platform for the user from which to include the adaptation options, after assessing the nature of impacts and vulnerabilities for the specific community scenario. For example, long-term sustainable water access will not be improved if dams are built in areas where catchment yield tends to decrease over time due to climate change. If, however, a sound understanding of climate change impacts on rainfall and runoff is used in dam developments, where dams with a high MAR ratio are built in areas where catchment water yield will increase with time, then water availability and access will be improved in time. These considerations are included in the adaptation framework to come up with suitable adaptation options.

10.5.2 Adaptation options at local scale

The adaptation framework was developed with the household as the point of first level inputs. As such, the representation of adaptation options is set to target local scales first before aggregating these to broader or more global scales. The adaptation interface allows the user to evaluate the provided adaptation options for a settlement or village, and identify the geographical location of the settlement/village or suburb, including the ward number. At localised scales, some of the adaptation options may not require direct institutional support, while many others will undoubtedly require such support. Adaptation options available for each community have to be appreciated holistically to ensure that the best possible approaches are pursued. This is possible in the adaptation framework, where all possible options are captured and can be presented to communities. This includes sharing the information on adaptation options between communities. The interface for adaptation option inputs in the framework is illustrated in Figure 43.

10.6 Role of institutions in the adaptation toolbox

Institutions such as local and district municipalities which are responsible for water access are considered to be the drivers in using the climate change adaptation framework. A number of adaptation options in water access and use have to be built into those systems developed for water provision, and the services associated with water access. In South Africa, the responsibility for ensuring that all citizens have access to water is jointly bestowed on the Department of Water Affairs and the Department of Provincial and Local Government (DPLG). While DWA's role is usually the provision of bulk water on very large scales, DPLG focuses on actual water provision and services at local community level. The framework is designed to bridge the gap between the usual top-down approaches and present the bottom-up perspective in implementing water access services for communities. It is envisaged that the framework will provide a systematic approach for dealing with water access for all local municipalities, and allow for the systematic development of water access adaptation options, including providing inputs to the planning of new water provision services.

11 Application of HCCAF in pilot studies

11.1 Introduction

Pilot studies implemented in the case study areas as explained in Section 1.4.2 of this report were implemented with the local municipality as the main institutional unit, or in other words, the institution expected to provide direct support in climate change adaptation. This institutional unit of the local municipality consisted of local communities, with those in the study also being referred to as settlements. These settlements were either suburbs or villages, and several settlements made up a ward. In a few cases, the suburbs were so large that they constituted several wards. The Climate Change Adaptation Framework was developed for capturing detailed information on water access and use, the impacts of climate change on a local community, analysing the sensitivity and adaptive capacity of the community to climate change impacts, and ultimately to derive the vulnerability of the community in question. With the developed understanding of the local community, the framework is used as the platform for determining the most appropriate climate change adaptation options for the community.

11.2 Pilot study methodology: Data collection

The data collection for the pilot study followed the procedures developed and explained in Section 1.4 of this study. The main factors in this approach were to focus on community inputs first and then follow this with institutional inputs. Inputs from other sources also played a role in cases where required data could not be obtained from communities or institutions that are directly involved. A typical example of such data was that on climate change impacts. This data was obtained from past climate change investigations, especially the general data available from international climate change modelling centres. The climate data ultimately used was obtained through the Council for Scientific and Industrial Research (CSIR) after being generated by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia. This climate change data scenario is referred to as CCAM-CSIRO Mk3.5.

11.2.1 Indices and indicators in quantifying the state of water access

The description and assessment of water access and vulnerability to climate change impacts were based on the methodology explained in Chapter 5.3 of this report. In this approach, state of water access and vulnerability are defined using the following variables:

- Climate change impacts;
- community sensitivity; and
- adaptation capacity.

The variables defining vulnerability at community level were broken down into the three subsets of exposure, sensitivity and adaptation capacity. The exposure was defined using the indicators in Table 18 below.

Table 18: Indicators for evaluating exposure of water access to climate change impacts

	Indicator
1	Predicted temperature change
2	Predicted rainfall change
3	Predicted change in likelihood of weather extremes

Following initial identification, the indicators used to define the components needed to assess water access vulnerability were reviewed by stakeholders through consultations and a targeted project workshop. In terms of the indicators used for defining exposure, additional inputs from the workshop indicated that it was also important to account for changes in weather seasonality. Furthermore, the issue of changes in maximum temperature was considered to be important in determining exposure levels in different local areas. Finally, the extent of changes in consecutive rain days due to climate change was also considered to be an important measure of water access.

The sensitivity of a community to climate change impacts was defined using 19 variables. These are listed in Table 19 below.

Table 19: Indicators for evaluating sensitivity to climate change impacts on water access

	Indicator		Indicator
4	Location of household	14	Water quality
5	Nature of house	15	Ability to pay for water
6	Household size	16	Access to suitable alternative water sources
7	Education level/literacy rate	17	Distance to institutional water service infrastructure
8	Main livelihood activity	18	Type of farming
9	Income of household	19	Water shortage in farming
10	Diversification of household income	20	Institutional water service provision capacity
11	Source of water	21	Institutional ability to bill and collect rates for water provision
12	Nature of water service	22	Results of institutional performance audits in past five years
13	Water shortage		

Adaptive capacity

The ability of communities to implement measures to alleviate the impacts of climate change, or in other words, their capacity to adapt to water access and use, were analysed based on ten indicators. These indicators are listed in Table 20 below.

Table 20: Adaptive capacity indicators

	Indicator		Indicator
23	Community organisation and networks with functional leadership	28	Presence of subsistence farming or small gardens in local community
24	Dependable employment	29	Knowledge of climate change
25	Income	30	Institutional capacity to provide water services now and into the future
26	Scale of commercial agriculture	31	Nature of water provision infrastructure
27	Ability to diversify agricultural activities	32	Human resources in the local institution

11.2.2 Quantification and weighting of indicators

Water access variables quantification was based on the relationships between the indicators for evaluating community vulnerability to water access. In this approach, developed in an earlier project output on vulnerability mapping, the indicators are described to provide a quantitative representation of their role in the description of water access vulnerability from the community's perspective. In Table 21 below, an example is provided on how the exposure indicators were quantified in the pilot study.

Table 21: Quantification of exposure using indicators

	Indicator *(for each local community)*	Quantification *(Indicator value x_{ji})*	Category
1	Predicted temperature change (From Project Deliverable 3- Impacts mapping)	Average Daily °C change / 3 °C * 10 if greater than 9 enter 9. If below 1 enter 1, Otherwise enter actual value	Exposure (High values increase exposure) (Exposure weights add up to 1)
2	Predicted rainfall change (From Project Deliverable 3- Impacts mapping)	Average Daily Rainfall Increase mm change /0.5). If <=-1 enter 9, if >-1 to <=0 enter 6, if >0 to <=1 enter 3, if greater than 1 enter 1	
3	Predicted change in likelihood of weather extremes (From Project Deliverable 3- Impacts mapping and mapping source data)	A measure of level of change where none = 0, Low = 3, medium =6, high = 9	

The indicators were also weighted, with the weights based on the intensity or significance of the indicator in extending the overall effect or objective. For example, how does the indicator show ability to adapt to climate change impacts? Entering a weight of 3 for the indicator 'knowledge of climate change' and 6 for 'income of household' will mean that the 'income of household' has twice as much significance as the 'knowledge of climate change' in the overall objective of extending adaptive capacity.

Not all indicators have the same significance to the overall vulnerability to water access. Vulnerability is unique to the different indicators and to varied extents or intensity. To illustrate the use of weights, a look at an urban area setting will reveal that the indicator, 'type of housing', has less significance to vulnerability to water access when compared to the indicator measuring 'availability of water service infrastructure'. In such a case, the indicator for 'type of housing' will have a lower weight than the indicator for 'availability of water service infrastructure'. In this study, the intention is to produce an adaptation framework where the weights can be varied to capture new insights or knowledge. For the purposes of the case studies, an expert judgment approach was initially used to generate weights. Suggestions from stakeholders were further incorporated in the weights of indicators. This approach is influenced by determining the extent to which the common information derived from the variables which constitute the indicator are most aligned to pushing the vulnerability indicator in the positive direction, i.e. increasing vulnerability. The value of each weight (b_i) was assigned within the range 1 to 10. The indicator value after weighting is then given using Equation 8 of Section 5.3.

In the study, the weights were aggregated and factored proportionately to give the total weights of one unit for exposure, one unit for sensitivity and two units for adaptive capacity such that Equation

1 in section 5.3 gives zero as the resultant vulnerability value for cases where there is no resultant vulnerability.

The mathematical representation of water access vulnerability was then given as shown in Equation 9 of Section 5.3.

The pilot study scenarios dealt with domestic water access and use and excluded commercial farming, which is hardly practised in two of the pilot study areas. The list of indicators and the value attached to each indicator, according to how the indicators were represented in the HCCAF, are illustrated in Annexure 2.

11.2.3 Data entry and framework scenario

The data used in defining water access, vulnerability and adaptation options were captured from households using questionnaires, interviews, desktop studies from institutional sources and literature. The data obtained were both quantitative and qualitative in nature. Average and more general descriptions of water access indicators, vulnerability elements and adaptation options were entered into the adaptation framework using a Microsoft Access database. The data entry followed the geographical referencing of the data where each entry was identified in a relational database as illustrated in Figure 42. On the GIS interface, the settlement data is linked to the relevant areas using the 'settlements data interface' illustrated in Figure 49 below.

The data for each village or settlement was captured in the framework using the individual entry forms or the automated import technique for capturing data from a whole local municipality. The exposure data for the whole area can be captured for each municipality using tabulated inputs and the import option of the framework. The tabulated exposure data is illustrated in the framework in Figure 50 for the Thulamela area.

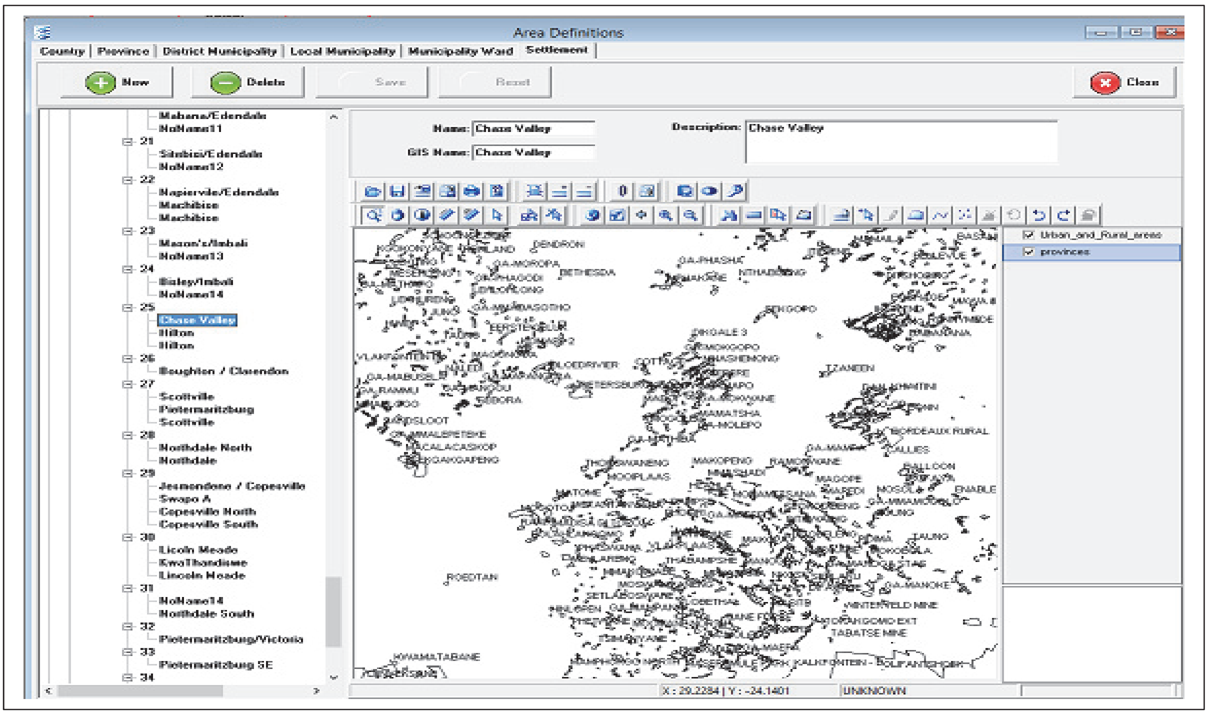


Figure 49: Individual addition of data per settlement or village

Exposure | Sensitivity | Adaptive Capacity

Export | Print | Show Area Data | Close

Index	Country	Province	District	Local	Ward	Temperature	Rainfall	WeatherChange
1	South Africa	Limpopo	Vhembe	Thulamela	1	5.333333333333	3	6
2	South Africa	Limpopo	Vhembe	Thulamela	2	5.333333333333	3	6
3	South Africa	Limpopo	Vhembe	Thulamela	3	5.666666666666	3	6
4	South Africa	Limpopo	Vhembe	Thulamela	4	6	3	6
5	South Africa	Limpopo	Vhembe	Thulamela	5	6	3	6
6	South Africa	Limpopo	Vhembe	Thulamela	6	5.666666666666	3	6
7	South Africa	Limpopo	Vhembe	Thulamela	7	6	3	6
8	South Africa	Limpopo	Vhembe	Thulamela	8	5.333333333333	3	6
9	South Africa	Limpopo	Vhembe	Thulamela	9	5.333333333333	3	6
10	South Africa	Limpopo	Vhembe	Thulamela	10	5.666666666666	3	6
11	South Africa	Limpopo	Vhembe	Thulamela	11	5.666666666666	3	6
12	South Africa	Limpopo	Vhembe	Thulamela	12	5.666666666666	3	6
13	South Africa	Limpopo	Vhembe	Thulamela	13	6	3	6
14	South Africa	Limpopo	Vhembe	Thulamela	14	6	3	6
15	South Africa	Limpopo	Vhembe	Thulamela	15	6	3	6
16	South Africa	Limpopo	Vhembe	Thulamela	16	5.666666666666	3	6
17	South Africa	Limpopo	Vhembe	Thulamela	17	6	3	6
18	South Africa	Limpopo	Vhembe	Thulamela	18	6	3	6
19	South Africa	Limpopo	Vhembe	Thulamela	19	6	3	6
20	South Africa	Limpopo	Vhembe	Thulamela	20	6	3	6
21	South Africa	Limpopo	Vhembe	Thulamela	21	6.333333333333	3	6
22	South Africa	Limpopo	Vhembe	Thulamela	22	6.333333333333	3	6
23	South Africa	Limpopo	Vhembe	Thulamela	23	6.333333333333	3	6
24	South Africa	Limpopo	Vhembe	Thulamela	24	6.333333333333	3	6
25	South Africa	Limpopo	Vhembe	Thulamela	25	6.333333333333	3	6
26	South Africa	Limpopo	Vhembe	Thulamela	27	6.333333333333	3	6
27	South Africa	Limpopo	Vhembe	Thulamela	28	6.5	3	6
28	South Africa	Limpopo	Vhembe	Thulamela	30	6.333333333333	3	6
29	South Africa	Limpopo	Vhembe	Thulamela	31	6.333333333333	3	6
30	South Africa	Limpopo	Vhembe	Thulamela	32	6.333333333333	3	6
31	South Africa	Limpopo	Vhembe	Thulamela	33	6.333333333333	3	6
32	South Africa	Limpopo	Vhembe	Thulamela	34	6.333333333333	3	6
33	South Africa	Limpopo	Vhembe	Thulamela	35	6.333333333333	3	6
34	South Africa	Limpopo	Vhembe	Thulamela	36	6.333333333333	3	6
35	South Africa	Limpopo	Vhembe	Thulamela	37	6.333333333333	3	6
36	South Africa	Limpopo	Vhembe	Thulamela	38	6.333333333333	3	6
37	South Africa	North West	Bojanala	Madibeng	1	6.666666666666	3	6
38	South Africa	North West	Bojanala	Madibeng	2	6.666666666666	3	6

Figure 50: Exposure data as captured in the adaptation framework using the access database

In addition to the water access information and data, adaptation options were also captured per ward, based on the settlements in each ward. The description of adaptation options in the ward was based on the areas visited in the study area and is not necessarily applicable to the whole ward. This focus was biased towards domestic water use. The entries for adaptation options were done at a point in the municipality especially targeting identified points where data were collected. In Figure 51 below, the points in the wards and the vulnerability indices are shown in the relevant geographical location on a window in the HCCAF.

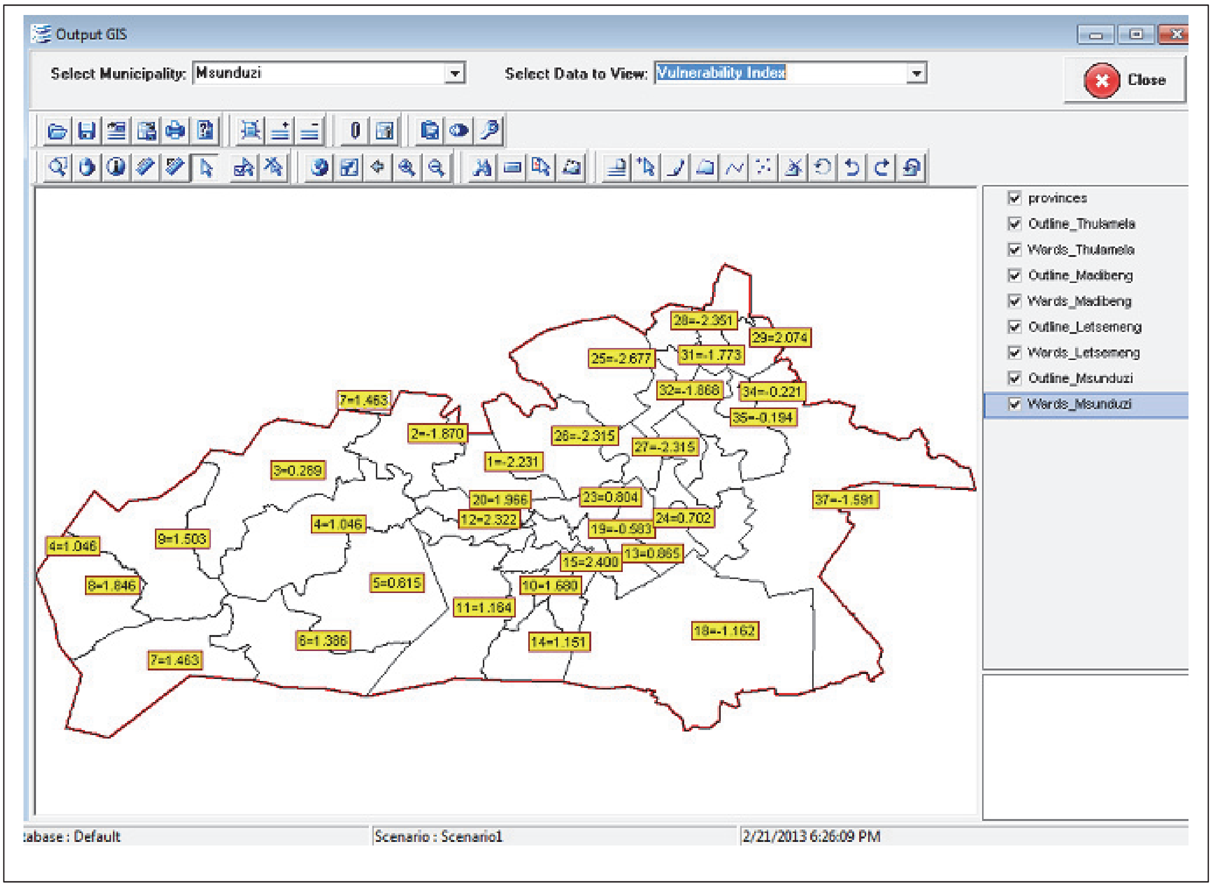


Figure 51: Msunduzi Local Municipality showing the ward boundaries, ward numbers and vulnerability indices

11.2.4 Analysis using adaptation framework

In the adaptation framework the information obtained from communities to describe the state of water access is used in the quantification of the relevant indicators. These indicators constitute the water access vulnerability and provide pointers on the nature of water access areas requiring specific adaptation responses. In each area, possible climate change adaptation options, which could be implemented by both local communities and local institutions, are determined and included in the framework to constitute the range of possibilities for each area. The HCCAF user is expected to match these with the quantified indicators and water access vulnerability elements.

Using the HCCAF, the comparison of findings from each study area was made. These findings, which describe the state of water access and quantify this state to provide a method for determining areas where specific indicators performed the best or worst, are used as the basis for determining the most suitable areas for applying adaptation options. It is envisaged that the local institution will assist the local community through the support of adaptation options that are relevant to their needs or their specific water access circumstances as analysed in the adaptation framework. The HCCAF analysis will determine the performance of each indicator in each settlement and ward, exposure to climate change indicators, the sensitivity to climate change, adaptive capacity and vulnerability to water access. The outputs in the framework are presented in tables, graphs and as information at points on the map at the GIS-represented spatial locations. In addition to information about water access, the HCCAF also provides images taken from locations in the settlements for the wards. The photographs are intended to enable visual assessment of the nature of settlements and other features which are useful in understanding water access and use factors for the area, as well as to help decide on the most appropriate adaptation options (see Figure 52).

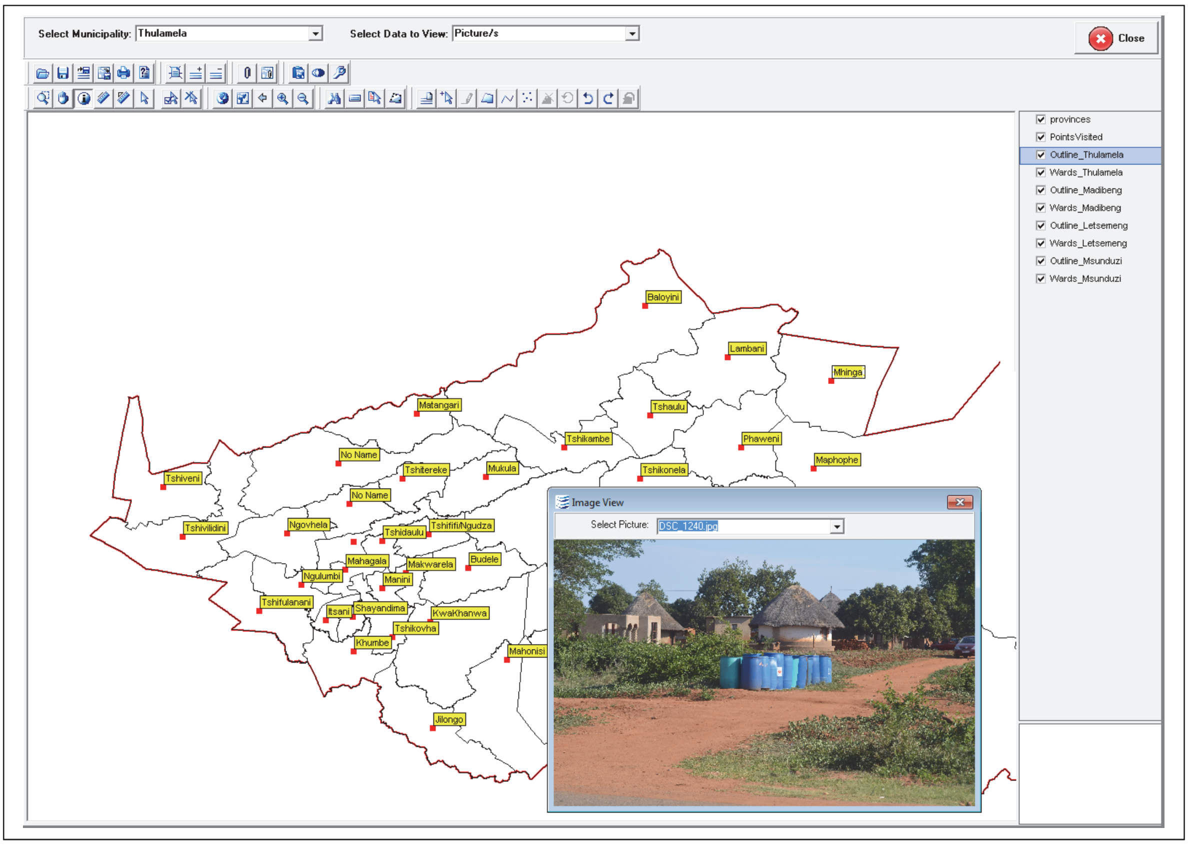


Figure 52: Point information in HCCAF showing visual clues of water access in one ward of Thulamela Local Municipality

11.3 Pilot study scenario development

The pilot study model building was done as a scenario in the adaptation framework, with data from settlements being used to describe water access indicators at ward level. The scenario model structure was based on information obtained at ward level using data from a few households as being representative of the whole ward. To define the scenario the “File” option in the HCCAF dashboard window is selected, as illustrated in Figure 53.

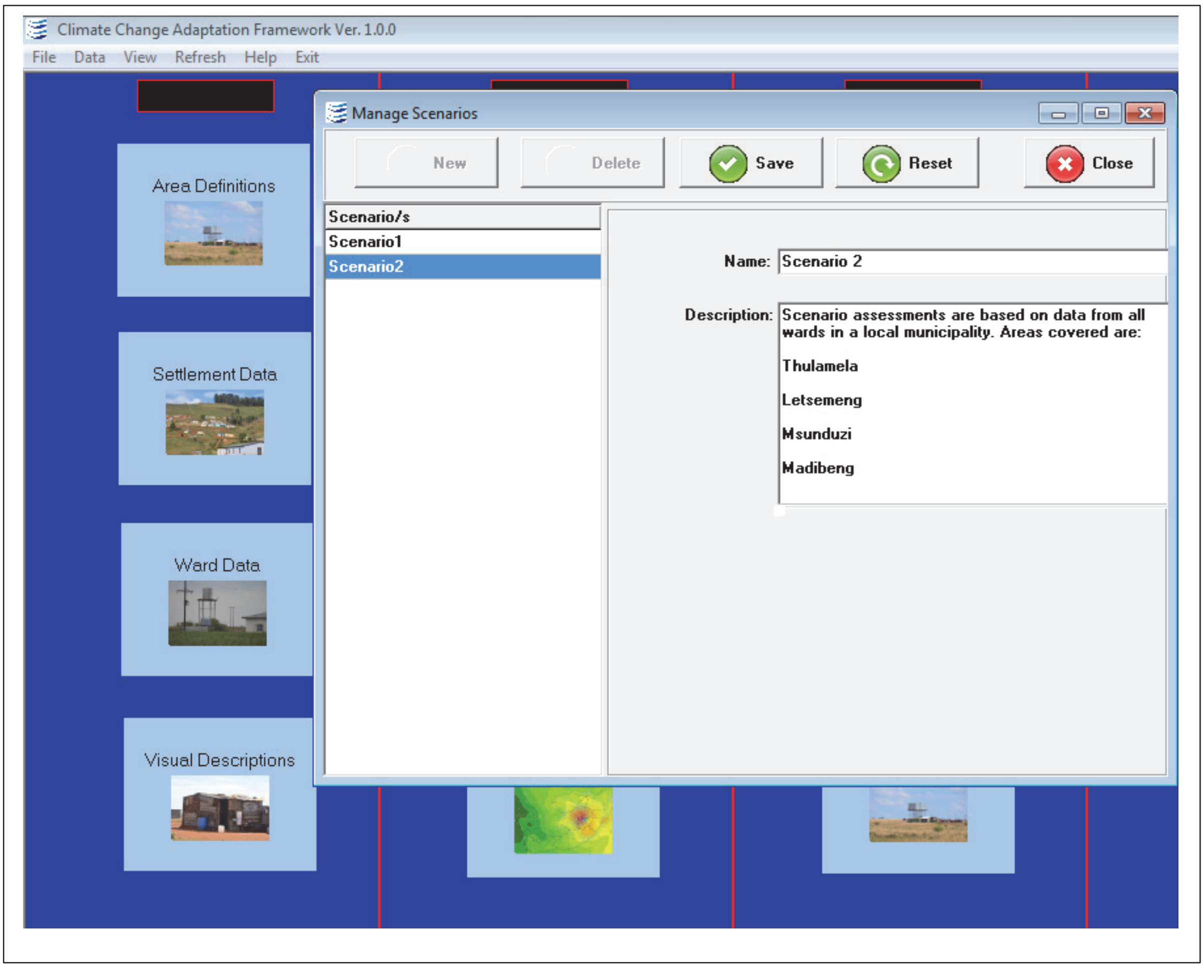


Figure 53: Building the scenario for the pilot study in the HCCAF.

Once the scenario is defined, the user is expected to import the settlements and points data. The settlements data comprise all the data for water access variables for each settlement, as captured for the households and averaged for the local settlement. The points data are the photographs, descriptive content of water access and adaptation options defined for selected points at the settlement level.

In the "Data" selection option, the collected settlement data is normalised to produce a data set that is on a common scale for each indicator. The normalisation of data is done using Equation 2, as illustrated below:

$$z_{j,i} = \frac{Z_{ji} - Z_{min,i}}{Z_{max,i} - Z_{min,i}} \times 100 \qquad \text{Equation 2}$$

$z_{j,i}$ *is* j^{th} *normalised value for indicator* i;

Z_{ji} *is* j^{th} *actual value for indicator* i;

$Z_{min,i}$ *is minimum value for all* i^{th} *indicator values*;

$Z_{max,i}$ *is maximum value for all* i^{th} *indicator values*;

The last tab under the "Data" selection button in the toolbar allows the user to apply Equation 1 of this report to all the normalised indicator values. The HCCAF will quantify all indicator values and water access vulnerability elements for each local area and ward.

The methodology for entering the data, running the framework and obtaining the output is described in the user manual provided on the DVD with the Hydrosoft Climate Change Adaptation Framework software.

11.3.1 Thulamela

In the pilot study, Thulamela Local Municipality showed the weakest adaptive capacity. A low adaptive capacity is generally due to low incomes and a poorly staffed local municipality, which serves as the main water provision institution. For the institution to support the local community with water access both presently and in the future, a strong institutional establishment is required. In Thulamela, the municipal institution lacks both administrative and technical human resources, while the need for infrastructure is huge. Additionally, the population is large and dispersed, making it difficult to develop water access infrastructure and connect all the people within this area. At this point, the HCCAF also revealed that all areas in the Thulamela Local Municipality are vulnerable to climate change impacts and are subject to problematic water access. Thulamela's level of sensitivity is the lowest of the four case study areas as a result of very poor performance in the following indicators:

- Nature of water sources;
- nature of water services;
- frequency of water shortages;
- institutional water service capacity; and
- institutional ability to bill and collect rates for water provision.

The graphical illustration in Annexure 3.1 shows the indices obtained in defining the nature of water access and vulnerability to climate change impacts as determined for Thulamela LM settlements and wards.

11.3.2 Letsemeng

Taking into consideration that its population is only 38 600 people, Letsemeng is considered to be a small local municipality. Nevertheless, at 10 180 km² (Stats SA, 2011), its land area is the largest of the four study areas, giving it a much lower population density when compared to the other pilot study areas (see Table 1 in Chapter 1). The majority of the inhabitants of Letsemeng live in five small towns with water provision systems not connected to each other. It follows then that water access issues in one area are mostly unique, and not the same as the other areas. Issues emerging as a result of the institutions that support water access, however, tend to be the same. In the case of Letsemeng, local communities had fewer water access challenges with the local municipality, reporting that 100% of the inhabitants of this area have access to suitable water. While water provision coverage is generally good in Letsemeng, the study revealed that there were gaps in water provision for informal and low income settlements.

It was noted in the pilot study that Letsemeng was the most susceptible area to extreme weather events, especially flooding, due to the nature of the rivers passing through it. Nevertheless, the study also determined that Letsemeng performed well on adaptive capacity and sensitivity. The location of Letsemeng is such that a great deal of water has been made available to communities through developed canal systems. This factor obviously makes it easy to improve water access and achieve service delivery targets. In this area Petrusburg is the most vulnerable town to impacts on water access. The future supply for Petrusburg, however, should be the surface water supplies from the established water conveyance canals. The graphical illustration in Annexure 3.2 shows the indices obtained in defining the nature of water access and vulnerability to climate change impacts as determined for Letsemeng LM settlements and wards.

11.3.3 Msunduzi

The pilot study indicated that Msunduzi Local Municipality is an urbanised area with a well-established water services infrastructure. Access to water services both at present and in the future, however, is defined by the inequalities of past water provision systems where large areas of Msunduzi Local Municipality, Imbali and Edendale still have poor water provision infrastructure. The majority of Msunduzi's population reside in Edendale and Imbali, which are historically poorer townships where black communities have resided since the mid-nineteenth century. The pilot study further showed that while Msunduzi's water access indicators were on average better than in Madibeng and Thulamela, wards in Pietermaritzburg with a majority of white and Indian inhabitants were much better off compared to township residents. These areas have a high adaptive capacity indicator and low sensitivity to exposure to climate change impacts. The graphical illustration in Annexure 3.3 shows the indices obtained in defining the nature of water access and vulnerability to climate change impacts as determined for Msunduzi LM settlements and wards.

The nature of water access for most community members in Msunduzi Local Municipality will be defined by the success of the municipal water infrastructure development programmes decided on by the Msunduzi Local Municipality and uMgeni Water. The settlement patterns and the concentration of people in this municipality mean that water access issues now and in the future are best addressed by institutions, especially the municipality, uMgeni Water and to some extent the Department of Water Affairs. The area has a small rural community in Wards 3 to 12 where access to water is a greater challenge compared to other areas. It was observed by researchers in these areas that there are currently no government-issued rainwater harvesting tanks.

11.3.4 Madibeng

Overall assessments using HCCAF showed that Madibeng Local Municipality suffered from the worst overall exposure and very high sensitivity to climate change impacts. Madibeng communities have few available resources to supplement water provision on their own or other land in order to develop gardens and improve their livelihoods, which in turn could generate more resources for building personal water provision infrastructure. In the pilot study, the HCCAF tool showed that areas in Madibeng had the poorest scores in the following water access and adaptation indicators (Table 22):

Table 22: Worst performing indicators in Madibeng

• Water quality; • ability to diversify household income; • institutional ability to bill and collect rates for water provision; • nature of water provision infrastructure; and • institutional capacity to provide water services.

All the areas utilised in the pilot study for Madibeng demonstrated that the water access issues of this municipality make all communities vulnerable, with a great need for external support from relevant institutions. The graphical illustration in Annexure 3.4 shows the indices obtained in defining the nature of water access and vulnerability to climate change impacts as determined for Madibeng LM settlements and wards.

Townships situated in the Madibeng Local Municipality demonstrated the highest prevalence of illegal water connections. These illegal connections have negative financial implications in that they reduce the resources available to the local municipality for providing water. Illegal connections also reduce the water pressure in the system to such an extent in some areas that other legally connected consumers fail to receive water. This in turn causes much tension and unrest within affected communities. The local municipality also experiences immense difficulty in revenue collection and accounting for water supplied to illegally connected consumers. Associated problems as a result of non-payment of water supply are illustrated in Table 16 of section 8.5.2 where leakages and unauthorised connections contribute up to 28.6% of non-revenue water.

In the HCCAF, of the indicators for Madibeng's financial capacity and its ability to bill and collect revenue for water use, numbers 21, 30 and 31 generally perform poorly. The capacity of the municipality to provide support in water access at present and adaptation needs as time progresses relies on the resources and capacity of the institutions involved.

The increasing temperature due to climate change is one indicator that is expected to cause more devastation to Madibeng's water system, especially surface water flows, than in the other pilot case study areas. This is the result of highly polluted water bodies and river water, and continued ground water pollution, all of which tend to be exacerbated by an increase in temperature.

The pilot study further revealed that the nature of settlements is also a constraint to water access and possible adaptation options in the Madibeng Local Municipality. The communities are concentrated in urban and semi-urban areas without adequate services. Unlike Thulamela, the developments in the Madibeng area are concentrated in the mining areas, in Brits and around the Hartbeespoort Dam, with the rest of the municipality showing little sign of changes in water provision infrastructure. The poor performing indicators on the state of water infrastructure and the ability of the institutions to provide solutions will require attention if water access in the future is to be sustainably improved. While present water infrastructure is a constraint to water access, there are plans to supply water to most areas in Madibeng by connecting to Rand Water's infrastructure. It is envisaged that this programme will drastically improve bulk water provision to Madibeng in the long term.

12 Findings and conclusions

12.1 Livelihoods and water access dynamics

12.1.1 Livelihoods

Local and district municipalities are the main institutions responsible for water provision to the majority of the country's population. This study confirmed that more than 90% of the population in the case study areas depend on municipalities for water access. It was also observed that if the municipality is not providing water to a community, the chances are good that the affected community has a severely compromised state of water access. Water users adequately supplied with water from institutions other than municipalities constitute less than a few thousand in each of the municipalities studied. This observation led to the modelling of the climate change adaptation framework around municipal water provision.

In contrast to the findings of most literature records, the majority of households in the case study areas do not depend on agriculture for their livelihoods. The perception that rural communities practise agriculture for a livelihood is based on widely available literature from international studies originating from many other developing countries which do not share the same history as South Africa. These studies generally highlight the perception that '*if a poor African is in a rural area then he or she is a subsistence farmer who relies on agriculture for a livelihood*'. Information from the four study areas investigated, however, reveal that communities in rural areas have little to depend on, with a large percentage relying on grants, ad-hoc jobs – usually hard to come by – in nearby towns and farms, informal trading on roadsides and financial support from family members employed in distant urban areas. It was also observed that while a few rural communities could be practising some form of agriculture through gardening or other land-based practices, they cannot be classified as being dependent on agriculture for their livelihood since agricultural activities hardly constitute 20% of their income in most cases. Rural communities in all the municipalities investigated are concentrated in densely populated rural settlements where there is little additional land for cultivation or for carrying out other forms of subsistence farming.

By the very nature of community livelihoods, it is clear that the tale of pervasive and persistent poverty is associated with the map of community vulnerabilities in water access. With more than 48% of South African households living below the poverty line [considered here to be R342 per household per adult equivalent per month (Jacobs et al*.* 2009)], there is no earthly way that communities in such a state of poverty could afford adequate water services at present or indeed in the future. This is particularly the case when one considers the pace of service delivery and increased water demands, as well as escalations in lost water due to pollution and also loses due to evaporation, among other impacts of climate change. The assessment of poverty in municipalities (Bhorat and van der Westhuizen, 2010) has the same trend as the general water access vulnerability status obtained in this study. In similar vein, areas with poor communities, especially rural areas, displayed the highest sensitivities, with very little potential for adaptation. This situation was aggravated by the fact that municipal water services in poorer communities are either of a very low standard or not available at all.

12.1.2 Dynamic state of water access

Communities in urban or semi-urban areas tend to have the capacity to highlight their needs when faced with evidently deteriorating water service provision. During the study period the town of

Petrusburg, which was included in the study, experienced widespread water service-related rioting which continued for several weeks, resulting in scenes of violence and the closure of a national highway (N12). This was a typical case where communities could clearly perceive the deterioration in their water services. It was also observed that there are some areas, especially in Madibeng and Thulamela, where communities do not have any water services at all, and as a result their situation in respect of water access is far worse than Petrusburg communities.

Indeed, in some of these areas community members have never enjoyed any municipal water provision. These areas are generally inhabited by rural community members not known to resort to violent demonstrations for provision of services. While there is much speculation as to why they do not show their anger at the complete lack of service delivery, one line of thought is that they have never experienced any better service provision to use as a benchmark for their needs. The discussion on climate change and adaptation in these communities tends to be less important in their lives as they are currently faced with the major challenges of poor access to water before even considering any effect that climate change may have.

Deterioration of water services in Petrusburg took place during the study period. Responses to questionnaires during an earlier visit to the town did not reveal the problematic water access challenges the community was facing, since this was during a period when boreholes used in the area were generating good yields. In the second visit during summer, the area was already experiencing chronic water shortages, with some suburbs having gone for at least two weeks without water services. This sort of situation demonstrates that the analysis and mapping of water access and vulnerability should not be a one-off exercise, but should rather be regularly implemented to capture the dynamic nature of the problem. As such, the adaptation framework was developed in such a way that input data and parameters for determining adaptation options can be changed regularly to capture minor and major changes.

12.2 Analysis of HCCAF findings

The CISRO CCAM dataset used in the study showed temperature increases of around 2°C and rainfall increases of up to 17% when modelled climate data for the period 1961 to 1990 were compared with projected climate data for the period 2071 to 2100. While the general rainfall increases are not commonly discussed in past research, such as the results captured in the IPCC (2007) report, similar findings which show even higher rainfall increases of up to 36% were predicated in the dataset used in the recently completed DWA project on the climate change Status Quo Analysis report.

The HCCAF development generated a modular tool that is capable of handling dynamic and varied inputs describing water access, exposure to climate change impacts, sensitivity to exposure, adaptive capacity and community vulnerability, while allowing the user to capture adaptation initiatives suitable for each community under investigation. Through the HCCAF, the various indicators and indices generated in defining the state of water access and vulnerability are mapped and analysed using an open source GIS platform for easy analysis, comparison and presentation.

In the pilot study scenario analysis of various indices for different communities per ward were aggregated from ward values to municipal values. The results of the aggregation are shown in Table 23 below. The table shows the overall findings for the scenario that was used in the pilot study scenario.

Table 23: Overall results of pilot study assessments in case study areas.

Vulenerability	Max	Min	Range	Median	Average	Rank
Thulamela	4.363	1.107	3.257	3.227	3.132	4
Letsemeng	1.305	-0.191	1.495	0.813	0.748	1
Madibeng	4.566	1.060	3.506	2.297	2.407	3
Msunduzi	3.602	-2.812	6.414	1.248	0.780	2

Sensitivity	Max	Min	Range	Median	Average	Rank
Thulamela	2.639	0.821	1.818	1.885	1.885	4
Letsemeng	1.908	1.112	0.797	1.705	1.622	2
Madibeng	2.317	1.125	1.192	1.812	1.791	3
Msunduzi	2.461	0.313	2.148	1.531	1.388	1

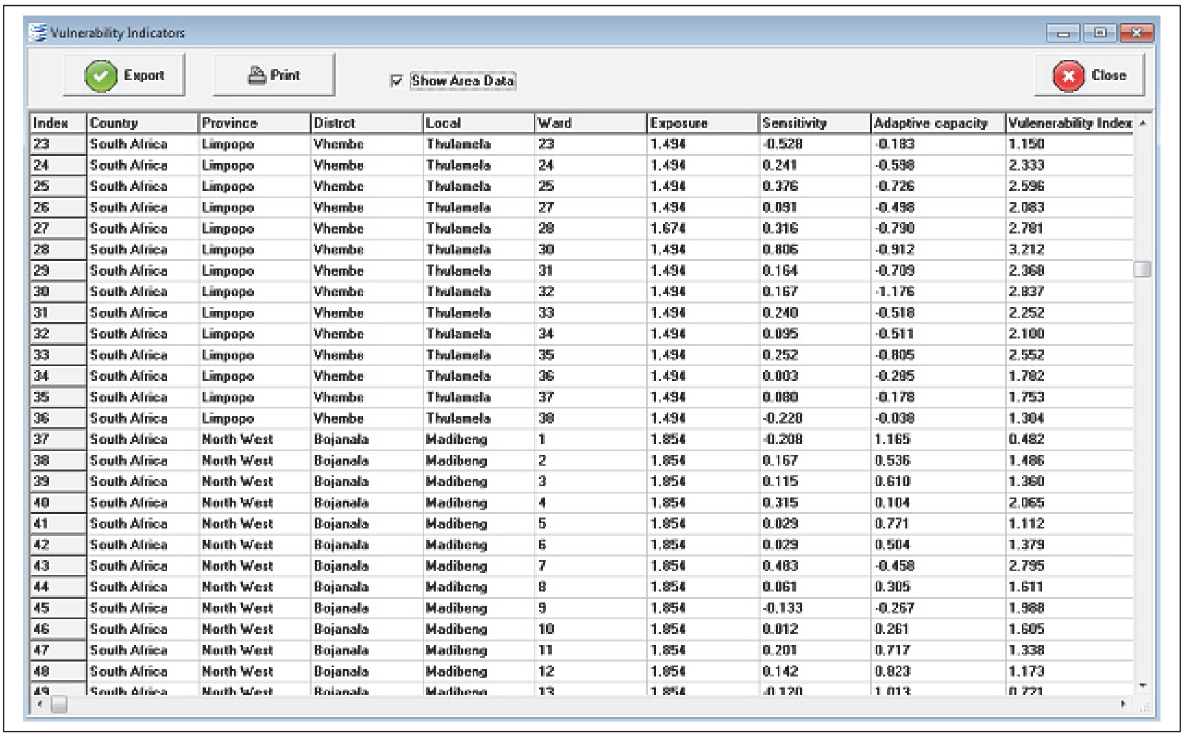
Exposure	Max	Min	Range	Median	Average	Rank
Thulamela	2.597	1.095	1.501	1.846	1.912	3
Letsemeng	0.968	0.968	0.000	0.968	0.968	1
Madibeng	2.597	2.597	0.000	2.597	2.597	4
Msunduzi	1.140	1.140	0.000	1.140	1.140	2

Adaptive Ca	Max	Min	Range	Median	Average	Rank
Thulamela	1.935	0.000	1.935	0.610	0.665	1
Letsemeng	2.327	1.251	1.076	1.881	1.842	3
Madibeng	2.790	0.348	2.442	2.125	1.981	4
Msunduzi	4.323	0.000	4.323	1.302	1.749	2

In the tabulated findings presented in Table 23, Letsemeng was the best performing on the overall vulnerability of local communities to impacts of climate change on water access and use. This overall assessment is for communities in both urban and rural settings, with an emphasis on datasets for water access at household level. Data from commercial agricultural farmers were not used in the pilot study to ensure that the outputs would be capable of comparison, as they will represent communities of a similar nature. Communities in Msunduzi had the least sensitivity and also performed fairly well in both Exposure and Adaptive Capacity, while Thulamela recorded the worst performance for most of the indicators. In the analysis, Thulamela came out as an area where communities were exposed to the worst levels of climate change vulnerabilities and the poorest levels of water access. The high levels of adaptive capacity obtained for Madibeng reflect improved future bulk water provision, especially as more areas in this municipality are connected to the Rand Water system. The area is still compromised by poor reticulation infrastructure, however, and the poor performance of a key institution, the local municipality.

In addition to the overall assessment, the HCCAF also provided graphical representation of levels of indicator performance for each settlement and ward. The graphs in Annexure 3 show the performance of all the pilot study areas for the various indicators used in defining water access, sensitivity, potential to adapt and vulnerability.

The tabulated results for the different indicators are also available by exporting from the HCCAF. A typical output which shows the individual Exposure, Sensitivity and Adaptive Capacity indicators, that is E_t, S_t and A_t in Equation 10, for the pilot study assessments, are shown in Figure 54 below.



Index	Country	Province	District	Local	Ward	Exposure	Sensitivity	Adaptive capacity	Vulenerability Index
23	South Africa	Limpopo	Vhembe	Thulamela	23	1.494	-0.528	-0.183	1.150
24	South Africa	Limpopo	Vhembe	Thulamela	24	1.494	0.241	-0.598	2.333
25	South Africa	Limpopo	Vhembe	Thulamela	25	1.494	0.376	-0.726	2.596
26	South Africa	Limpopo	Vhembe	Thulamela	27	1.494	0.091	-0.498	2.083
27	South Africa	Limpopo	Vhembe	Thulamela	28	1.674	0.316	-0.790	2.781
28	South Africa	Limpopo	Vhembe	Thulamela	30	1.494	0.806	-0.912	3.212
29	South Africa	Limpopo	Vhembe	Thulamela	31	1.494	0.164	-0.709	2.368
30	South Africa	Limpopo	Vhembe	Thulamela	32	1.494	0.167	-1.176	2.837
31	South Africa	Limpopo	Vhembe	Thulamela	33	1.494	0.240	-0.518	2.252
32	South Africa	Limpopo	Vhembe	Thulamela	34	1.494	0.095	-0.511	2.100
33	South Africa	Limpopo	Vhembe	Thulamela	35	1.494	0.252	-0.805	2.552
34	South Africa	Limpopo	Vhembe	Thulamela	36	1.494	0.003	-0.285	1.782
35	South Africa	Limpopo	Vhembe	Thulamela	37	1.494	0.080	-0.178	1.753
36	South Africa	Limpopo	Vhembe	Thulamela	38	1.494	-0.220	-0.038	1.304
37	South Africa	North West	Bojanala	Madibeng	1	1.854	-0.208	1.165	0.482
38	South Africa	North West	Bojanala	Madibeng	2	1.854	0.167	0.536	1.486
39	South Africa	North West	Bojanala	Madibeng	3	1.854	0.115	0.610	1.360
40	South Africa	North West	Bojanala	Madibeng	4	1.854	0.315	0.104	2.065
41	South Africa	North West	Bojanala	Madibeng	5	1.854	0.029	0.771	1.112
42	South Africa	North West	Bojanala	Madibeng	6	1.854	0.029	0.504	1.379
43	South Africa	North West	Bojanala	Madibeng	7	1.854	0.483	-0.458	2.795
44	South Africa	North West	Bojanala	Madibeng	8	1.854	0.061	0.305	1.611
45	South Africa	North West	Bojanala	Madibeng	9	1.854	-0.133	-0.267	1.988
46	South Africa	North West	Bojanala	Madibeng	10	1.854	0.012	0.261	1.605
47	South Africa	North West	Bojanala	Madibeng	11	1.854	0.201	0.717	1.338
48	South Africa	North West	Bojanala	Madibeng	12	1.854	0.142	0.823	1.173
49	South Africa	North West	Bojanala	Madibeng	13	1.854	-0.120	1.013	0.721

Figure 54: Extract of quantified and tabulated output indicator values for all case study areas as obtained in the HCCAF for Scenario 1

12.3 Adaptation options

The adaptation options for each settlement and ward were documented based on information from each area. In addition to defining the state of water access and identifying the adaptation option for each area, researchers also took photographic records of locations, settlements, households, water use features and other water access clues in the settlements and wards they visited. The adaptation options and images for the areas were also entered into the HCCAF against the relevant locations. With the HCCAF tool, the user can then decide on the level of performance of each area. This could be the municipality, as is the case in this instance, and the assigned adaptation options which suit the area. The listing of information on adaptation options, water access descriptions and the images taken at the locations in the wards are included as part of the HCCAF programme which accompanies this report. This information on the nature of water access and adaptation is accessed through the HCCAF window illustrated in Figures 43 and 52 of this report.

12.4 Conclusions

12.4.1 Study approach

A bottom-up approach was emphasised in this study, meaning that communities provided the initial inputs used to characterise the nature of water access issues both at present and in the future. Further data were collated from institutions and other stakeholders who usually provide a top-down approach. Investigations at the local level, starting with households, showed up a general lack of institutions which could play various roles to support water access, whereas many previous reports tended to suggest that such institutions were already actively playing various roles in supporting programmes to extend water access in local communities. While the municipality was considered in this study as the main institution that will support community adaptation responses, there are in fact a few other institutions which have some scope in water access and use by communities. The roles of these other institutions in water access are best captured as part of the variables used in the HCCAF indicators which define water access. Furthermore, this data may be captured directly in instances where they provide support for adaptation initiatives.

The conceptualisation and functions of HCCAF were based on the premise that adaptation in water access is built on the current state of water service provisions. The adaptation framework is designed to be a tool that presents an opportunity to interrogate how adaptation can be part of water service development planning by the institutions as they work with the communities in addressing present and future water access and use challenges.

The climate change adaptation framework (HCCAF) was developed to be the link between those communities exposed to climate change impacts and the local institutions that help them to adapt.

12.4.2 Application and use of HCCAF

The Climate Change Adaptation Framework presents a method whereby all study areas can be compared based on various water access issues, while at the same time enabling interested parties to see how each area performs on each water access indicator (Figure 55). The HCCAF showed that water access variables were at their worst in rural areas where communities have poor access and usually seek to satisfy the most basic of uses and needs. With such a finding, the user of the HCCAF can select possible adaptation options from those provided for these rural areas, and develop the relevant adaptation actions as part of the institutional role of improving water access in affected areas. In this case, the HCCAF will function as a decision-making tool supporting water access development planning, and will incorporate a method of including adaptation options.

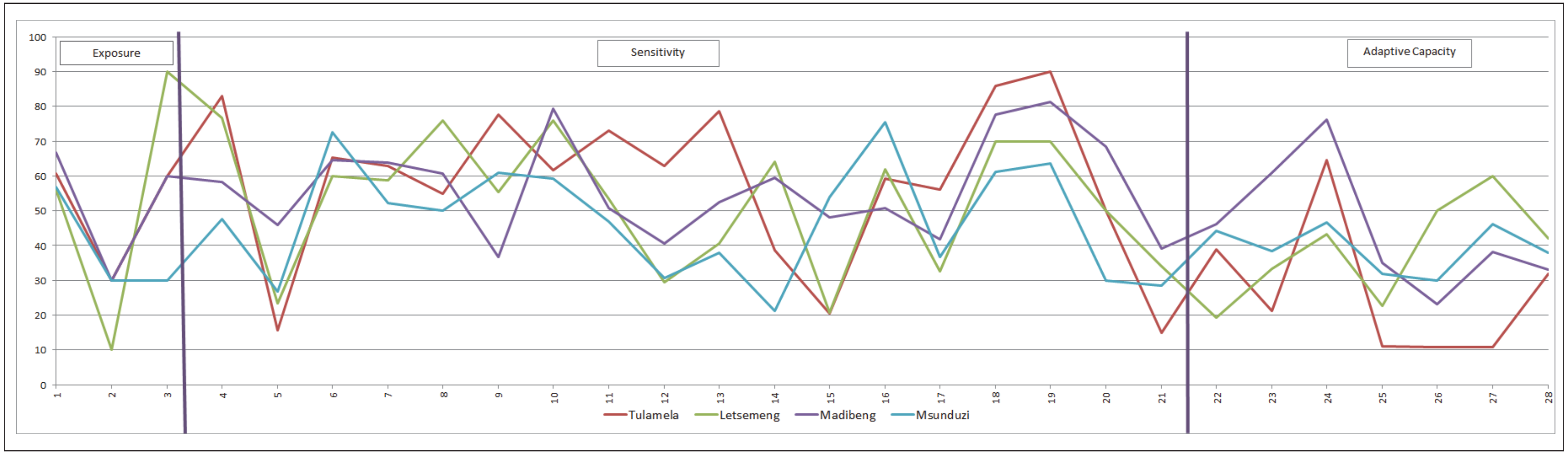


Figure 55: Performance of study areas on various water access variables used in the HCCAF

12.4.3 Urban and rural water access and adaptation

HCCAF findings for the pilot study scenario showed that communities in rural areas usually suffer from a poorer state of water access than their counterparts in urban areas. The investigations in the local settlements also showed that communities in rural areas were most likely to have no contact with any supporting institutions for water access at present or in the future. Thulamela Local Municipality, where the majority of community members are in rural areas, has the worst levels of water access at present and there is little prospect of everyone receiving the minimum levels of water access as stipulated by national water legislation. Multi-faceted issues restrict water access and the potential to adapt in rural communities, as shown by the overall poor performance of rural community settlements for most indicators used in the HCCAF. The HCCAF, however, presents the issues in these rural communities in a way that allows a user to compare the water access and adaptation performance within one set of outputs for all areas, irrespective of whether they are urban or rural.

12.4.4 Comparison of HCCAF findings with census 2011 data

In the Climate Change Adaptation Framework, the findings on water access vulnerability and adaptation needs showed that the measure of performance was at its worst in the Thulamela Local Municipality, while the Letsemeng Local Municipality produced the best performance. The values obtained for water access vulnerability from the HCCAF are depicted in Table 24 below. The findings clearly demonstrate that the areas currently observed to have the greatest need for institutional support to access water are the same areas with the lowest levels of economic development and the highest levels of unemployment (Table 25). With the HCCAF, the institutions which support communities will have more information regarding the actual communities, their locations and how each community performs against the various indicators used to define water access. The water institutions can then develop targeted solutions for each specific case. This observation also makes it clear that strengthening the role of institutions in supporting communities to adapt to climate change impacts may involve a whole range of initiatives, especially that of bringing economic development to these communities. This development is not necessarily the development of water infrastructure but includes any programmes which generate employment and improve community livelihoods.

Table 24: Summary of HCCAF findings

Study Area	Thulamela	Msunduzi	Madibeng	Letsemeng
Water access vulnerability	3.132	0.78	2.407	0.748
Performance ranking	4	2	3	1

Table 25: Study area service delivery statistics (Stats SA, 2011)

Study Area	Thulamela	Msunduzi	Madibeng	Letsemeng
Unemployment rate	43.8%	33.0%	30.4%	22.3%
Piped water inside dwelling	15.2%	47.91%	22.2%	49.8%
District municipality	Vhembe	uMgungundlovu	Bojanala	Xhariep
Percentage of population receiving below RDP level of service	60%	9%	44%	9%

The investigations at community level also revealed that generally very poor communities are also poor in the amount of water they access, how they access the water and their ability to use the water to satisfy other needs, apart from the most basic needs. For example, the many communities in RDP houses and informal dwellings do not even have house fittings to bring water to a shower, a sink or a bath tub. They tend to collect water in a bucket from a distant location and use this water to satisfy water needs for the whole day. As such, they demonstrate very basic water needs and, even if there was more water, they would still have only a limited capacity to access it. It is therefore important that in-house plumbing is included in the development of RDP housing units. In this way, communities can access adequate water to meet basic and other needs, including regular bathing.

12.4.5 Institutional capacity in community adaptation

The investigations revealed that the institutions serving local communities in urban and rural areas have no comprehensive plans to take these communities to a level of comfortable water service provision. Instead, they target the very minimum RDP level of water service delivery. The study areas with the least prospects for sustainable water services delivery also come across as the municipalities with the lowest level of service delivery. In Vhembe and Bojanala, the level of service delivery at present is very poor, and the local municipalities find it difficult to look at climate change and adaptation when they are already struggling with current water service requirements. The use of a HCCAF framework will ensure that the municipality will have fewer challenges in incorporating adaptation at the water development planning stages.

12.4.6 The way forward

This study focused on developing a method that will be utilised in the delivery of institutional support for community adaptation of water access and use. It is envisaged that this tool will be applied nationally to provide the basis for national, regional and municipal development in improving water access, and also in developing whatever is required for communities to adapt to the changing climate. The use of the framework is expected to be overseen by a wide range of institutions, including various local water institutions as well as higher level institutions such as the Department of Water Affairs, Department of Cooperative Government and Traditional Affairs, Water Boards, CMAs and the Development Bank of South Africa. The higher level institutions can use the tool to decide on the areas to target for water access development as well as which adaptation options to include in the development of water infrastructure and other water service provision initiatives. It is envisaged that the project team will take the project to the next stage by inviting partnerships with the institutions targeted in the use and application of the framework.

The state of water access and the vulnerability of communities to climate change impacts are dynamic, changing over time, and these changes may affect members of the same community differently due to their own specific circumstances. The HCCAF captured several variables in a way that allows the user to develop new scenarios and account for changes, while taking advantage of better data for one or all areas under consideration. As such, it is envisaged that the framework can be used regularly to capture and develop understanding of water access, water use, exposure to climate change, sensitivity to impacts, adaptive capacity and vulnerability in respect of water access, as well as climate change adaptation options. Municipalities are expected to take advantage of the freely available HCCAF to build scenarios for their own settlements and wards.

In the early stages of the development of the adaptation framework it became evident that water access and adaptation issues for domestic water users and water use in agriculture and other sectors are driven by largely different variables. These variables, as well as how they should be interpreted, are better represented in separate frameworks. Water management and planning in the agriculture sector could be improved if the approach developed in such a study is developed specifically for water access and adaptation in that sector. Plans for further development, with the focus on agriculture, have been presented for consideration by the Department of Agriculture.

Bibliography

ADB. (2007). Climate change ADB programs: Strengthening mitigation and adaptation in Asia and the Pacific. Asian Development Bank. Philippines.

Adger, W. N., Huq, S., Brown, K., Conway, D. and Hulme, M. (2003). Adaptation to Climate Change in the Developing World, *Progress in Development Studies*, 3(3), pp.179-195.

Adger, W. N., Lorenzoni, I. and O'Brien, K. L. (2009). Adapting to climate change: Thresholds, values, governance. Cambridge: Cambridge University Press.

Agrawal, A. (2010). Local institutions and adaptation to climate change. In R. Mearns and A. Norton (eds) Social dimensions of climate change: Equity and vulnerability in a warming world. The World Bank, Washington DC.

Agrawal, A., McSweeney, C. and Perrin, N. (2008). Local institutions and climate change adaptation. In Social Development Notes. No. 113. July 2008. The Social Dimensions of Climate Change. The World Bank, Washington DC.

AMCEN. (2009). Report of the Ministerial segment of the special session on climate change of the African Ministerial Conference on the environment; AMCEN/SS/III/6. Accessed on the internet on 31 August 2012 at www.unep.org/roa/Amcen

Anderson, G., Traish, F., Tharakan, P., Tarrant, J. and Telingator, P. (2007). Adapting to climate variability and change: a guidance manual for development planning, USAID/EGAT Project Report No. EPP-1-00-03-00013-00, USA.

Arnell, N. (1996). Global warming, river flows and water resources. Wallingford, England.

Arnell, N. W. and Charlton, M. B. (2009). Adapting to the effects of climate change on water supply reliability. In W. N. Adger, I. Lorenzoni and K. L. O'Brien (2009) Adapting to climate change: Thresholds, values, governance. Cambridge: Cambridge University Press.

Ashley, C. and Jones, B. (2001). Joint ventures between communities and tourism investors: experience in Southern Africa, *International Journal of Tourism Research*, vol. 3, no. 5, pp. 407-423, 2001

Aurecon. (2009). Water Services Development Plan for Vhembe District Municipality. Aurecon Pty Ltd, Polokwane, South Africa.

Bartholomew R. (2012). Consultations with the Head of the Msunduzi environmental section: Rodney Bartholomew (June, 2012). Msunduzi Local Municipality. Pietermaritzburg.

Baskilevsky, A. (1983). Applied matrix algebra in the statistical sciences. New York: Elsevier.

Beldring, S., Engen-Skaugen, T., and Forland, E. J. (2008). Climate change impacts on hydrological processes in Norway based on two methods for transferring regional climate model results to meteorological station sites. Tellus 603A, 439-450

Benston, M. and Stephenson, D. B. (2004). Extreme climate events and their evolution under changing climatic conditions, Global and Planetary Change, vol. Pages 1-9, Science Direct.

Berkes, F., Colding, J. and Folke, C. (2000). Rediscovering of traditional ecological knowledge as adaptive management, Ecological Applications, Vol. 10, Issue 5, page 1251-1262, Ecological Society of America.

Bertrand, C., Van Ypersele, J. P. and Berger, A. (1999). Volcanic and solar impacts on climate since 1700. *Climate Dynamics*. 15 pp.355-367.

Bhorat, H. and van der Westhuizen, C. (2010). Estimating a Poverty Line: An Application to Free Basic Municipal Services in South Africa, Report for South African Local Government Association, Pretoria.

Blanco, A. V. R. (2006). Local initiatives and adaptation to climate change, Disasters, vol. 30, issue 1, page 140-147, Blackwell Publishing.

Bojanala. (2010). Integrated Development Plan Review. Rustenburg, South Africa.

Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., Osman-Elasha, B., Tabo, R. and Yanda, P. (2007). Africa Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge UK, 433-467.

Bolton, S. and Talman, A. (2010). Interactions between HIV/AIDS and the Environment: A Review of the Evidence and Recommendations for Next Steps. Nairobi, Kenya: IUCN ESARO Office. viii + 62pp.

Brauner, C. (2002). Opportunities and risks of climate change, Order Number 1491585_02 en Swiss Reinsurance Company Report, Zurich, Switzerland

Brown, C. and Magoba, R. (2009). Rivers and Wetlands of Cape Town. Report no TT 376/08, Water Research Commission, Pretoria, South Africa.

Burley, H. and Haslam, C. (2008). How can I stop climate change? Collins/Friends of the earth. United Kingdom.

Cai, W., Sullivan, A. and Cowan, T. (2009). Methods of assessing the performance of IPCC-AR4 models in simulating Australian rainfall teleconnections with Indo-Pacific climate drivers. Paper presented at the *18th World IMACS / MODSIM Congress*, 13-17 July 2009. Cairns: Australia.

Chinese Hydraulic Engineering Society. (1991). A Concise History of Irrigation in China (on occasion of the 42nd International Executive Council Meeting of ICID, Beijing), April, p. 29-30.

CSIR (2011). Data only: Projected climate-change signal in simulations by the Conformal-Cubic Atmospheric Model (CCAM) over southern Africa for periods 1961-1990 and 2071-2100. Climate Change Unit, Centre for Scientific and Industrial Research (CSIR). Pretoria

COGTA. (2011). Vhembe District Municipality Profile. Cooperative Governance and Traditional Affairs, August 2011, Thohoyandou, South Africa.

COGTA. 2009. State of Local Government in South Africa – Cooperative Governance and Traditional Affairs: Overview Report, Pretoria.

Connor, R., Gallopín, G., Hellmuth, M. and Rast, W. (2009). Climate Change and possible Futures, Chapter 5 of The United Nations World Water Development Report 3 of 2009, UN, United Kingdom

Cottrel Propst, S. (2012). Innovative approaches for adapting to water variability in the West. Georgetown Centre for Climate Change. Washington DC. Accessed on 18 March 2013 from http://www.georgetownclimate.org/sites/default/files/WaterVariability.

Crowley, T. J. (2000). Causes of climate change over the past 1 000 years, Science vol. 289, page 270-277, American Association of Advancement of Science.

Cullis, J., Görgens, A. and Lyons, S. (2007). Review of the selection of acceptable flood capacity for dams in South Africa in the context of dam safety. WRC Report No. 1420/1/07, Water Research Commission, Pretoria, South Africa.

DBSA. (2010). Project to enhance the socio-economic impact of infrastructure maintenance in South Africa Final report 7 May 2010. Accessed on internet on 12 November 2011 at www.dbsa.org/Research/Maintanance

De Villiers, G. T., Schmitz, P.M.U. and Booysen, H. J. (1996). South Africa's water resources and the Lesotho Highlands water scheme: A partial solution to the country's water problems in water resources development, *International Journal of Water Resources Development*, 12(1), 1996, pp. 65-77

De Wrachien, D. and Fasso, C. A. (2007). Conjunctive use of surface and groundwater. ICID: 22nd European Regional Conference – Keynote Lecture on Topic 3. Accessed from the internet on 15 July 2012 at http//air.unimi.it/bitstream/2434/29163/1/Wrachien.Corrected art.doc

Department of Environmental Affairs. (2004). A National Climate Change Response Strategy. Department of Environmental Affairs and Tourism. Pretoria. South Africa.

Department of Environmental Affairs. (2012). Initial national communication under the United Nations Framework Convention: South Africa. Accessed on the internet on 13 March 2012 at http://unfccc.int/files/meetings/seminar/application/pdf/sem_sup4_south_africa.pdf

Department of Environmental Affairs and Tourism. (2006). South Africa Environment Outlook. A report on the state of the environment. Department of Environmental Affairs and Tourism, Pretoria. 371pp.

Del Nino, C., Dorish, P. A., Smith, L. C. and Roy, D. K. (2001). The 1998 floods in Bangladesh: Disaster impacts, household coping strategies and response. International Food Policy Research Institute Research Rep. 122, 114 pp.

DeMenocal, P. B. (2003). African climate change and faunal evolution during the Pliocene_Pleistocene. *Earth and Planetary Science Letters*,2201-2:3-24pp

Denison, J. and Wotshela, L. (2009). Indigenous water harvesting and conservation practices: historical context, cases and implication. Report no. TT392/09. Water Research Commission, Pretoria, South Africa.

Dinar, A., Hassan, R., Mendelsohn, R. and Benhin, J. (2008). Climate Change and Agriculture in Africa, Earthscan, London.

Department of Provincial and Local Government. (2005). The Disaster Management Regulations: Disaster Management Act, 2002 (Act No. 57 of 2002). Department of Provincial and Local Government. Government Gazette of 9 September 2005. Pretoria, South Africa.

Department of Provincial and Local Government. (2009). National framework: guidelines for provinces and municipalities in the implementation of the ward funding model. Department of Provincial and Local Government. South Africa.

Department of Science and Technology. (2010). South African Risk and Vulnerability Atlas, Department of Science and Technology, South Africa.

Department of Science and Technology. (2012). SA Risk and Vulnerability Atlas: Electronic Spatial Database. Department of Science and Technology. South Africa. Accessed on the internet on 28 April 2012 at http://rava.qsens.net/themes/climate_template/projections-of-future-climate-change/ccam- dynamic-downscalings/

Douglas, I., Alam, K., Maghenda, M., Machonnell, Y., Mclean, L. and Campbell, J. (2008). Unjust wars: Climate change, flooding and the urban poor in Africa, Environment and Urbanization, Vol. 20, page 187-205, International Institute for Environment and Development.

Durand, J. F. (2007). Living in karst environments: Challenges associated with living in karst environments, such as the historical Cradle of Humankind. Department of Zoology, University of Johannesburg. Johannesburg, South Africa.

DWA. (2009a). Department of Water Affairs Annual Report- 2008/2009. Department of Water Affairs, Pretoria, South Africa.

DWA. (2009b). A Drinking Water Quality Framework for South Africa: Minimum Requirements for Blue Drop Qualification, Edition 4. May 2009. Department of Water Affairs, Pretoria, South Africa.

DWA. (2009c). Water reconciliation strategy study for KwaZulu-Natal coastal metropolitan areas, Executive Summary, Department of Water Affairs Report Number PWMA 11/000/00/1107, Department of Water Affairs, Pretoria, South Africa.

DWA. (2009d). Orange River: Assessment of water quality data, Department of Water Affairs – Water Resource Planning Systems Report No. 6 (P RSA D000/00/8009/3), Department of Water Affairs, Pretoria, South Africa.

DWA. (2009e). Design report for the Orange-Riet Balancing Dam S1. Department of Water Affairs: Strategic asset management, Department of Water Affairs, Pretoria, South Africa.

DWA. (2009f). Bojanala District Municipality: Madibeng Local Municipality: First order reconciliation strategy for the Sandspruit Rand Water Supply Scheme. Department of Water Affairs, Pretoria.

DWA. (2010a). Bojanala District Municipality: Madibeng Local Municipality: First order reconciliation strategy for the Dikgophaneng and Fafung supply schemes. Department of Water Affairs, South Africa. Accessed on the internet on 17 Feb 2012 at:http://www6.dwa.gov.za/iwrp/dss/DashboardEngine.aspx?DashboardID=IWRP\Map_Search

DWA. (2010b). Blue drop report. South African drinking water quality management performance. Department of Water Affairs, South Africa. Accessed on the internet on 28 Feb 2012at: www.dwaf.gov.za/documents/blue drop.pdf.

DWA. (2010c). Development of a reconciliation strategy for all towns in the northern region Bojanala district municipality Madibeng local municipality: first order reconciliation strategy for the Hartbeespoort Dam supply area. Prepared by SRK Consulting. Department Of Water Affairs.

DWA. (2011a). Limpopo Region Directorate Water Regulation and Use Status Report on Groundwater Levels, Department of Water Affairs, Pretoria, South Africa.

DWA. (2011b). Implementation and maintenance of the reconciliation strategy of the Crocodile West water supply system. Presentation by Tendani Nditwani, Chief Water Resource Planner, to the Hartbeespoort Dam HIF/TUT Working Group. Department of Water Affairs. 20 Sept 2011, Pretoria, South Africa.

DWA. (2011c). Water quality management: surface water quality status in Crocodile (West) catchment. Department of Water Affairs presentation to the Hartbeespoort Dam HIF/TUT Working Group. 20 Sept 2011, Pretoria.

DWA. (2011d). Water services information systems – Systems. Department of Water Affairs. Pretoria, South Africa. Accessed on 21 April 2011 on site http://www.dwa.gov.za/dir_ws/

DWA. (2011e). Blue Drop Report for the year 2011, Department of Water Affairs, Pretoria, South Africa.

DWA. (2011f). Weekly State of Reservoirs on 15 October 2011. Hydrology Directorate. Department of Water Affairs, Pretoria. Accessed on 20 October 2011 at the website http://www.dwa.gov.za/Hydrology/Weekly/Weekly.pdf

DWA. (2012). Blue drop provincial performance log: Free State. Available online http://www.dwaf.gov.za/Documents/BD2012/FS.pdf

DWA. (2013a). Department of Water Affairs Annual Performance Plan (APP) and budget 2013/14 to 2015/16. Department of Water Affairs. Pretoria. South Africa.

DWA. (2013b). Status quo analysis: Climate change impacts on water resources. Climate Change Directorate. DWA report Number P RSA 000/00/17912/4. Department of Water Affairs. Pretoria, South Africa.

DWAF. (1999). Orange River development project: replanning study. BKS (Pty) Ltd and Ninham Shand (Pty) Ltd in co-operation with the Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF. (2001). The Luvhuvhu River catchment: state of the rivers report, Letaba and Luvuvhu River systems. Department of Water Affairs and Forestry. Accessed on the internet on 10 March 2011 at: http://www.dwaf.gov.za/iwqs/rhp/state_of_rivers/state_of_letluv_01/luvuvhu.html.

DWAF. (2002). National Water Resources Strategy (NWRS), Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF. (2004a). Policy on financial assistance to resource poor irrigation farmers – in terms of Sections 61 and 62 of the National Water Act of 19198, Section 2.4.6. Rain-water tanks for household productive uses by the poor, Department of Water Affairs and Forestry. Pretoria, South Africa.

DWAF. (2004b). Internal strategic perspective: Luvuvhu/Letaba water management area. Department of Water Affairs and Forestry. DWA Report No. PWMA 02/000/00/0304. Pretoria

DWAF. (2004c). Internal strategy perspective: upper Orange Water Management Area. Department of Water Affairs and Forestry. Report No. P WMA 13/000/00/0304, Pretoria.

DWAF. (2004d). Internal strategic perspective: Limpopo Water Management Area. DWAF Report Number PWMA 01/000/00/0304. November 2004. Department of Water Affairs and Forestry, South Africa.

DWAF. (2006). Portfolio committee on water affairs and forestry oversight visit to the Limpopo and North West provinces. Report of the Portfolio Committee on Water Affairs and Forestry. 15 November 2006, Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF. (2008a). Policy on financial support of the water user associations. Draft 2.0 For Final Approval. Department of Water Affairs and Forestry, Unpublished.

DWAF. (2008b). The Development of a reconciliation strategy for the Crocodile (West) Water supply: Summary of previous and current studies. Department of Water Affairs. Report Number P WMA 03/000/00/3408, Pretoria, South Africa.

Eales, K. (2010). Equity and efficiency in water services: – The climate change dimension. Paper presented to the Water Institute of Southern Africa, April 2010.

EDRC. (2003). Sustainable development and climate change in South Africa: Two case studies for the development and climate change project, Energy and Development Research Centre, University of Cape Town, South Africa.

Ellis, F. (2000). Rural livelihoods and diversity in developing countries. Oxford University Press. Oxford. United Kingdom

Embarcadero. (2012). Deliphi: Multi-device, true native app development for iOS and Windows. Embarcadero Delphi. Accessed on internet on 17 February 2012 at http://www.embarcadero.com/

Ensor, J. and Berger, R. (2009). Understanding climate change adaptation: lessons from community-based approaches. Practical Action Publishing. Warwickshire, UK.

Eriksen, S. (2005). The role of indigenous plants in household adaptation to climate change: the Kenyan experience. In P, S. Low. Climate change and Africa. Cambridge University Press.

Erikson, C. (2003). Agricultural landscapes as world heritage: raised field agriculture in Bolivia and Peru. In Managing change: Sustainable approaches to the conservation of the built environment. Edited by Jeanne-Marie Teutonico and Frank Matero, Getty Conservation Institute, Los Angeles, pp.181-204.

Eskom. (2010). Orange River Scheme – Gariep and Vanderkloof Power Stations, ESKOM: Generation Communication, Unpublished Report HY 0005. Johannesburg, South Africa.

Filmer, D. and Pritchett, L. H. (2001). Estimating wealth effects without expenditure data – or tears: An application to educational enrolments in States of India. Demography, 38 (1), pp. 15-131.

Finley, S. (2008). Reuse of domestic grey water for the irrigation of food crops. Thesis submitted to McGill University in partial fulfilment of the requirements of the Master of Science degree. Sara Finley.

Food and Trees for Africa. (2012). Partnering to make a difference. Accessed on the internet on 3 February 2012 on www.trees.co.za

Fowler, H. J., Blenkinsop, S. and Tebaldi, C. (2007). Linking climate change modelling to impacts studies: Recent advances in downscaling techniques for hydrological modelling. *International Journal of Climatology* 27:1547-1578.

Gagnon-Lebrun, F. and Agrawala, S. (2006). Progress on adaptation to climate change in developed countries: An analysis of broad trends, ENV/EPOC/GSP(2006)1/FINAL, OECD, Paris.

Gbetibouo, G. A. and Ringler, C. (2009). Mapping the South African farming sector's vulnerability to climate change vulnerability. IFPRI Discussion Paper No. 885 (Washington, DC: International Food Policy Research Institute).

Giorgi, F., Jones, C. and Asrar, G. (2009). Addressing climate information needs at the regional level: The CORDEX framework, WMO Bulletin 58 (3) – July 2009, France Accessed on 09 November 2010, http://wcrp.ipsl.jussieu.fr/RCD_Projects/CORDEX/CORDEX_giorgi_WMO.pdf

Goldman, I. and Reynolds, K. (2008). Rural local governance. In Van Donk, M., Swilling, M., Pieterse, E. and Parnell, S. (eds) Consolidating developmental local government. Lessons from the South African experience. UCT press.

Gould, E. A., Higgs, S. (2009). Impact of Climate Change and other factors on emerging arbovirus diseases, Transactions of the Royal Society of Tropical Medicine and Hygiene vol 103 pages 109-121, Elsevier.

Green, G. C. (2008). Towards defining the WRC research portfolio on climate change for 2008-2013. WRC Report No. KV 207/08.

GTZ. (2007). Orange River integrated water resources management plan: Review of surface hydrology in the Orange River Catchment. German Development Cooperation /SADC Water Sector Cooperation, Gaborone, Botswana.

Hamblyn, R. (2009). The Whistleblower and the Canary: Rhetorical Constructions of Climate Change. *Journal of Historical Geography,* vol 35 (2009), pp. 223-36. Accessed on the Internet on 11 June 2011 at www.richardhamblyn.wordpress.com/other-writing/

Haramata. (2010). Haramata 55, March 2010. International Institute for Environment and Development (IIED). London: UK.

Herbertson, P. W. and Tate, E. L. (2001). Tools for water use and demand management in South Africa. World Meteorological Organization: Technical reports in hydrology and water resources no. 73. Secretariat of the World Meteorological Organization – Geneva – Switzerland.

Herrera-Pantoja, M. and Hiscock, K. M. (2008). The effects of climate change on potential groundwater recharge in Great Britain. Hydrological Processes 22: 73-86.

Hewitson, B. C. and Crane, R. G. (2006). Consensus between GCM climate change projections with empirical downscaling, in press in *International Journal of Climatology*.

Hewitt, G. (2000). "The genetic legacy of the Quaternary ice ages," *Nature* 405:907-913.

Houghton, J. (2005). Global warming, reports on progress in physics. Vol. 65, page 1343-1403, IOPSCIENCE, iopscience.iop.org.

Houston, G. F. and Somadoda, F. P. (1996). Constitutional development and the issue of traditional leadership in rural local government in South Africa. Paper presented at the International Conference on the new South African Constitution at the Holiday Inn, Umtata, South Africa 25-26 April, 1996.

Howard, G. and Bartram, J. (2003). Domestic water quantity, service level and health. New York: World Health Organization.

Hughes, D. (2012). Adapting to climate change – keep uncertainty in mind. The Water Wheel Nov/Dec 2012. Volume 11. No. 6

Iglesias, A., Garrote, L., Flores, F. and Moneo, M. (2007). Challenges to manage the risk of water scarcity and climate change in the Mediterranean, Water Resources, vol. 21, 775-788, Springer Science.

IPCC. (2001). Climate Change 2001: Impacts, adaptation vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Geneva: UNEP/WMO.

IPCC. (2007a). Climate Change 2007: The Physical Science basis, contributions of working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, IPPC Secretariat, Geneva.

IPCC. (2007b). Summary for Policymakers, In: Climate Change (2007): Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., IPCC. UNEP. WMO. Cambridge University Press, New York. USA.

IPCC. (2007c). http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-chapter3.pdf

IPCC. (2012a). Review of processes and procedures followed by the IPCC, United Nations / World Meteorological Organization (WMO). Geneva. Accessed on the internet on 13 February 2013 at http://www.ipcc.ch/organization/organization_review.shtml#.UYSdQMrS6Q4

IPCC. (2012b). Managing the risks of extreme events and disasters to advance climate change adaptation. Special report of the Intergovernmental Panel on Climate Change (IPCC). UNEP. WMO. Cambridge University Press, New York. USA.

IUCN. (2003). The Lesotho Highlands Water Project (LHWP): Environmental flow allocations in an international river. International Union for Conservation of Nature, Pretoria.

IWMI. (2008). A Global Irrigated Area Map (GIAM) Using Remote Sensing at the End of the Last Millennium, International Water Management Institute, Colombo, Sri Lanka. Accessed on the internet on 17 June 2011 at http://www.iwmigiam.org/info/gmi-doc/GIAM-world-book.pdf

Jacobs, E., Punt, C. and Botlhoko, C. (2009). A Profile of the North West Province: Demographics, Poverty, Income, Inequality and Unemployment from 2000 till 2007, Provincial Decision-Making Enabling (PROVIDE) Project, National Department of Agriculture. Accessed on the internet on 9 October 2011 at www.elsenburg.com/provide.

Jagwanth, S. (2003). Democracy, civil society and the South African Constitution: Some challenges. UNESCO/MOST-Management of Social Transformations, Discussion Paper 65, United Nations Educational, Scientific and Cultural Organization (UNESCO), Paris.

Jia-Lin, L. (2007). The Double-ITCZ Problem in IPCC AR4 Coupled GCMs: Ocean-Atmosphere Feedback Analysis, *Journal of Climate* Volume 20, pp. 4497-4525.

Joubert, A. M. and Mason, S. J. (1996). Droughts over Southern Africa in a doubled-CO2 climate, International Journal of Climatology, vol. 16, page 1149-1156, The Royal Meteorological Society.

Kahinda, J., Sejamoholo B.B. P., Taigbenu, A. E., Boroto, R.J., Lillie, E.S.B., Taute, M., and Cousins, T. (2008). Water Resources in Rainwater Harvesting: An Integrated Systems Approach. Report No. KV 1563-1-08, Water Research Commission, Pretoria. South Africa.

Kundzewicz, Z. W., Mata, L. J., Arnell, N. W., Döll, P., Kabat, P., Jiménez, B., Miller, K. A., Oki, T., Sen, Z and Shiklomanov, I. A. (2007). Freshwater resources and their management. Climate Change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., IPCC. UNEP. WMO. Cambridge University Press, Cambridge, UK, 173-210.

Lahiff, E. (1997). Land, water and local governance in South Africa. A case study of the Mutale River valley. Rural Resources Rural Livelihoods Working Paper Series. Paper No. 7

Larson, B., Minten, B. and Razafindralambo, R. (2006). “Unravelling the linkages between the millennium development goals for poverty, education, access to water and household water use in developing countries: Evidence from Madagascar”, *Journal of Development Studies*, 42(1), pp.22-40.

Lavell, A., Oppenheimer, M., Diop, C., Hess, J., Lempert, R., Li, J., Muir-Wood, R. and Myeong, S. (2012). Climate change: new dimensions in disaster risk, exposure, vulnerability, and resilience. In: Managing the risks of extreme events and disasters to advance climate change adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 25-64.

Lenart, M. (2008). Climate of the Southwest. Tucson, AZ, Southwest Climate Change Network, University of Arizona.

Letsemeng. (2011a). Letsemeng Integrated Development Plan (IDP) 2011/2012. Letsemeng, Koffiefontein, South Africa.

Letsemeng. (2011b). Municipal Water Safety Plans: Letsemeng, Koffiefontein, South Africa.

Letsemeng. (2012). Letsemeng Local Municipality Annual Report. Final Annual Report 2009/2010. Letsemeng Local Municipality. Koffiefontein.

Lin, E., Yang, X., Ma, S., Ju, H., Guo, L., Xiong, W., Li, Y. and Xu, Y. (2005). Case study 1: China benefiting from global warming: agricultural production in Northeast China. IDS Bulletin, Vol. 36 No. 4 October 2005.

Low, P.S. (Editor). (2005). Climate change and Africa. Cambridge University Press. Cambridge.

Lynch, S. (2003). Development of a Raster Database of Annual, Monthly and Daily Rainfall for Southern Africa. Water Research Commission, WRC Report No.1156/1/03, Pretoria, South Africa.

Lumsden, T., Schulze, G. and Hewitson, B. C. (2009). Evaluation of potential changes in hydrologically relevant statistics of rainfall in Southern Africa under conditions of climate change, *Water SA* Vol. 35 No. 5, ISSN 0378-4738.

Madibeng. (2011). Madibeng Water Services Development Plan. Madibeng Local Municipality, Brits.

Madibeng. (2010). Water Safety and Security Plan, Brits, South Africa.

Madibeng. (2006). Water Supply Network Rehabilitation and Master Plan Detailed Report, prepared by Utility Informatics/Hydro-comp Enterprises. Madibeng Local Municipality Department of Technical Services, Brits.

Magadza, C. H. D. (2000). Climate Change Impacts and Human Settlements in Africa: Prospects for Adaptation, Environmental Monitoring and Assessment, Vol 61: pages 193-205, Kluwer Academic Publishers, Netherlands.

Marschke, M. and Berkes, F. (2006). Exploring strategies that Build Livelihood Resilience: a Case from Ecology and Society, Vol. 11 no.1, Resilience Alliance.

Martin, R. and Dillion, P. (2002). Aquifer storage and recovery: Future directions for South Australia. Report DWLBC 2002/04. Department of Water, Land and Biodiversity Conservation, Australia.

Mason, S. J. (2001). El Niño, Climate Change, and Southern African Climate. *Environmetrics* 12: 327-345.

Matczak, P., Flachner, Z. and Werners, S. E. (2007). Institutions for adapting to climate change in the Tisza River basin. Earth system governance. Amsterdam.

McGregor, J. L. and Dix, M. R. (2001). The CSIRO Conformal-Cubic Atmospheric GCM. IU-TAM Symposium on Advances in Mathematical Modelling of Atmosphere and Ocean Dynamics, P. F. Hodnett, (Editor). Kluwer, 197-202

McLeman, R. (2011). Climate change, migration and critical international security considerations. IOM Migration Research Series No. 42. International Organisation for Migration (IOM). Geneva, Switzerland.

McMichael, A. J. (2004). "Environmental and social influences on emerging infectious diseases: past, present and future." Philos Trans R Soc Lond B Biol Sci 359(1447): 1049-58.

Mearns, R. and Norton, A. (Eds). 2010. Equity and vulnerability in a warming world: introduction and overview. In Social dimensions of climate change. The World Bank, Washington DC.

Mendelsohn, R. (2009). Development in the balance: Agriculture and water. In L, Brainard, A Jones and N Purvis (ed) Climate change and global poverty: a billion lives in the balance? Brookings Institution Press. Washington DC.

Mendelsohn, R., Morrison, W., Schlesinger, M and Adronova, N. (2000). Country specific market impacts from climate change. Climatic Change 45:553-569

Middleton, B. J. and Bailey, A.K. (2008). Water Resources of South Africa, 2005 Study (WR2005) Water Research Commission Research Report No.TT381/08, Pretoria. South Africa.

Msunduzi. (2006a). Msunduzi Municipality Integrated Development Plan (IDP) 2010/2011 and Beyond. Pietermaritzburg.

Msunduzi. (2006b). Msunduzi Spatial Development Framework, Msunduzi GIS Department, Msunduzi.

Msunduzi. (2012a). Annual Report 2010/2011. Accessed on the internet 12 August 2012 on www.msunduzi.gov.za/site/search/downloadencode/nra8rKWMqp2zp4Sx

Msunduzi. (2012b). The Msunduzi Municipality and its Municipal Entity Consolidated Annual Financial Statements for the year ended 30 June 2010. Msunduzi Municipality. South Africa.

Msunduzi. (2012c). Msunduzi Municipality Improved Service Delivery through Non-Revenue Water Reduction Program. Blue drop certification. Msunduzi Municipality, South Africa.

Mukheibir, P. (2007). Access to water – the impact of climate change in small municipalities, A Climate change capacity development (C3D) Report, Energy Research Centre, University of Cape Town, South Africa.

Mukheibir, P. and Sparks, D. (2005). Climate variability, climate change and water resource strategies for small municipalities. Project: K5/1500 Water Research Commission. Pretoria, South Africa.

Mukheibir, P. and Ziervogel, G. (2006). Framework for Adaptation to Climate Change in the City of Cape Town, Report to the Department of Environment Resource Management, Cape Town, South Africa.

Municipal Demarcation Board. (2011). Publication for general information: the outer and ward boundaries of the Thulamela Local Municipality (LIM343). Map number 152. Available on http://www.demarcation.org.za/Downloads/Boundary/2011/Limpopo/LIM343/Map152_LIM343.pdf

Mvula Trust. (2011). The potential of civil society organisations in monitoring and improving water quality. Water Research Commission Report K8/968/1, South Africa.

Mwangi, E. (2005). The transformation of property rights in Kenya's Maasailand: Triggers and motivations, CAPRI Working Paper no. 35, CGIAR System-wide program on collective action and property rights, Washington, D.C. USA.

Niang, I. (2007). Climate change adaptation in Africa Programme- Institutional framework in relation to climate change in West and Central Africa. Climate Change Adaptation in Africa, a DFID-IDRC Initiative, United Kingdom.

Noble, M. and Wright, G. (2012). Using indicators of multiple deprivation to demonstrate the spatial legacy of apartheid in South Africa. Centre for the Analysis of South African Social Policy, Oxford Institute of Social Policy, University of Oxford, Springer, Oxford.

NWDACE. (2008). North West Province Environment Outlook. North West Department of Agriculture, Conservation and Environment. Accessed on the internet on 20 August 2011 on: http://www.marshafrica.com/sector/environment/documents/NWPEODraftEOReportRev3_000.pdf.

Nyong, A. (2009). Climate change impacts in the developing world: implications for sustainable development. In L, Brainard, A Jones and N Purvis (ed) Climate change and global poverty: a billion lives in the balance? Brookings Institution Press. Washington DC.

O'Keef, W. and Kueter, J. (2004). Climate Models: A Primer. Marshall Institute. Washington D.C. Accessed on internet on 13 December 2011 at http://www.marshall.org/pdf/materials/225.pdf

OECD. (2009). Policy guidance on integrating climate change adaptation into development co-operation. Published by the Organisation for Economic Co-operation and Development (OECD), Paris, France (ISBN-978-92-64-05476-9).

Olivier, J. and Van Heerden, J. (2002). Implementation of an operational prototype fog water collection system: project implementation: report to the Water Research Commission. Gezina, South Africa.

ORWUA. (2013). Discussion with the CEO (Mr Hanke du Toit) and Technical Manager (Mr Danie de Wet) of the Orange Riet Water User Association in Letsemeng in January of 2013. Letsemeng. Free State.

Ospina, A. V. and Heeks, R. (2010). Linking ICTs and Climate Change Adaptation: A Conceptual Framework for e-Resilience and e-Adaptation. IDRC, Canada.

Oxfam. (2009). Climate change, development and energy problems in South Africa: Another world is possible. Sustainable Energy and Climate Change Partnership (SECCP), Earthlife Africa, Johannesburg.

Palitza, K. (2012). Traditional leaders wield the power, and they are almost all men: The importance of involving traditional leaders in gender transformation. Sonke Gender Justice Network. Accessed on the internet on 7 May 2012 on site http://www.genderjustice.org.za/

Pandey, D. N., Gupta, A. K. and Anderson, D. M. (2003). Rainwater harvesting as an adaptation to climate change, In *Current Science*, Vol. 85, NO. 1, July 2003.

Partridge, T. C., Demenocal, P., Lorentz, S. A., Paiker, M. J. and Vogel, J. C. (1997). Orbital forcing of climate over South Africa: a 200 000-year rainfall record from Pretoria Salt Pan. *Quaternary Science Reviews,* Vol16 (10), pp.1125-1133.

Pope, V. D., Gallani, M. L., Rowntree, P. R. and Stratton, R. A. (2000). The impact of new physical parametrizations in the Hadley Centre climate model—HadAM3. *Climate Dynamics*. 16, 123-146. doi:10.1007/s003820050009.

Postel, S. (1999). Pillar of sand: can the irrigation miracle last? New York. London: WW Norton & Company.

Rahman, A. (2009). Integrating climate change into development: multiple benefits of mitigation and adaptation. In L, Brainard, A Jones and N Purvis (ed) (2009). Climate Change and Global Poverty: A Billion Lives in the Balance? Brookings Institute. Washington Institution Press. Washington D.C.

Raleigh, C. and Jordan, L. (2010). Climate change and migration: emerging patterns in the developing world. In R, Mearns and A, Norton's (eds) Social Dimensions of Climate Change Equity and Vulnerability in a Warming World. The International Bank for Reconstruction and Development/ The World Bank.

Rand Water. (2009) Annual Reports: Review of Operations. Rand Water. Johannesburg.

Reidlinger, D., and Berkes, F. (2001). Responding to climate change in northern communities: impacts and adaptations arctic 54(1):96-98.

Republic of South Africa. (1997). Water Services Act of 1997. Government Gazette of 19 December 1997. Pretoria, Republic of South Africa.

Republic of South Africa. (1998a). The National Water Act of 1998. Government of South Africa. Pretoria, South Africa: Government Printer.

Republic of South Africa. (1998b). Local government Municipal Structures Act. Government Gazette of 18 December 1998. Pretoria: Republic of South Africa.

Republic of South Africa. (2002). Disaster management act of 2002. Act No. 57. Government Gazette of 15 January 2003. Pretoria: Republic of South Africa.

Republic of South Africa. (1996). The Constitution of the Republic of South Africa as adopted by the Constitutional Assembly on 8 May 1996 and as amended on 11 October 1996. Pretoria: Government Printer. (B34B-96).

Republic of South Africa. (2000). Local Government Municipal System (Act No. 32 of 2000). Pretoria: South Africa.

Republic of South Africa. (2013). Sebegoe appoints rapid response team for water challenges in Madibeng. South African Government Information. Accessed on internet on 1 March 2013 at http://www.info.gov.za/speech/DynamicAction?pageid=461&sid=34588&tid=100039

Reuveny, R. (2007). Climate Change-induced Migration and Violent Conflict. Political Geography 26 (2007) 656-673. USA

Sadoff, C. and Muller, M. (2009). Water management, water security and climate change adaptation: Early Impacts and essential responses. Stockholm: Global Water Partnership Technical Committee (TEC). In Department of Science and Technology, (2010). South African Risk and Vulnerability Atlas, Department of Science and Technology, Republic of South Africa.

SANCOLD. (1991). Guidelines on safety in relation to floods. Safety evaluation of dams: Report No. 4.

SAWS. (2011). South African Weather Services Historic Rainfall Maps: Seasonal Maps. Pretoria South Africa. http://metzone.weathersa.co.za/images/articles/rainfallmaps/

Seager, J. and Mohlakoana, N. (2007). Horizon scanning in South Africa: The potential impacts of climate change on poor households. Human Sciences Research Council. Pretoria.

Sedibeng. 2009. Drought Relief Project For Petrusburg / Bolokanang, Bloemfontein.

Setswe, G. (2010). Township communities and urbanisation in South Africa, Human Sciences Research Council of South Africa Discussion guide for the 4th AMREP World Health Day workshop session on "Current Challenges in Urbanisation and Health" on 8 April 2010, Burnet Institute, Monash University and Compass, Johannesburg, South Africa.

Severskiy, I. V. (2004). Water-related problems of Central Asia: some results of the GIWA International Water Assessment Program. *AMBIO*: Vol.33, Issue 1, 52-62.

Shewmake, S. (2008). Vulnerability and impact of climate change in South Africa's Limpopo River Basin, International Food Policy Research Institute (IFPRI) Discussion Paper 00804, IFPRI.

Shili, W. (2006). Coping strategies with desertification in China. China Meteorological Administration, http://www.wamis.org/agm/meetings/worisk06/S5-Wang_WORISK.pdf.

Smit, B. and Skinner, M. (2002). Adaptation options in agriculture to climate change: A typology, mitigation and adaptation strategies for global change, Vol 7 pages 85-114, Kluwer Academic Publishers, Netherlands.

Smit, B. and Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change* 16 (2006) 282-292. [AO] at www.sciencedirect.com

Stats SA. (2007). Community survey, 2007. (Revised Version). Statistics South Africa. Downloaded on 11 November 2011 http://www.statssa.gov.za/publications/P0301/P0301.pdfStats SA. (2008). Community Survey, 2007 basic results: Municipalities, Pretoria: South Africa.

Stats SA. (2010). General household survey 2010. Statistics South Africa, 2011. Accessed on internet on 11 March 2012 from www.statssa.gov.za.

Stats SA. (2011) Census 2011. Highlights of Key Results. Statistics South Africa. Accessed on internet on 15 June 2012 from www.statssa.gov.za.

Stats SA. (2012). Census 2011 statistical release-P 0301.4. Statistics South Africa. Pretoria, South Africa

Steele-Dunne, S., Lynch, P., McGrath, R., Semmler, T., Wang, S., Hanafin, J. and Nolan, P. (2008). The impacts of climate change on hydrology in Ireland, Journal of Hydrology vol. 356, page 28-45, Science Direct, Elsevier.

Stern, N. (2007). The economics of climate change: the Stern review. Cambridge University Press.

Swart, R., Robbert, B., Svend Binnerup., Timothy, R., Carter, C., Cowan, T., Henrichs, S., Loquen, H., Mela, M., Moritz, R. and Daniela, R. (2009). Europe adapts to climate change: Comparing national adaptation strategies, Partnership for European Environmental Research (PEER) Report No 1. Helsinki.

Swartz, C. D., du Plessis, J. A., Burger, A. J. and Offringa, G. (2006). A desalination guide for South African municipal engineers. Paper presented at the 2006 Water Institute of South Africa (WISA) Biennial Conference, Durban, South Africa, 21-25 May 2006.

Tanser, F., Sharp, B., le Sueur, D. (2003). Potential effect of climate change on malaria transmission in Africa. Lancet 2003; 362: 1792-98

TatukGIS. 2012. TatukGIS Developer Kernel for Compact Framework. Accessed on the internet on 12 January 2012 at site http://www.tatukgis.com/Home.aspx

Thebaut, J., Webb, E. and Rivenburg D. (2010). Coping with drought and water scarcity: Report to the Army Corps of Engineers. Proceedings of the panel discussion event held by the Chronicles Group and USA Army Corps of Engineers. 16 to 17 June 2010. Washington D.C.

Thomas, D. S. G. and Twyman, C. (2005). Equity and Justice in climate change adaptation amongst natural-resource-dependent societies, *Global Environmental Change*, 15, pp.115-124. *Science Direct*, Elsevier.

Thomas. D. S. G., Twyman, C., Osbahr, H. and Hewitson, B. (2007). Adaptation to climate change and variability: Farmer responses to intra-seasonal precipitation trends in South Africa, *Climate Change*, 83, pp. 301-322, Springer Science.

Thompson, L. G. (2000). Ice core evidence for climate change in the Tropics: Implications for our future, *Quaternary Science Reviews*, 19, pp.19-35, Pergamon, Elsevier Science Ltd.

Thulamela. (2008a). Thulamela IDP Report Review, Thohoyandou, South Africa.

Thulamela. (2008b). Thulamela Municipality water services infrastructure asset management plan, Thohoyandou, South Africa.

Thulamela. (2010). Thulamela Municipality. Review of Thulamela Municipality Integrated Development Plan 2010. Thohoyandou, South Africa.

Thulamela. (2012). Thulamela Municipality integrated development plan review 2012/2013. Thohoyandou, South Africa. Accessed on the internet on 3 February 2013 at www.thulamela.gov.za/docs/idp.

Toulmin, C. (2009). Climate change in Africa. Zed Books, London:New York.

Tredoux, G. and Cain, J. (2010).The Atlantis water resource management scheme: 30 years of artificial groundwater recharge. DWA Report Number P RSA 000/00/11609/10-Activity 17 (AR5.1). Department of Water Affairs.

Trimble, S. W., Stewart, B. A. and Howell, T. A. (2008). Encyclopedia of Water Science, Second Edition. Routledge Group. USA.

uMgeni. (2011). uMgeni water infrastructure master plan 2011/2012-2041/42. uMgeni Water. Pietermaritzburg: South Africa.

UN. (1992). United Nations Framework Convention on Climate Change. United Nations. Geneva. Switzerland.

UN. (2003). 1st UN World Water Development Report: Water for People, Water for Life. United Nations/World Water Assessment Programme. Paris, New York and Oxford. UNESCO (United Nations Educational, Scientific and Cultural Organisation).

UN. (2009). Copenhagen Accord: Decision -/CP.15, Working Group on Long-term Cooperative Action and decision x/CMP.5, United Nations Climate Change Conference of 18 December 2009 in Copenhagen.

UN. (2012). Evolution of Income Inequality: Different Time Perspectives and Dimensions. United Nations Conference on Trade and Development, UNCTAD/TDR/2012. Geneva.

UNDP. (2002). Human development report. United Nations Development Programme. New York: United Nations.

UNDP. (2007). Human development report 2007/2008. Fighting climate change: human solidarity in a divided world. United Nations Development Programme. Palgrave Macmillan: New York.

UNESCO. (2006). The 2nd United Nations World Water Development Report: 'Water, a shared responsibility' – Accessed from the internet on 11 November 2010. http://www.unesco.org/water/wwap/wwdr/wwdr2/case_studies/pdf/south_africa.pdf

UNFCCC. (2006). Technologies for adaptation to climate change. UNFCCC. Bonn: Germany.

UNFCCC. (2007). Climate change: Impacts, vulnerability and adaptation in developing countries, Information Services of the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat. United Nations Framework Convention on Climate Change.

UNISA. (2010). Water from inkungu. Unisa e-news, Vol 4, March 2010. Pretoria.

Unmusig, B. and Cramer, S. (2008). Climate Change in Africa, German Institute of Global and Area Studies (GIGA) Focus, No. 2, ISSN 1862-3603, www.giga-humburg.de/giga-focus.

Unver, O. and Cosgrove, W. (2009). Preface in The United Nations World Water Development Report: Water in a changing world. Third Edition. UNESCO. United Kingdom.

Van Averbeke, W. (2012). Performance of smallholder irrigation schemes in the Vhembe District of South Africa. Kumar, M Problems, perspectives and challenges of agricultural water management. Accessed 20 March 2013 from http://www.intechopen.com/book.

Van der Merwe, C. (2010). Wind-energy developer teams up with Eastern Cape traditional leaders. Engineering News online. Accessed on www.engineeringnews.co.za

VDM. (2007). Vhembe District Municipality Local Economic Development Strategy. Kayamandi Development Services, Hatfield, Pretoria.

Vhembe. 2009. Report on Vhembe District Water Services Backlog, Thohoyandou, South Africa.

Vhembe. (2010). Vhembe District Municipality Quarterly Organisational Performance Report: Second Quarter, Thohoyandou, South Africa.

Vicuna, S. and Dracup, J.A. (2007). The evolution of climate change impact studies on hydrology and water resources in California, Climatic Change, 82, 327-350.

Viljoen, M. F. and Armour, R. J. (2002). The economic impact of changing water quality on irrigated agriculture in the lower Vaal and Riet Rivers. Water Research Commission Report No. 947/1/02, Pretoria.

Vimont, D. J., Wallace, J. M. and Battisti, D. S. (2003). The seasonal foot printing mechanism in the Pacific: Implications for ENSO. *Journal of Climate*, 16, pp.2668-2675.

Wang, S., Kang, A., Zhang, L. and Li, F. (2008). Modelling hydrological response to different land-use and climate change scenarios in the Zamu River basin of northwest China, *Hydrological processes*, vol. 22, page 2502-2510, Wiley InterScience.

West, J.J. (2009). Perceptions of ecological migration in Inner Mongolia, China: summary of fieldwork and relevance for climate adaptation. CICERO (Center for International Climate and Environmental Research) Report 2009:05. http://www.cicero.uio.no/media/7543.pdf

Westra, S., Alexander, L. V. and Zwiers, F. W. (2012). Global increasing trends in annual maximum daily precipitation. Journal of Climate 2012, doi: http://dx.doi.org/10.1175/JCLI-D-12-00502.1.

Wilcox, E. M. and Donner, L. J. (2007). The frequency of extreme rain events in satellite rain-rate estimates and an atmospheric general circulation model. *Journal of Climate American Meteorological Society*. 26:4, 1457-1466.

WHO (1997). "The World Health report 1996 – fighting disease, fostering development." World Health Forum 18(1): 1-8.

World Bank. (2009). The costs to developing countries of adapting to climate change: New methods and estimates – The global report of the economics of adaptation to climate change study, New York, USA.

World Bank. (2012). Turn down the heat: Why a 4° C warmer world must be avoided. A Report for the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics. International Bank for Reconstruction and Development / The World Bank. Washington DC

WRC. (2004). Water User' Associations: Orange River Artery Keeps South Western Free State Heart Beating. The Water wheel July/August 2004. Water Research Commission. Pretoria

WWF, 2010. World Wide Fund for Nature Round Table: 'You have struck a rock'. University of the Western Cape. South Africa. Accessed from the internet on 11 February 2012 on http://www.wwf.org.za/what_we_do/climate_change/?3260/Roundtable-inspires-proactive-climate-change-engagement

Yifu Lin, J. and Yao, Y. (2009). Chinese rural industrialization in the context of the East Asian miracle. China Center for Economic Research, Beijing University, China.

Ziervogel, G., Cartwright, A., Tas, A., Adejuwon, J., Zermoglio, F., Shale, M. and Smith, B. (2008). Climate change and adaptation in African agriculture, Report prepared for Rockefeller Foundation, Stockholm Environment Institute, Stockholm.

Annexures

Annexure 1: The questionnaire that was administered to local community members in four municipal areas

Annexure 2: Indicators used, quantification and weights for each settlement and ward in the evaluation of community vulnerability to climate change impacts

Annexure 3.1: Graphical illustration of indices defining nature of exposure to climate change, sensitivity, adaptive capacity and vulnerability in the wards of Thulamela local municipality

Annexure 3.2: Graphical illustration of indices defining nature of exposure to climate change, sensitivity, adaptive capacity and vulnerability in the wards of Letsemeng local municipality

Annexure 3.3: Graphical illustration of indices defining nature of exposure to climate change, sensitivity, adaptive capacity and vulnerability in the wards of Msunduzi local municipality.

Annexure 3.4: Graphical illustration of indices defining nature of exposure to climate change, sensitivity, adaptive capacity and vulnerability in the wards of Madibeng local municipality

Annexure 4: A list of the students who participated in field investigations and analysis of field work results

Vulnerability Mapping: Climate Change Impacts on Water Access and Use

Background

This questionnaire is set to evaluate community water access needs. This questionnaire is a step towards addressing the requirements of the research entitled: The role of local community institutions in the adaptation of rural and urban communities to the impacts of climate change on water access and use. In this research, the Water Research Commission, a unit of Department of Water Affairs is supported by researchers from the University of South Africa (UNISA) and HYDROSOFT in administering the questionnaire.

Your participation in this research is based on your own free will. Your inputs will help the researchers in building climate change adaptation support mechanisms that are aimed at assisting community members such as yourself.

General Information

1 Location description (e.g Name of community) ______ Ward ______ District municipality ______

2 Address (Street, Village/Town, Postal code or other identification) ______ ______ ______

3 Name of respondent ______ Contact number ______

4 Age ______ Female ______ Male ______

5 Highest education level achieved: **No education** ______ Highest grade achieved ______ Certificate/ Diploma / Artisan ______ Degree ______ Other ______

6 Type of house Stand alone ______ Flat ______ Informal ______ Temporary ______ Backyard ______

7 How many people live at this household everyday? ______ How many rooms does the house have? ______ How many showers and bath tubs in house? ______

8 Where is this house? Rural area ______ Urban ______ Semi-urban ______ On a Farm ______ In a mining area ______ Other area ______

9 Occupation, employment or main livelihood activity ______ List other income generating activities ______

10 Total **monthly** income of all household members(R) R0 to R300 ______ R301-R600 ______ 601-1000 ______ 1001-3000 ______ 3001-6000 ______ 6001-10000 ______
10001-20000 ______ 20001-30000 ______ 30001-50000 ______ Above R50000 ______

11 Types of grants received at household: Grant 1 ______ Grant 2 ______ Grant 3 ______ Amounts (R) Grant 1 ______ Grant 2 ______ Grant 3 ______

12	Nature of water services?	Municipality		Private		Other institution/s		From neighbours		Name other supplier/s	
13	Water Source?	Piped water inside house		Tap inside household yard		Street tap		Borehole		Direct from river or dam	
14	List other water sources?	Rainwater harvesting		Describe other							
15	Distance or time taken to collect water if outside yard	in Kms or metres		Number of minutes to go and return from water source							
16	Do you get water bills?		How much do you pay for water every month?		Do you get free basic water?						
17	If the water is not paid for, why is this so? To give reason why the household is not billed:										
18	What does the water service provider do if water bills are not paid?										

Water quantity needs.

19	Household's main water uses?	**Delete if not applicable:**	**1.** Domestic (Cook, wash, bath, toilet, clean floors)	**2.** Wash car, irrigate small gardern,							
		3. Irrigate large gardern (If agriculture use then how many Ha?)	Ha	**4.** List any other uses:							
20	About how much do you use per day? (give estimate using drums, canes, water bill, number of 20 litre containers, etc)										
21	How much more water do you wish to have per day?										
22	What other uses would you wish to use the water for if supplied quantity is increased? List:										
23	Frequency of water shortages	No water cuts		Daily water cuts		Once every year in dry season?		Water cuts in some years		Other-specify	
23b	What is the general cause of the water shortages or water cuts?										
23c	How do you know about the water problem? Also, are you informed of when it will be addressed?										

Water quality needs.

24	Is the water clean or of good quality for use? List the water quality problems associated with your water.				
24b	Which water source has these water quality problems?				
25	If quality is not good, what do you do to improve quality?				
26	In the long term (10 to 20 years) what options do you have to maintain good water quality?				
27	What would you wish the water service provider could do about water quality?				

Institutional role in water access and use.

28 Who is providing you with water? List if more than one service provider:

29 What does the water service provider do to support you in cases of water cuts/shortage?

29b What does the household and your community do to get water in cases of water shortage/cuts?

30 How do you communicate your needs to the water service provider?

31 Is the municipality addressing the concerns of water users? Explain your answer?

Family and community based initiatives for water access and use.

32 What are you doing in your household to ensure better access to water?

33 What are you doing as a community to obtain good access to water now and in the future?

34 What would you need (nature of resources, tools etc.) to build a state of good water access for you and your family now and in the future?

Future perspective (with climate change - discusion first).

35 Do you know about climate change and how it affects you? Researcher will explain or read extract on climate change.

36 In your access to water and other water issues, what are your concerns in light of climate changes?

37 If you are not worried about climate change, what are you worried about regarding water access?

38 How are you going to adapt to climate change? Answers need to be practical, i.e something the your household and community can do. 1

2 3

39 What could stop you from adapting to climate change? List all: 1 2

40 What would you and your community need that will support you in adapting to climate change? List.

41 How can the municipality or other institution help your household and your community in adapting to climate change?

Questionnaire administered by

Contact number

Thank you.

Local Municipality: Thulamela
District Municipality: Vhembe

	Thulamela	EXPOSURE			SENSITIVITY																ADAPTIVE CAPACITY								
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	20	21	22	23	24	25	28	29	30	31	32
		Predicted temperature change (From Project Deliverable 3- Impacts mapping)	Predicted rainfall change (From Project Deliverable 3 Impacts mapping)	Predicted change in weather extremes (From Project Deliverable 3- Impacts mapping and mapping source data)	Location of household (Q1, Q2, Q8)	Nature of house (Q7)	Household size (Q5)	Education level / Literacy rate (Q6)	Main livelihood activity (Q12)	Income of household (Q11, Q12, Q13)	Diversification of household income (Q11, Q12, Q13)	Source of water (Q15, Q16, Q18, Q19)	Nature of water service (Q16)	Water shortage (Q18. Q19)	Water quality (Q26)	Ability to pay for water (Q11, Q12, Q13, Q21)	Access to suitable alternative water sources especially rainwater harvesting (Q15, Q31, Q34)	Distance to institutional water service infrastructure (Information from GPS or Maps)	Institutional water service provision capacity (Information is in annual report of specific municipality)	Institutional ability to bill and collect rates for water provision (Use annual report of municipality)	Results of institutional performance Audits in past five years (National treasury audits)	Community organization and networks with functional leadership (Q47, Q48, Q50)	Dependable employment (Q12)	Income of household (Q11, Q12, Q13)	Presence of subsistence farming or small gardens in local community	Knowledge of climate change (Q35, Q36, Q38, Q39)	Institutional capacity to provide water services now and into the future (Use information from institutions and other studies)	Nature of water provision infrastructure (Use the DBSA infrastructure barometer report, DBSA, 2010 and specific municipality annual reports)	Human resources in the local institution
	Local Community or Ward	Average Daily °C change / 3 °C * 10 if greater than 9 enter 9. If below 1 enter 1, Otherwise enter actual value	Revised: (Average Daily Rainfall Increase mm change /0.5). If <=-1 enter 9, if >-1 to <=0 enter 6, if >0 to <=1 enter 3, if greater than 1 enter 1	A measure of level of change where - none = 0, Low = 3, medium =6, high = 9	Large Town or City = 1, Small Town =5, Rural = 9	Formal House = 1 , Mixed Housing =5, Informal house = 9	When there are two or less household members = 3, three to five members= 6, above five members = 9	Degree and above = 2, Certificate or Diploma = 4, Up to Grade 12 = 6, Up to Grade 8 = 8, No education = 9	Permanent and dependable = 1, Permanent but inadequate = 3, Inadequate and non-permanent = 6, Grants or unemployed = 9	Revised: 10 - (Monthly Income (R) / 5000 * 10). If answer is greater than 9 enter 9, if below 1 enter 1, otherwise enter the obtained value (Values to the nearest integer, zero decimal points)	If diversification with sustainable income is generally possible in the community 2 if not enter 9	Highly rated water source provider =1, River Dam or BH with service provider or good service provider = 4, poorly rated service provider =7, River Dam or BH without service provider = 9. (Captures service provision in area).	Inbuilt plumping/infrastructure = 1, Using only stand pipe or street pipe = 3, Collect water direct from river or dam= 6, No services and in Rural areas =9	No water shortages = 1, in some years=3, seasonal=5, daily = 7, Never been connected after shortages = 8, never been connected at all = 9	If no respondent identified water quality problems = 1, If one or two respondents say water quality is not good for use =4, if half of the respondents = 7, If most respondents indicated that water quality is bad = 9	Revised: Water bill is affordable if it is below 3% of income. Water Bill/income*100. If value obtained is below 3 enter 1, if value is 3% to 10% = 5, If value is above 10% = 9	Fully installed rainwater harvesting tanks = 2, Functional BH as an alternative =2, Infield rainwater harvesting = 2, No alternative = 9	Distance is favourable if it is below 1Km = 3, 3Km to 10 Km =5, Above 10km = 9	100% = 1, 90% to 99% = 3, 75% to 89% = 5, 60% to 74% = 7, below 60% = 9	Rates collection efficiency of 100% = 1, 90% to 99% = 3, 75% to 89% = 5, 60% to 74% = 7, below 60% = 9	No Qualified audits in past five year =1, 2 out of 5 years = 3, 3 out of last five years =5, 4 out of 5 = 7, Qualified Audits for all last five years = 9	Good leadership with sharing of water resources by community in periods of shortage = 9, Reliable communication with service provider = 5, No communication = 1	Permanent and dependable = 9, Permanent but inadequate = 6, Inadequate and non-permanent = 3, Grants or unemployed = 1	Revised: Monthly Income / 5000 * 10. If answer is greater than 9 enter 9, If answer is below 1 enter 1, Otherwise enter the obtained figure (Values to the nearest integer. - 0 decimal points	Identified or observed activity = 9, No activity =2	Demonstration of high knowledge level with ideas on adaptation = 9, Demonstration of knowledge without ideas on adaptation = 6, Some minimum level of understanding = 4, No knowledge demonstrated = 1	If institution is developing new water service provision infrastructure beyond targets = 9, Just meeting the targets = 5, Below the targets = 1	Adequate infrastructure that is well maintained = 9, Ageing but well maintained = 6, Ageing and poorly maintained = 4, Serious problems = 1	Adequate skilled manpower for water provision (80% and above posts are filled) = 9, 50% to 79% of posts are filled =5, Chronic shortage of skilled manpower (below 50%) = 1
1	Mhinga	5.33	3	6	9	1	6	8	6	7	9	9	9	9	7	1	2	5	9	9	5	1	3	3	9	1	1	1	1
2	Lambani	5.33	3	6	9	1	6	8	6	8	9	4	9	9	4	1	9	5	9	9	5	1	3	2	9	1	1	1	1
3	Tshaulu	5.67	3	6	9	1	6	8	6	9	9	9	9	9	4	1	2	5	9	9	5	1	3	1	2	1	1	1	1
4	Tshikambe	6.00	3	6	9	1	6	6	6	8	9	4	9	9	1	1	2	5	9	9	5	1	3	2	2	1	1	1	1
4	Tshidzini	6.00	3	6	9	1	6	6	6	9	9	9	9	9	4	1	2	5	9	9	5	1	3	1	9	1	1	1	5
4	Tshifudi	6.00	3	6	9	1	6	8	6	9	9	7	3	7	1	1	9	5	9	9	5	1	3	1	2	1	1	1	5
5	Mukula	6.00	3	6	9	1	9	6	9	9	9	7	9	9	9	1	9	5	9	9	5	1	1	1	4	1	1	1	1
6	Baloyini/Luvhaladi	5.67	3	6	9	5	9	8	9	9	9	7	9	9	9	5	9	9	9	9	5	1	1	1	9	1	1	1	1
7	Phaweni	6.00	3	6	9	1	6	6	6	9	2	9	9	9	1	1	2	5	9	9	5	1	3	1	2	1	1	1	5
7	Nhengani	6.00	3	6	9	1	6	6	6	9	9	9	9	9	4	1	9	5	9	9	5	1	3	1	9	1	1	1	5
7	Xikundu	6.00	3	6	9	1	6	9	6	9	9	9	9	9	4	1	9	5	9	9	5	1	3	1	9	1	1	1	5
8	Maphophe	5.33	3	6	9	1	6	8	6	9	9	7	9	9	4	1	9	5	9	9	5	1	3	1	9	1	1	1	5
8	Boxahuku	5.33	3	6	9	1	6	4	3	9	2	9	9	9	1	1	2	5	9	9	5	1	6	1	2	1	1	1	5
8	Makuleke	5.33	3	6	9	1	6	4	3	9	2	7	3	7	1	1	9	5	9	9	5	1	6	1	9	1	1	1	5
9	Nthabeni	5.33	3	6	9	1	6	8	6	9	9	7	3	7	4	1	9	5	9	9	5	1	3	1	9	1	1	1	5
10	Matskali	5.67	3	6	9	5	9	6	9	9	9	7	9	9	9	9	9	5	7	9	5	1	3	2	9	1	1	1	1
11	Xigalo	5.67	3	6	9	5	6	4	3	9	2	7	3	7	1	1	9	5	9	9	5	1	6	1	9	1	1	1	5
12	Tshikonela	5.67	3	6	9	1	6	8	6	9	9	7	9	9	4	1	9	5	9	9	5	1	3	1	9	1	1	1	5
13	Malamuloele	6.00	3	6	5	1	6	4	3	6	2	7	1	7	1	1	2	5	7	9	5	1	6	3	2	1	1	1	5
13	Section C	6.00	3	6	5	1	6	4	3	7	2	9	1	7	1	1	2	5	7	9	5	1	6	3	2	1	1	1	5
14	Mphambo	6.00	3	6	9	1	6	6	6	8	2	9	9	9	1	1	9	5	9	9	5	1	3	2	9	1	1	1	1
15	Rulani	6.00	3	6	9	9	6	9	9	9	9	9	9	9	4	1	2	5	9	9	5	1	1	1	2	1	1	1	1
15	Mavambe	6.00	3	6	9	1	6	6	6	9	2	7	9	9	1	1	2	5	9	9	5	1	3	1	9	1	1	1	1
16	Jilongo/Plange	5.67	3	6	9	5	9	8	9	9	9	7	9	8	9	9	9	5	7	9	5	1	3	1	9	1	1	1	1
17	Mahonisi	6.00	3	6	9	1	6	4	3	9	2	4	9	9	1	1	9	5	9	9	5	1	6	1	2	1	1	1	1
18	KhaKhanwa	6.00	3	6	9	1	6	9	6	7	9	9	9	9	7	1	2	5	9	9	5	1	3	2	9	1	1	1	1
18	Tshiulungoma	6.00	3	6	9	5	9	8	6	9	9	7	3	7	1	9	9	5	7	9	5	1	3	1	9	1	1	1	5
19	Budele	6.00	3	6	9		6	4	3	7	2	9	9	9	1	1	2	5	9	9	5	1	6	3	2	1	1	1	5
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20	Makwarela X3	6.00	3	6	5	1	6	4	3	7	2	4	3	9	7	1	9	5	7	9	5	1	6	3	9	1	1	1	5
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21	Thohoyandou	6.33	3	6	1	1	6	8	9	6	9	7	1	7	9	5	2	3	7	9	5	5	1	4	2	1	5	6	5
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22	Maungani	6.33	3	6	5	1	6	5	3	8	2	7	3	1	1	5	9	5	9	9	5	1	6	2	2	1	1	1	5
23	Tshidaulu	6.33	3	6	9	1	6	4	6	7	2	7	3	9	1	1	9	5	9	9	5	1	3	3	2	1	1	1	5
23	Unit D	6.33	3	6	5	1	6	2	1	1	2	1	1	1	1	1	9	3	7	9	5	5	9	9	2	1	1	1	5
24	Tshififi	6.33	3	6	9	1	6	4	6	6	2	9	9	7	1	1	2	5	9	9	5	1	3	3	9	1	1	1	5
24	Ngudza	6.33	3	6	9	1	6	6	9	9	9	9	5	7	9	9	2	9	9	9	5	1	3	1	9	1	1	1	1
25	Tshitereke	6.33	3	6	9	5	9	8	6	9	9	7	3	7	1	1	2	9	7	9	5	1	3	1	9	4	1	1	1
27	Tshivhilidini	6.33	3	6	9	1	6	8	6	9	2	9	3	9	4	1	2	5	9	9	5	1	3	1	9	1	1	1	5
28	Tshiheni	6.67	3	6	9	1	6	8	6	9	9	9	9	9	4	1	2	5	9	9	5	1	3	1	2	1	1	1	5
28	Thononda	6.33	3	6	9	1	6	8	6	9	9	9	9	9	4	1	2	5	9	9	5	1	3	1	9	1	1	1	5
30	Matangari	6.33	3	6	9	1	6	9	9	9	9	9	9	7	9	5	9	9	9	9	5	1	3	1	9	1	1	1	1
31	Block 4	6.33	3	6	9	1	6	6	6	7	2	7	9	9	4	1	2	5	9	9	5	1	3	2	9	1	1	1	1
31	Block B/ Ngovhela	6.33	3	6	9	1	6	9	9	7	9	7	3	7	1	5	9	5	9	9	5	1	1	2	9	1	1	1	1
31	Phiphidi	6.33	3	6	9	1	9	8	3	7	2	7	3	7	4	1	9	9	9	9	5	5	6	2	9	1	1	1	1
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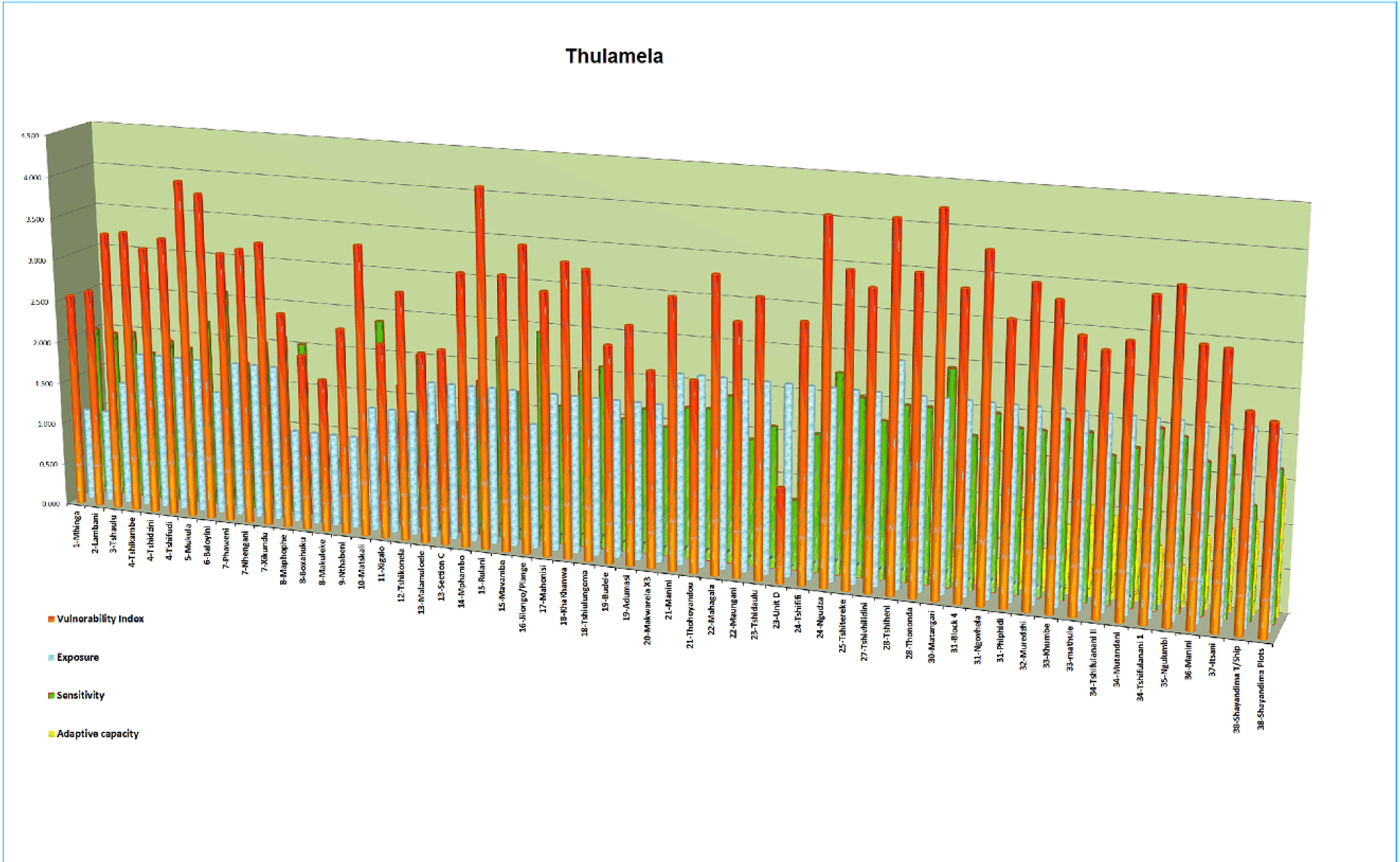
33	Zone 4/ Khumbe	6.33	3	6	9	1	6	4	6	5	9	7	3	7	9	5	9	9	9	9	5	1	3	5	9	1	1	1	1
33	mathule /Khumbe	6.33	3	6	9	1	9	4	1	7	2	9	9	9	7	1	9	9	9	9	5	5	9	3	2	1	1	1	1
34	Tshifulanani II	6.33	3	6	9	1	9	6	1	8	2	5	5	9	1	1	2	9	9	9	5	1	9	2	9	1	1	1	1
34	Mutandani	6.33	3	6	9	1	6	6	1	8	9	1	9	1	7	1	9	9	9	9	5	5	9	2	2	1	1	1	1
34	Zone 2/Tshifulanani	6.33	3	6	9	1	6	6	6	7	9	5	5	7	7	1	9	9	9	9	5	5	3	2	9	1	1	1	1
35	Ngulumbi	6.33	3	6	9	1	6	8	6	8	9	5	3	7	4	5	9	5	9	9	5	1	3	2	9	1	1	1	1
36	Manini, Tshikovha	6.33	3	6	9	1	9	4	3	7	9	5	3	7	7	1	9	5	7	9	5	1	3	3	9	1	1	1	5
37	Itsani	6.33	3	6	9	1	6	6	6	6	9	9	3	9	4	1	2	5	9	9	5	1	3	4	9	1	1	1	5
38	Shayandima T/Ship	6.33	3	6	5	1	6	4	6	3	2	7	1	7	1	1	9	3	7	9	5	1	3	7	2	1	1	1	5
38	Shayandima Plots	6.33	3	6	5	1	6	8	6	6	9	9	3	7	1	1	2	5	9	9	5	5	6	3	9	4	1	1	5

Indicator Minimum	5.33	3.00	6.00	1.00	1.00	6.00	2.00	1.00	1.00	2.00	1.00	1.00	1.00	1.00	1.00	2.00	3.00	7.00	9.00	5.00	1.00	1.00	1.00	2.00	1.00	1.00	1.00	1.00
Indicator Maximum	6.67	3.00	6.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	5.00	5.00	9.00	9.00	9.00	4.00	5.00	6.00	5.00
Indicator Weight (b,)	0.500	0.222	0.200	0.042	0.068	0.025	0.059	0.068	0.085	0.059	0.051	0.042	0.059	0.059	0.051	0.042	0.068	0.059	0.059	0.042	0.098	0.197	0.328	0.098	0.230	0.262	0.230	0.164

Thulamela Local Municipality: Sample of indicators as used in HCCAF


Thulamela
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4.000
3.500
3.000
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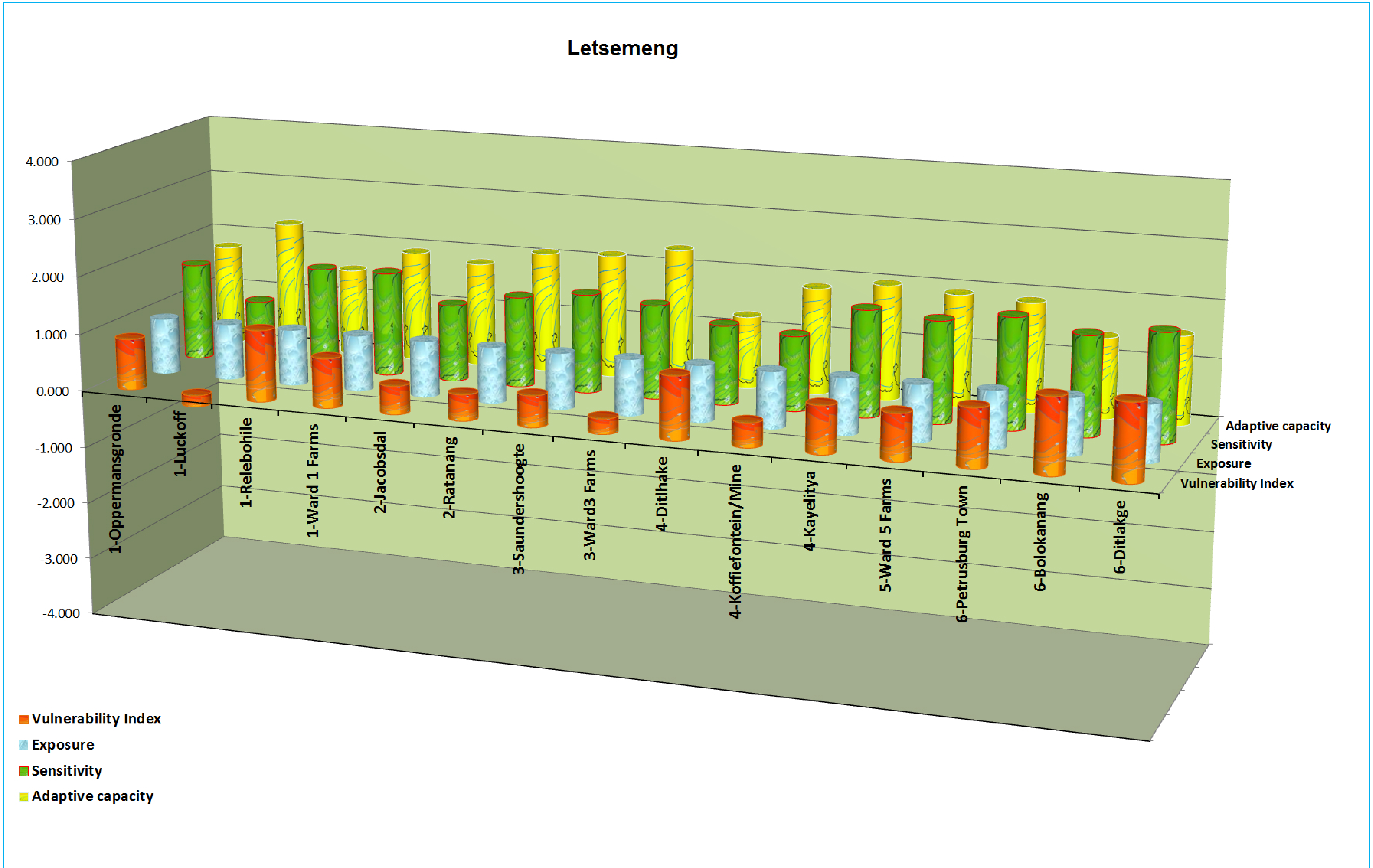
2.000
1.500
1.000
0.500
0.000
1-Mhinga
2-Lambani
3-Tshaulu
4-Tshikambe
4-Tshidzini
4-Tshifudi
5-Mukula
6-Baloyini
7-Phaweni
7-Nhengani
7-Xikundu
8-Maphophe
8-Boxahuku
8-Makuleke
9-Nthabeni
10-Matsheli
11-Xigalo
12-Tshikonela
13-Malamulele
13-Section C
14-Mphambo
15-Rulani
15-Mavambe
16-Jilongo/Plange
17-Mahonisi
18-Kha Khanwa
18-Tshiulungoma
19-Budele
19-Adamasi
20-Makwarela X3
21-Manini
21-Thohoyandou
22-Mahagala
22-Maungani
23-Tshidaulu
23-Unit D
24-Tshififi
24-Ngudza
25-Tshitereke
27-Tshishiludini
28-Tshiheni
28-Thononda
30-Matangari
31-Block 4
31-Ngovhela
31-Phiphidi
32-Muredzhi
33-Khumbe
33-mathule
34-Tshifulanani II
34-Mutandani
34-Tshifulanani 1
35-Ngulumbi
36-Manini
37-Itsani
38-Shayandima T/Ship
38-Shayandima Plots
Vulnerability Index
Exposure
Sensitivity
Adaptive capacity


Letsemeng
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3.000
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0.000
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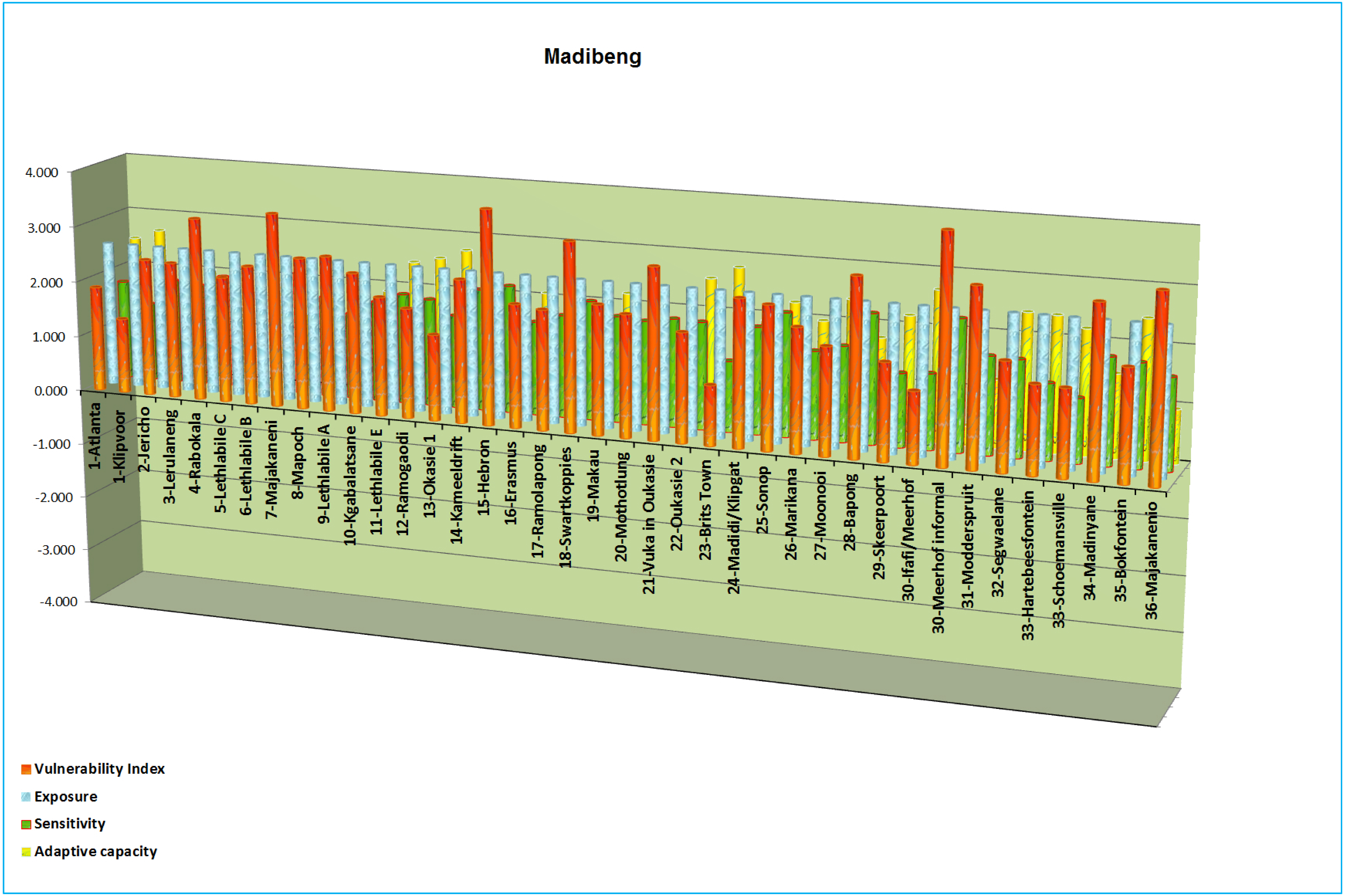
-2.000
-3.000
-4.000
1-Oppermansgronde
1-Luckoff
1-Relebohile
1-Ward 1 Farms
2-Jacobsdal
2-Ratanang
3-Saundershoogte
3-Ward3 Farms
4-Ditlhake
4-Koffiefontein/Mine
4-Kayelitya
5-Ward 5 Farms
6-Petrusburg Town
6-Bolokanang
6-Ditlakge
Adaptive capacity
Sensitivity
Exposure
Vulnerability Index
Vulnerability Index
Exposure
Sensitivity
Adaptive capacity

Msunduzi

Msunduzi
5.000
4.000
3.000
2.000
1.000
0.000
-1.000
-2.000
-3.000
1-Blackridge
2-Sweet Waters
3-KwaDulela
4-Kwa Mpande
4-Hanley
5-Entembeni
5-France
6-Mbongweni
7-Mafunze
8-Songonzima
9-KwaMcane
10-Edendale South
11-Mimosa-Edendale
12-Stebisi-Edendale
12-Esigodini
13-Imbali East
14-Ridgeway-Edendale
15-Imbali West
16-Imbali NE
16-Imbali DD
17-Zayeka/Edendale
18-Wingrove-Lynnfield
19-Filanpark/Imbali
20-Mabana/Edendale
21-Sitebisi/Edendale
22-Napierville/Edendale
22-Machibise
23-Mason's/Imbali
24-Bisley/Imbali
25-Chase Valley
25-Hilton
26-Boughton/Clarendon
27-Pietermaritzburg
27-Scottsville
28-Northdale North
28-Northdale
29-Jesmondene/Copesville
29-Swapo A
29-Copesville North
29-Copesville South
30-KwaThandiswe
30-Lincoln Meade
31-Northdale South
32-Maritzburg/Victoria
33-Pietermaritzburg SE
34-West End
35-Willowtown
36-Oribi/Mkondeni
37-Ashburton Plots
Vulnerability Index
Exposure
Sensitivity
Adaptive capacity



Madibeng
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-2.000
-3.000
-4.000
1-Atlanta
1-Klipvoor
2-Jericho
3-Lerulaneng
4-Rabokala
5-Lethlabile C
6-Lethlabile B
7-Majakaneni
8-Mapoch
9-Lethlabile A
10-Kgabalatsane
11-Lethlabile E
12-Ramogaodi
13-Okasie 1
14-Kameeldrift
15-Hebron
16-Erasmus
17-Ramolapong
18-Swartkoppies
19-Makau
20-Mothotlung
21-Vuka in Oukasie
22-Oukasie 2
23-Brits Town
24-Madidi/Klipgat
25-Sonop
26-Marikana
27-Moonooi
28-Bapong
29-Skeerpoort
30-Ifafi/Meerhof
30-Meerhof informal
31-Moddenspruit
32-Segwaelane
33-Hartebeesfontein
33-Schoemansville
34-Madinyane
35-Bokfontein
36-Majakanenio
Vulnerability Index
Exposure
Sensitivity
Adaptive capacity

STUDENT RESEARCH ASSISTANTS

Student Name	Institution	Area Researched
Rebecca Solomon	UKZN-PMB	Msunduzi
Rudolf Muhembo	UKZN-PMB	Msunduzi
Faith Tokologo Mohlala	UKZN-PMB	Msunduzi
Maxwell Ndou Thovhedzo	UKZN-PMB	Msunduzi
Sibahle Khawula	UKZN-PMB	Msunduzi
Robert Mphahlele	UNISA	Madibeng
Previous Chidi	UNISA	Madibeng
Ngobeni Matshidiso	TUT	Madibeng
Azwimbavhi L Magoro	UNISA/TUT	Madibeng
Thabisile Zuma	UP/UNISA	Madibeng/Xariep
Mpho Nndwambi	University of Venda	Thulamela
Masingi Precious	Turfloop	Thulamela
Lizzy Ngomani	University of Venda	Thulamela
Fhulufhelo Tshitahe	University of Venda	Thulamela
Fundzane E Ntsedzeni	Vaal University of Technology	Thulamela/Xariep /Msunduzi
Lebogang Mogodi	Not a student	Xariep
Ello Louw	UNISA	Xariep
Tshokolo Metsimetsi	Not a student	Xariep
Clearance Molete	Not a student	Xariep