OPTIMAL UTILISATION OF THERMAL SPRINGS IN SOUTH AFRICA

Report to the
WATER RESEARCH COMMISSION

by

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UNISA

WRC Report No. TT 577/13

November 2013

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The publication of this report emanates from a project entitled *Optimal Utilisation of Thermal Springs in South Africa* (WRC Project No. K5/1959).

ISBN 978-1-4312-0481-6

EXECUTIVE SUMMARY

Thermal (hot) springs have been used for religious and/or medicinal purposes for hundreds, if not thousands of years. Many of these developed into flourishing centres of culture, health and tourism. Although some remained popular over time, many have fallen into disuse. Even the most spectacular of these phenomena (such as geysers) were perceived as having only limited development potential – merely as tourist resorts. Consequently, most research focused on the geological characteristics of this natural phenomenon. However, during the last few decades, their potential as versatile natural resources has become increasingly apparent. In addition to being popular tourist resorts, recent thermal spring uses include: the generation of electricity (geothermal power) and for agriculture, aquaculture, bottling, the extraction of rare elements, and the use of thermophilic bacteria for industrial purposes. Moreover, the natural health industry is expanding rapidly and the possible therapeutic properties of thermal spring waters are being reinvestigated by scientists in many different countries.

In South Africa, about half of the documented 74+ thermal springs have been developed as family leisure and recreational resorts alone, while the rest remain undeveloped. Thus, in comparison with global trends, South African geothermal resources appear to be under-utilized. Decisions regarding the viability of alternative and optimal uses of a thermal spring resource are largely based on their physical and chemical characteristics but, apart from research carried out on thermal springs during the early and mid-20th Century, little is known about their existing characteristics.

The principal aim of this project was to determine the optimal uses of thermal springs in South Africa. The following three objectives were used to accomplish this:

1. Determination of the geological, biological, physical and chemical characteristics of the thermal springs in South Africa;
2. Identification of current uses of the springs and assessment of whether these are suitable with regard to national water quality guidelines; and
3. Evaluation of their suitability for recognized applications of low enthalpy thermal resources. The intention here was to identify uses for small-scale developments so as to generate income and empower communities with knowledge, skills and resources.

This report comprises 6 chapters, the first of which gives an overview of the nature of thermal spring resources as well as past and present trends in resource use – both globally and in South Africa. Chapter 2 provides a brief note on the geological and biological characteristics of South African thermal springs with emphasis on the results obtained in the course of this project. Details of these results are provided on the CD. This is followed by a summary of the current situation regarding resource use and an assessment of their potential risk to human and animal health. Chapters 4 and 5 form the crux of the report. The former uses the physical and chemical properties of the springs to identify springs with potential for bottling, agriculture (e.g. greenhouse heating, crop drying and irrigation), aquaculture (for the production of tilapia, *Spirulina* and oysters), in the cosmetic industry, for mineral extraction, geothermal energy production and for the health and wellness industry. This information is then used in chapter 5 to suggest possible applications for development at two sites in Limpopo Province. The final chapter presents a summary of the project and assesses the outcomes and outputs in terms of the “knowledge tree”.

Numerous field trips were undertaken to collect water samples from thermal springs throughout the country. A number that had been documented and mapped during the 1950s were found to have dried up. A few ‘new’, previously unrecorded thermal springs were found including seven in the Kruger National Park. These data, together with that sourced from literature were used to compile a comprehensive database of the physical and chemical properties (Addenda A and B) and to map their location. All addenda are included on the CD.

The hottest thermal spring/borehole was found to be that at Siloam in the Limpopo Province (~71°C) followed by Brandvlei (64°C). These temperatures are low in comparison to those found in countries with volcanic activity, such as Iceland, New Zealand, Indonesia and Japan. Flow rates are mostly meager (< 5 l/s) with a few reaching more than 30 l/s. The single exception is Brandvlei with a flow rate of 126 l/s.

Geophysical and isotope studies added to the body of knowledge regarding the origin and age of thermal spring waters of Limpopo Province, the structural geology controlling the location of springs and the geochemical processes occurring at depth. Further proof was offered for the meteoric origin of the waters. Results of magnetic, electrical and electromagnetic surveys indicated that all thermal springs in Limpopo Province are associated with faults and impenetrable dykes or sills. The most important hydrogeochemical process controlling the chemical composition of thermal groundwater was found to be water-rock interaction and to a lesser extent, crystallization. The geochemical processes affecting the carbon isotopes are natural decay and isotope exchange between soil CO_2 and aquifer matrix – thus placing the age of the waters in the Holocene. Deliverables reflecting this research can be found in the CD.

This project provided the first opportunity to investigate the bacterial and algal diversity of South African thermal springs. Bacterial identification was conducted using 454 genome sequencing. Most of the microbes found in these springs also occur under mesophilic conditions and are not true thermophiles. However, there is a possibility that some thermal springs in Limpopo might contain novel species. If so, they could have considerable industrial potential. A full dataset with the results of the 454 sequencing is included as Addendum C (on the CD).

The major focus of this report was on the current uses of springs and their development potential for alternative or supplementary uses. Decisions regarding the fitness for use of thermal springs for a particular use were based solely on the physical and chemical characteristics of the waters. A simple rating scale was used to indicate conformity (a score of 1) and non-conformity (score = 0) to known and accepted standards. A formula was used to calculate the Total Suitability Score (TSS). This is explained in Chapter 4.

Application of this rating scale showed that the majority of thermal spring waters, barring those in the Western Cape, have unacceptably high concentrations of fluorine and are not suitable for consumption. Ingestion of large amounts of fluoride-rich waters over an extended period of time may pose a health hazard to humans or animals. Despite non-conformity of water for recreational use at some resorts (due to high fluoride levels), the small amount of water ingested during recreational activities such as swimming should not pose a hazard. Nevertheless, resort owners should take cognisance of the presence of these and other toxic minerals such as mercury and arsenic. However, even those springs which were fit for consumption, do not conform to South African National Bottled Water Association (SANBWA) standards and are thus not suitable for bottling. This apparent contradiction is due to the use of different suitability criteria (such as bromine) by Department of Water Affairs (DWA) (previously Department of Water Affairs and Forestry, DWAF) and SANBWA.

The suitability assessments in Chapter 4, reveals that each thermal spring can be used for a number of different purposes. At some springs, multiple alternative or supplementary uses could be implemented. All of the springs can be used for agriculture and aquaculture; some springs are suitable for niche markets such as bottled spring water, balneology, for the cosmetic industry, while a few can be used to generate electricity. In the majority of the cases it is the thermal energy that is useful rather than the water itself. This implies that – although the water quality may not be suitable – thermal spring waters could be used (for example) for the production of aquatic crops such as *Tilapia* fish or *spirulina*. In addition, the utilization of the heat from the geothermal resource could ensure crop production (including greenhouse crops) throughout the year. In general, the hottest springs suitable for a greater variety of uses. Only the hottest springs could be used for the generation of geothermal electricity. This could contribute to the use of renewable energy – even if applied on a small scale during winter when the differential between thermal spring water and ambient temperatures reach a maximum. Only two thermal springs, namely Brandvlei and Tshipise, could be suitable for power generation at present, but the rate of development of this technology could soon increase the viability of geothermal energy production in South Africa.

It is important to note that the very properties of spring waters that prohibit its use for some purposes may make it eminently suitable for another. For example, spring water that might be unfit for drinking and bathing purposes due to high mineral content could be suitable for water mining. Technological advances over the last few years have made it possible to extract only specific minerals from brines. Although the concentrations of minerals in South African spring waters are low in comparison to the very hot geothermal resources in countries with volcanic springs, small scale mineral appears to be feasible – especially for the extraction of boron, titanium and strontium.

Ideally, a thermal spring development should exploit the full potential of a spring. This could be done by cascading the thermal waters through many tiers of uses with benefits accruing at each. This is illustrated by using two case studies (chapter 5). In both cases, the suggested developments made use of existing infrastructure and/or potential. It should be kept in mind that these reflect but one of many permutations and combinations of uses.

One of the strengths of this project was the interdisciplinary nature of the research. Although basic research was included (geological and microbiological components), most emphasis was placed on applying the results to optimise water resource use. If thermal spring developments could be implemented, the outcome could contribute – albeit in a small way – to problem of rural unemployment. Thermal springs could also be used to promote education and training. Benefits of establishing a resource-based educational centre in a rural area would be advantageous at all levels of education – from primary school through secondary and eventually tertiary levels. Skills development would form an integral part of the functions of the centre as would the incorporation of traditional knowledge into learning material.

The use of geothermal water resources has many advantages. Most of the thermal springs in South Africa are located in rural areas. Unemployment is a major problem in many of these areas. Geothermal developments are labour intensive and could provide a stable source of employment for a wide variety of skills. Moreover, the use of geothermal energy rather than electricity will lower a development's carbon and environmental footprint. This might provide an avenue for funding. It is thus clear that thermal spring developments address many issues raised in the National Development Plan for 2030. However, such developments could only become a reality if both industry and Government are prepared to commit to such small-scale development projects.

ACKNOWLEDGEMENTS

The research team wishes to acknowledge and extend our thanks to all owners and resort managers who allowed us access to their thermal springs, especially Erna Stander, Nelis Nel, the Drs Naude, Mr Rooms and Dept Correctional Services, Mphephu Resort, Eiland Resort, Sagole, Evangelina, Vischgat, Amanzimtaba, Natal Spa, Birlanyoni and Warmbaths, Mpumalanga – and all the other owners/staff of resorts. A special word of thanks to Forever Resorts, who provided us with information and allowed access to team members and post graduate students, and to SANBI for access to the Kruger National Park and the provision of guides and rangers.

Many thanks to the members of communities, garage attendants and police who pointed us in the right direction. We would have been lost without you.

We acknowledge the role played by the University of South Africa and The Council for Geoscience. A special word of gratitude to Ms Refilwe Legotlo and Mr Matome Sekiba for assistance with data acquisition and to Prof Don Cowan, Dr Thulani Makhalanyane**,** Prof Fanus Venter and Adele Lotter for their assistance with the extremophile microbiology. Thanks also to Ingrid Booyens for drafting the thermal spring map and to Annetjie van Rooyen and Samantha Jones at the ARC (ICSW) for analysing the flood of water samples and assisting with financial matters. Special thanks to Louis Verhoef for supplying information on mineral extraction methods.

Thank you to the WRC for providing the funding for this project and to Dr Shafick Adams for his guidance and forbearance as Research Manager and Charmaine Smith, Lani van Vuuren and Drinie J van Rensburg for their assistance and the steering committee for their suggestions and input. We gratefully acknowledge UNISA support staff for administrating the project and its finances as well as U-Travel for accommodation and travel arrangements. A special thanks to the Executive Dean: Environmental Sciences as well as past and present CoDs and administrative staff in the Department of Environmental Sciences.

All past and present members of the team – thank you for your enthusiasm and cooperation. This project could not have been possible without you. Thanks Nelia for the many hours spent on the layout and presentation of this report.

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LIST OF ACROMYMS/ABBREVIATIONS

AD	*anno Domini* (The year of our Lord)
AIDS	Acquired Immunodeficiency Syndrome
BLAST	Basic local alignment search tool
BC	Before Christ
°C	Degrees Celsius
CD	Compact disk
DNA	Deoxyribonucleic acid
DO	Dissolved oxygen
EC	Electrical conductivity
g/kg	Gram per kilogram
HIV	Human Immunodeficiency Virus
ICP-AES	Inductively coupled plasma atomic emission spectroscopy
ICP-MS	Inductively coupled plasma mass spectrometry
l/s	Litre per second
m^3/h	Cubic metre per hour
mcal/cm	Milli-calories per centimeter
mg/l	Milligram per litre
mW	Megawatts
PCR	Polymerase chain reaction
rRNA	Ribosomal ribonucleic acid
TDS	Total dissolved solids
TSS	Total suitability score
TWQR	Target water quality range
µg/l	Microgram per litre
µm	microgram

INSTITUTIONS/ASSOCIATIONS

ARC	Agricultural Research Council
CTFA	Cosmetic, Toiletry & Fragrance Association of South Africa
DAFF	Department of Agriculture, Forestry and Fisheries
DWAF	Department of Water Affairs and Forestry
ESKOM	Electricity Supply Commission (ESCOM). Also known by its Afrikaans name: Elektrisiteitsvoorsieningskommissie (EVKOM). The two acronyms were combined in 1986 and the company is now known as Eskom
ISCW	Institute of Soil, Climate and Water
KNP	Kruger National Park
NCBI	National Center for Biotechnology Information
SANBWA	South African National Bottled Water Association
SABS	South African Bureau of Standards
UCT	University of Cape Town
WRC	Water Research Commission

PROVINCES

N CAPE	Northern Cape
E CAPE	Eastern Cape
KZN	KwaZulu-Natal

LIST OF NAME CHANGES

CURRENT	PREVIOUS/ALTERNATIVE
Birlanyoni	Entambeni
Thangami	Black Umfolosi
Wagendrift	Warmbaths (Mpumalanga)
Sagole	Klein Tshipise; Klein Chipise
Moreson	Gordonia
Rhemardo	Welgevonden
Eiland	Letaba
Citrusdal	Die Bad
Fish Eagle Spa	Badtsfontein
Shu-Shu	Tugela Valley
Amanzimtaba	Mabalinwe; Kameelpoort
Tshipise	Chipise
Soutini	Souting; Sautini
Polile Tshisa	Kneghadrift
Towerwater	Toverwater, Toorwater

CHEMICALS (see Period Table included as Addendum F on the CD)

$BaCO_3$	Barium carbonate
$Ca(HCO_3)_2$	Calcium bicarbonate
CO_2	Carbon dioxide
CH_4	Methane
H_2S	Hydrogen sulphide
$MgCl_2$	Magnesium chloride
$NaHCO_3$	Sodium bicarbonate
Na_2CO_3	Sodium carbonate
$NaCl$	Sodium chloride
$NaOH$	Sodium hydroxide
N_2	Nitrogen
NO_2	Nitrite
NO_3	Nitrate
PO_4	Phosphate
O_2	Oxygen
SO_4	Sulphate

OPTIMAL UTILISATION OF THERMAL SPRINGS IN SOUTH AFRICA

CHAPTER 1: SETTING THE SCENE

Olivier J, Venter JS, Jonker CZ, Tekere M

1.1 INTRODUCTION: THE NATURE OF THERMAL SPRINGS

1.1.1 Background

Hot water sprouting from the Earth's surface has been the subject of awe since the dawn of humankind. Hot springs, also referred to as thermal springs, occur on every continent from Iceland to Antarctica. The most well-known springs usually erupt either as a mixture of steam and boiling water (geysers) (Fig. 1.1) or steam alone (fumeroles).

Fig 1.1 Old Faithful in Yellowstone National Park in Wyoming, USA (Wikipedia). This geyser erupts every 90 or so minutes and may send up to 32 000 litres of boiling water into the air

Erupting thermal springs are usually found in regions with recent volcanic activity where percolating water is heated by hot molten rock (magma) in the crust, and is released as steam or boiling water through channels in the rock at the surface (World Book Encyclopaedia, 1982). Thermal springs may also originate in non-volcanic regions, where faults in the Earth's crust allow water to penetrate to great depths. Due to increased pressure at depth, the rocks and water are heated. The rate of heating (the geothermal gradient) differs from one place to another, but is generally in the region of 2-3°C per 100 m (Press & Siever, 1986). When the hot, circulating underground water encounters an impermeable dyke or a fault, it may be forced to the surface as a thermal spring (Kent, 1969; Hoole, 2001). Such springs are said to be meteoric in origin, and the waters are usually cooler than those of volcanic origin. The mechanism for the development of a non-erupting or meteoric thermal spring is illustrated in Figure 1.2.

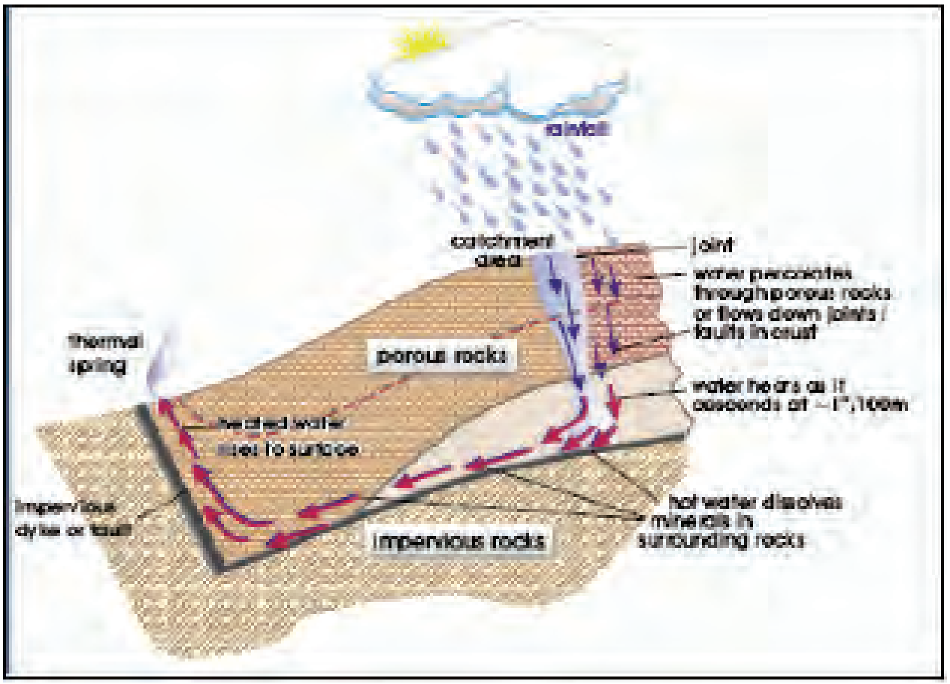


Fig. 1.2 Diagrammatic representation of the formation of meteoric thermal springs

Each thermal spring is unique with regard to its physical characteristics and chemical composition.

1.1.2 Physical characteristics

Thermal springs are by definition 'warm' – but there is no consensus regarding the exact temperature that distinguishes a spring from a thermal spring. In view of the fact that the climate of one region differs from that of another, what is 'warm' in one region may not be considered to be so elsewhere. Consequently, the definition of a thermal spring is often based on the mean annual air temperature of the specific site. La Moreaux and Tanner (2001) define springs with a temperature 'significantly higher' (i.e. by 10°F (6°C)) than the mean annual air temperature of the surrounding area, as thermal. However, the lack of a specific 'base' temperature may cause difficulties in interregional comparisons. In some countries a defining temperature of around 20°C is used following the climatological usage of this temperature to separate 'mild' from 'warm' climates (Kent, 1949). Most researchers use normal human body temperature (37°C) as the boundary between 'warm' and 'hot' waters.

The flow rates of hot springs range from tiny seeps to great gushes of water. The highest measured flow rate occurs at Evans Plunge in South Dakota, USA, where the water has a flow rate of 5 000 gallons (≈310 litres) per second (Wikipedia). Some springs alternate between high and low or no flow (La Moreaux & Tanner, 2001) such as Old Faithful, that erupts at intervals of about 90 minutes. Flow rates and volumes depend on differences in ground recharge and discharge elevations, and on the size of the fractures and openings discharging the groundwater to the surface (La Moreaux & Tanner, 2001; Helfrich *et al*., 2005). The discharge of a hot spring can also be influenced by weather patterns, especially in areas characterised by sinkholes and fractured rocks where floods and rainwater are directed into the ground (Grasby & Lepitzki, 2002; Witcher, 2002a; Helfrich *et al*., 2005).

1.1.3 Chemical composition

According to Allen (1934) and Knoblich (2002) the depth through which the water circulates contributes to the mineral composition of thermal springs. Since minerals are generally more soluble in hot water, thermal springs are often enriched with trace elements. The specific chemical composition of meteoric spring water will depend largely on the composition of rain water, its temperature and pH, the geology of the aquifer and the rocks through which the water circulates and rises to the surface. For example, springs rich in calcium bicarbonate are usually associated with limestone, while those with abundant alkali chlorides (NaCl and KCl) are normally associated with magma. Hot springs with little or no soluble components are affected by silicate rocks, such as granite, diorite, quartz porphyries, quartzite, slate and gneiss (Allen, 1934; Inguaggiato & Pecoraino, 2000).

The geology of area also determines the gaseous composition of thermal water. The most common gases associated with geothermal waters are nitrogen (N_2), carbon dioxide (CO_2), hydrogen sulphide (H_2S), oxygen (O_2), argon (Ar) and methane (CH_4) (Samsudin *et al.,* 1997). These gases may originate from the bacterial decomposition of organic material in the crust or as by-products of the reduction of sulphuric mineral deposits. Some are converted into carbonates and sulphates as a result of oxidation by air and reaction with water (Allen, 1934; Knoblich, 2002). The presence of gases such as H_2S, gives the water an unpleasant taste and odour (Samsudin *et al.*, 1997). It is interesting to note that thermal springs in the same geographic region may show different physical and chemical characteristics, indicating that the springs probably originate from different depths and thus reflect variations in the geological structure within the area (Allen, 1934; Knoblich, 2002).

1.2 GLOBAL PATTERNS OF THERMAL SPRING USE

Archaeological evidence indicates that thermal springs have been in use for religious and/or medicinal purposes since before 2000 BC in India and for hundreds of years in Crete, Egypt, China, Japan, Turkey and many European, middle-eastern counties as well as the Americas (Encarta Encyclopaedia, 1997). Many of these hot springs that originally began as sacred sites later evolved into centres of healing (Spicer & Nepgen, 2005: 13). The ancient Greeks were fanatical about cleanliness and a healthy body, and associated neatness with godliness. Early Greek baths were built near hot springs, and it was there that the Grecian elite met to exchange philosophical views and to treat their physical ailments (Spicer & Nepgen, 2005).

The Romans continued the ancient Greek tradition and utilised thermal spring waters for a multitude of purposes. Intricate systems of canals were constructed to warm chambers during winter (effectively constituting the forerunners of modern under-floor heating). The most enduring use of warm waters was the construction of communal baths. The baths included chambers and steam rooms and well as public baths – all fed by 'sacred springs'. The inner chambers of the bathhouses were used for social gatherings, 'serious' conversations, teaching and games (Hoole, 2001). The building of bathhouses spread throughout the Roman Empire. One of the most well-known public baths is situated at Bath, in England.

During Elizabethan times (late 1500s), the hot springs at Bath and Buxton were frequented by English aristocrats for health and recreational purposes. With the growth of interest in the curative abilities of thermal springs in the 1500s and 1600s, the English populace began to flock to these springs in large numbers (Hoole, 2001). However, in the early eighteenth century, after the discovery of the therapeutic benefits of sea water, people preferred travelling to the coast. As seaside towns developed, thermal spring resorts received fewer visitors and eventually their condition and popularity deteriorated (Towner, 1996; Hoole, 2001; Spicer & Nepgen, 2005). As a result, many countries were left with but few functional thermal resorts. Nevertheless, the use of thermal spring for leisure and tourism has continued to the present day in many countries. According to Lund and Freeston (2001), 48 countries were using thermal springs as resorts in the year 2000 (excluding data on countries such as South Africa, Malaysia, Ethiopia, Mozambique and Zambia). In some European counties and in Japan, the medicinal use of hot springs (balneology) is still considered as an integral part of medical care (Lund, 2002). Thermal waters are used for a wide range of ailments, such as chronic respiratory malfunctions, diseases of the peripheral nervous system, syphilis, rheumatism and disorders of the digestive system (Lund 2000; Bojadgieva *et al*., 2002).

Another use of thermal springs that started in the distant past and endured to the present is that of agriculture. Thermal springs have been used for irrigation purposes from time immemorial. It is claimed that Chinese people have used hot springs since the time of the Jin Dynasty (AD 265-420). La Moreaux and Tanner (2001) indicate that the Cunzhou City hot spring in the Hunan province in China was used to irrigate rice paddies so that they could grow rice even during the winter season (La Moreaux & Tanner, 2001). Over time thermal springs have come to be utilised for a greater variety of agricultural activities. Such activities include, but are not limited to, the heating of greenhouses and soils, aquaculture and crop drying. Countries known to use the heat from thermal for aqua- and agriculture include Iceland, USA, Macedonia and New Zealand (Rinehart, 1980; Lund & Freeston, 2001; Witcher, 2002; Fleischmann, 2006). Heat from thermal springs is also used to heat greenhouses and produce vegetables and flowers. The Oserian greenhouses in Kenya cover about 70 ha where roses and gerberas are produced for the export market. Here, steam from an early exploration well is used to control night-time (and wet season) humidity levels in the greenhouses while carbon dioxide from the well is used to enriched levels of CO_2 in air, resulting in improved plant growth. Traces of H_2S reduce disease occurrence (Deliverable 16).

Although coloured thermal mud was used historically as paint for pottery, skins and rock art, the mineral crusts of evaporates precipitated around the mouth of a thermal spring may be spectacular. The travertine deposits at Pamukkala in Turkey attract tourist from all over the world (Fig. 1.3). The economic importance of the mineral content of the waters has only recently become evident. Such deposits may be rich in calcium, sodium, gold, silver, boron, copper, lithium, manganese and zinc and a host of rare elements (Lewis *et al*., 1998).

Fig.1.3 Terraces of travertine in Turkey (Wikipedia)

The use of hot springs as a source of electricity is also relatively recent. According to DiPippo (1999), electricity was first generated from geothermal energy in the Tuscan village of Larderello in Italy when Prince Piero Gonori Conti powered a ¾-horsepower reciprocating engine to drive a small generator (Fig. 1.4). He was able to light a few bulbs in his boric acid factory situated amid the boron-rich geothermal steam field. The system was upgraded to 20 kW in 1905.

Fig. 1.4 The use of hot springs as a source of electricity 1905 (Chevalier & Musekiwa, 2010).

From this early beginning, the use of geothermal energy for the generation of electricity has mushroomed and in 1958, New Zealand became the first country to operate a commercial geothermal power plant using a liquid-dominated, hot water type reservoir at Wairakei. In 2010, there were 350 geothermal power stations in the world producing 10 000 MW for an estimated 60 million users (Chevalier & Musekiwa, 2010).

The most recent use of geothermal waters is for their biological wealth. Thermophiles are a group of extremophile organisms that live in hot environments. They contain enzymes that are stable at high temperatures, which make them useful for the pharmaceutical, food processing and chemical industries, in biofuel, biomass and thermo-stable protein production and in metabolic engineering. Table 1.1 presents examples of thermophilic bacteria used for industrial purposes.

TABLE 1.1: ENZYMES FROM THERMOPHILES

Enzymes	**Applications**	**Producing organisms (literature)**
Esterases and lipases	Organic synthesis	*Sulfolobus solfataricus*
Proteases and peptidases-: serine proteases, cysteine proteases, the threonine-dependent proteasomes, metal-dependent proteases,	Additives for laundering, organic solvents, peptide synthesis	*Thermococcus litoralis* *Pyrococcus furiosus* *Thermotoga maritime* *Thermococcus stetteri*
Saccharolytic / cellulolytic enzymes: *b*-glycosidase, *b*-glucosidase, *b*-galactosidase, endoglucanase, exoglucanase and *b*-glucosidaseand *b*-laminarinase	Pulp and paper, Starch and fermentation industries	*Sulfolobales* species *Pyrococcus furiosus* *Aquifex aeolicus*, *Thermococcus* species
Xylan-degrading enzymes: endo-b-1,4-xylanase and b-1,4-xylosidase.	Food, feed, pulp and paper industries	*Thermococcus* species *Thermoanaerobacter mathranii*
Chitin-degrading enzymes		*Thermococcus chitonophagus,* *Thermococcus kodakaraensis KOD1* and *P. Furiosus, Bacillus circulans*
Alcohol dehydrogenases	Chemical industry	*Sulfolobus solfataricus*
Nitrile-degrading enzymes: amidases and nitrilases	Industrial biotransformations	*Sulfolobales* species
Aminoacylases	Application in fine chemistry	*Thermococcus litoralis*

Egorova & Antranikian (2005); Van den Burg (2003)

1.3 HISTORICAL USE OF THERMAL SPRINGS IN SOUTH AFRICA

1.3.1 The period prior to 1900

The use of thermal springs far predates the arrival of the settlers in 1652 in South Africa. Paleontological and archaeological research uncovered stone artefacts and fossilised bones dating from about 120 000 years ago from the spring mound at Florisbad. The extraction of salt at Die Eiland (Letaba) and Soutini (Souting) hot springs is also an ancient practice. It has been estimated that salt production started during the early Iron Age (Antonites, 2006) at Soutini. There they "lixiviated the mud through which the water issued and evaporated the resultant solution over the open fire in clay pots" Kent (1942:35). The earth scattered over the Mamatzapi watercourse is said to be a relic of the salt-making industry. Salt-making is still practiced at the Souting (Baleni) hot spring (Fig. 1.5).

Fig. 1.5 Salt making at Baleni (Photo: Tshibalo, 2011)

Undoubtedly the European settlers heard about many of the South African thermal springs from the local 'Hottentots' or Khoi (Booyens, 1981). It is surmised that they Khoi and San most likely learnt of some of the medicinal properties of the springs from animals who instinctively sought the thermal spring when needing healing (Spicer & Nepgen, 2005). Some thermal springs, however, were discovered by accident (see box 1.1).

BOX 1.1

The Bath (Citrusdal) was accidentally discovered in the 1730s when an ox (called Kolberg) stepped into a hole and could not get out. When the herdsman and some helpers tried to rescue the animal, they discovered hot water in the hole. This led to the discovery of the main spring. It was originally established as a military post under the auspices of the Dutch East India Company. Since then it has undergone numerous changes of ownership until 1903 when it was sold to James McGregor, the great grandfather of the current owner. [Spicer & Nepgen, 2005: 17]

The use of South African thermal spas for medicinal and social purposes was well-established at the time of European settlement in the Cape. Prof Bun Booyens, in his book entitled *Bronwaters van Genesing: Die tradisionele warmbronkultuur in ons volksgeskiedenis* gives a detailed and entertaining overview of the discovery (by Europeans), geographical characteristics and medicinal use of South African thermal springs during the seventeenth, eighteenth and early nineteenth centuries from material compiled from letters, old periodicals and journals, official documentation from the Dutch East India Company and from anecdotal evidence obtained during visits to these springs.

His discussions follow, in chronological order, the ‘discovery’ and development of thermal springs from those relatively close to Cape Town – ‘over ‘t gebergte van Hottentots-Holland’ (the Overberg, including what are now known as Caledon, Brandvlei, Goudini, Malmesbury, Citrusdal, Warmwaterberg, Towerwater, Montagu and Cradock), to those further away at Graaff-Reinet and Beaufort West, Uitenhage and Aliwal North) and eventually the thermal springs in the north (Florisbad, Warmbaths (at Bela Bela, Die Oog, Badseloop, Tshipise and Machadodorp (Badplaas)) and KwaZulu-Natal (Natal Spa, Shu-Shu, Lilani and the ‘Swart Folozibad’ (Thangami)).

Although conflicting reports were given regarding their medicinal value in the late nineteenth century, water treatments were regarded as highly therapeutic for the treatment of especially arthritis, rheumatism and skin ailments. An example of this is provided in Box 1.2, in which Spicer and Nepgen (2005:20) describe the discovery of the curative properties of the thermal spring at Montagu.

BOX 1.2

Local legend has it than one of the Boer trekkers injured his hand and the whole party stopped to rest. The injured man’s hand soon began to fester. As he had sampled water in a stream, he followed its path to the source. When he saw water bubbling from a rock, he thrust his injured hand in it. To his surprise, the water was piping hot. He bathed his hand in the water for the next few days and soon the hand was healed. Word of this ‘miracle’ quickly spread and the fountain, **Montagu,** became famous (Spicer & Nepgen, 2005: 20)

Rindl in 1916 wrote a report on ‘Medicinal Springs of South Africa’ documenting their chemical characteristics and purported medicinal value of thermal springs. Prof LE Kent from the University of Cape Town, also referred to their medicinal value stating that as most of them were alkaline; they could be used for digestive ailments (Kent, 1952). Kent further acknowledged that drinking water containing certain chemical components cleansed the body by eliminating harmful substances (Booyens, 1981).

According to Booyens (1981), the first baths established were mere holes, hollows or pits which were dug in the course of the river. This led to the belief that mud was an inherent part of the warm water experience and that it had distinct healing qualities. As a result, people visited springs for mud healing, rather than swimming (Figs. 1.5 & 1.6). Mud baths were often covered with a roof of material or reeds with side panels erected to ensure privacy to the patient. Mud baths could only be constructed at springs discharging in clayey soils and in low-lying areas, ‘in which soil and plant materials had been deposited throughout the centuries’. Warmbaths (Bela Bela) was especially well known for its mud baths since the entire area around the spring is made up of deep layers of marshy soil (Booyens, 1981:103; Hoole, 2001:46). Its use as mineral baths only occurred much later.

Fig 1.6a Mud cure at Eendvoëlvlei (between Stellenbosch en Firgrove) (Photo from Ms A van der Westhuizen, Somerset-West (In Booyens, 1981)

Fig 1.6b The mud bath at Warmbath in Transvaal at the beginning of the 1900 century (Booyens, 1981)

Although many South African hot springs were visited for health reasons, people spent time around the spring relaxing. An example is the spring at Caledon. The entire family would accompany a single patient to the baths. As a result, the baths were used for both health and entertainment purposes. They developed into health and entertainment centres (Booyens, 1981:105). While some of the health spas, such as Badplaas, Christiana and Natal spa remained as recreational resorts, others developed into permanent settlements. Examples of such towns are Caledon, Aliwal North and Warmbaths (Bela Bela) (Hoole, 2001). By the mid-1900s, about 70 thermal springs had been identified. Their locations were mapped by Kent and are shown in Figure 1.7.

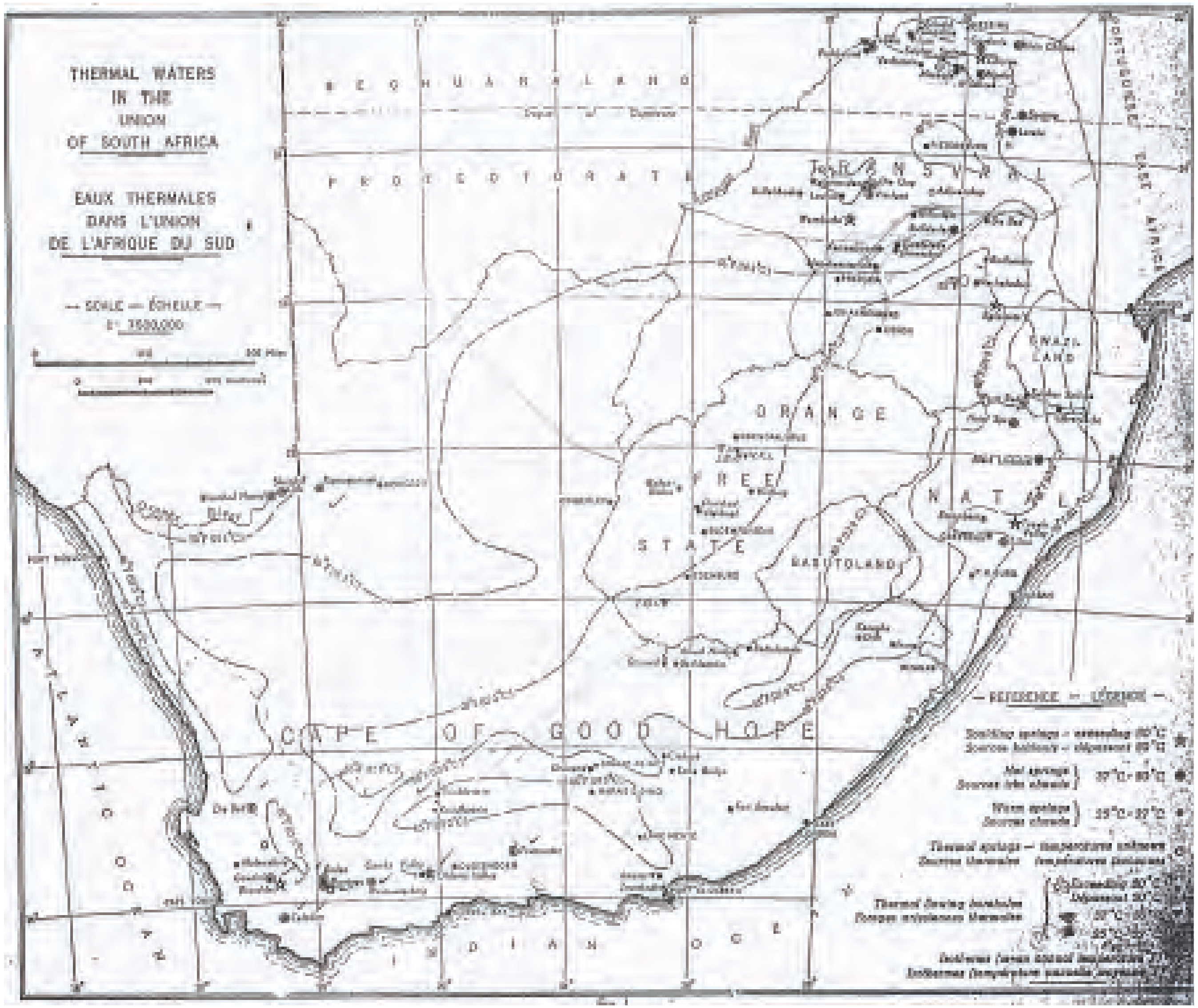


Fig. 1.7 Distribution of thermal springs according to Kent (1949)

1.3.2 The changing scene of thermal spring: the 20th Century

Unfortunately, not all previously developed springs in South Africa have maintained their popularity, with some being neglected over time. One of the latter is Baden Baden. This medicinal spring was used for its therapeutic properties during the early 1900s but all that currently remains is a derelict bath-house as shown in Figure 1.8.

Fig. 1.8 Current state of bath house at Baden Baden(2012)

Other resorts that have declined in popularity include Aliwal, Florisbad (Free State), Towerwater (Western Cape), Sagole (Limpopo Province) and Machadodorp (Mpumalanga). There is currently a concerted effort by local and national government to restore Aliwal North to its former glory. Renovations will hopefully be completed by the end of 2013 to reinstate Aliwal as one of the leading thermal spring health and wellness resorts in the country.

There are probably a number of factors that contributed to the decline of these resorts. The advent of the Anglo Boer War (1899-1902) and World War 1 (1914-1918) undoubtedly left their mark on these resorts. The discovery of archaeological artefacts at Florisbad and its proclamation as research centre contributed to its demise it as a balneology centre and tourist resort. A devastating tornado in 2010 compounded the dilapidated situation at the baths (Fig. 1.9)

Fig. 1.9 The old bath house at Florisbad after the 2010 tornado (SAWB site Photo Dr James Brink)

In addition to socio-historical influences, ownership may play a role on the state of development of the resources. Many of the highly developed tourism resorts are owned by companies specialising in the tourism market, such as Forever Resorts. Others belong to limited corporations with use restricted to members only (e.g. Libertas). Some, such as Badsfontein, in the Free State, have been developed by the owners into a guest house. Some thermal springs remain in private hands for exclusive use by the land owner. Examples are Loubad (where ownership of the thermal resource remains in family possession and, according to the will made by the previous owner, may not be developed at all); Sulphur spring in Limpopo (belongs to the Spanish Royal family and is not open to the public); the owner of Towerwater is a recluse and prohibits development of the spring; Machadodorp has suffered from repeated sale and purchase by new owners and a lack of sufficient funding; and Brandvlei, the second hottest spring in the country, is located within the ground of Brandvlei Prison, which is a maximum security facility. Special cases are that of Florisbad and Soutini. Both are of archaeological and anthropological importance and the latter – where salt has been ‘mined’ for hundreds of years – is now a national cultural heritage site.

The majority of thermal springs that remains undeveloped as resorts are located in previous homelands or tribal areas and fall under the control of the tribal authority. These include Minvamadi (Limpopo), Birlanyoni (KwaZulu-Natal), and Kneghadrif (Eastern Cape).

Land use is another anthropogenic factor that may have affected the development status of thermal spring resorts. It is speculated that springs, such as Winburg, dried up due to drilling operations which affected the water table and excessive pumping of groundwater may also have been responsible for the fluctuating flow rate at Eiland and Constantia. Other springs that have dried up in the intervening years since the research by Kent (1949) include Icon, Stindal and Masequa. The farm on which Vetfontein lies has been purchased by ZZ2 and is now used for cultivating tomatoes. A well-known coal exploration firm is current surveying the farm Windhoek in Limpopo. If mining operations do take place, the thermal resource will be lost for any type of development.

Accessibility could also account for the slow development of thermal springs, such as those at Riemvasmaak, Lilani and Shu Shu. The latter is found on an island in the Tugela River and cannot be reached during the wet summer months.

It is noticeable that those that are close to towns or settlements seemed to prosper. The availability of funds can play as important a role in development status as any other. It is, however, noticeable that the best developed resorts are those with the highest temperature and flow rates (barring Brandvlei).

It is thus clear from the above that, in accordance with global trends, the popularity of South African thermal spring resorts also waxed and waned over time. Nevertheless, it evident that most developed South African thermal springs are used almost exclusively for recreation and tourism. The springs still active as resorts at the turn of the 21st century were listed by Boekstein in 1998.

TABLE 1.2: SOUTH AFRICAN THERMAL SPRING RESORTS (BOEKSTEIN, 1998)		
Name	**Nearest town/ Province**	**Accommodation**
The Overberger	Caledon, W Cape	Hotel
Goudini Spa	Worcester, W Cape	Chalets, flats, camping sites
Brandvlei	Rawsonville, W Cape	Picnics facilities only
Avalon Springs	Montagu, W Cape	Hotel, self-catering flats
Warmwaterberg	Ladismith, W Cape	Flats, log cabins, caravans, caravan sites
Calitzdorp spa	Calitzdorp, W Cape	Self-catering chalets, flats, caravan sites
The Baths	Citrusdal, W Cape	Chalets, flats, caravan sites
Aliwal Spa	Aliwal North, E Cape	Chalets
Badsfontein Guest Farm	Aliwal North, E Cape	Cottage
Cradock Spa	Cradock, E Cape	Chalets, caravan sites
Riemvasmaak	Kakamaas, N Cape	Camping site
Forever Vaal Spa	Christiana, N W Province	Chalets, hotel, caravan sites
Florisbad	Bloemfontein, Free State	Picnic sites
Thangami Safari Spa	Vryheid, KwaZulu-Natal	Chalets, caravan sites, guest houses
Natal Spa	Vryheid, KwaZulu-Natal	Hotel, caravan sites
Shu Shu Hot Springs	Kranskop, KwaZulu-Natal	On island in Tugela river. Caravan and camping sites
Lilani	Greytown, KwaZulu-Natal	Chalets
Mabalingwe Spa	Pretoria, Gauteng	Chalets
Forever Spa Badplaas	Carolina, Mpumalanga	Hotel, chalets, caravan park
Zimthabi	Thabazimbi, Limpopo	Chalets caravan sites
Die Oog	Mookgophong, Limpopo	Chalets, caravan sites
Rhemardo	Mookgophong, Limpopo	Chalets, caravan sites
Mphephu	Louis Trichardt, Limpopo	Chalets
Sagole Spa	Sagole, Limpopo	Chalets, dormitories
Forever Eco Tshipise	Musina, Limpopo	Chalets, hotel, guest house, caravan sites
Forever Eco Eiland	Tzaneen, Limpopo	Chalets caravan sites
Makutsi Safari Farm	Tzaneen, Limpopo	Chalets
Libertas (Borehole)	Mookgophong, Limpopo	Chalets, log cabins, gaboose (train coach) caravan sites
Lekkerrus (borehole)	Mookgophong, Limpopo	Chalets, log cabins, caravan sites
Môreson	Musina, Limpopo	Private, houses, caravans
Vischgat	Mookgophong, Limpopo	Guesthouse

1.4 MOTIVATION, AIMS AND OBJECTIVES OF THE STUDY

It is thus evident that the only type of development considered for thermal springs was for their use as resorts. No attempt has been made to date to investigate the potential of South Africa's thermal spring resources for the host of alternative uses discussed in section 1.2. Such alternative uses could make an erstwhile 'useless' thermal spring economically viable or increase the number of uses at a specific spring, thereby increasing the economic sustainability of an enterprise. Moreover, it is not known whether the current use of a thermal spring is suitable for use for recreational activities. The identification of appropriate alternative uses for geothermal resources is based on up-to-date knowledge of the physical and chemical properties of the spring. Unfortunately, information of these aspects is sporadic and has not been collated or verified for accuracy.

There are thus a number in gaps in our knowledge concerning thermal spring use. The aim of this project was to identify the optimal uses of thermal springs in South Africa. In order to accomplish this, the following research questions needed to be answered:

1 What are the geological, biological, physical and chemical characteristics of the thermal springs in South Africa?
2 How are the springs currently used and are these uses appropriate – especially with respect to impacts on human health?
3 What alternative types of development could be instituted at the springs, and which would be most sustainable based on the physical and chemical properties of the springs?

The following chapter in this report deals with the geological and biological setting of thermal spring. It includes a summary of past knowledge as well as snippets of information obtained in the course of this project. Chapter 3 addresses the second objective, providing information on current uses of the springs and evaluating the possible risks to human and animal health based on the chemical characteristics of the waters. In chapter 4, the physical and chemical requirements of a variety of alternative uses are discussed and the springs evaluated for their 'fitness' for use. This information is collated for a limited number of case studies and suggestions given for integrative development utilizing the diversity of appropriate uses, and where possible indicating a cascade of uses for the same resource. This is the crux of chapter 5. The ultimate chapter provides a summary of the project and milestones achieved in terms of Water Research Commission requirements. The chapter concludes with a section on the significance of the research with respect to the National Development Plan for 2030.

In view of the interdisciplinary nature of the project, the research team comprised geologists, geophysicists, geochemists, microbiologists, geographers and environmental scientists – each using their particular methodologies. These will not be discussed in a separate chapter, but will be integrated into the relevant sections.

CHAPTER 2: THE GEOLOGICAL AND BIOLOGICAL HOT SPRING SCENE IN SOUTH AFRICA

Nyabeze P, Saeze H, Yibas B, Tekere M, Tshibalo AE, Venter JS, Olivier J, Jonker CZ, Sekiba M & Motlakeng T

2.1 THE GEOLOGICAL SETTING: AN OVERVIEW

2.1.1 Methodology

A thorough literature survey was undertaken to collect existing information on the physical and chemical characteristics of South African thermal spring waters. In addition, a series of field data collection trips were conducted during the period 2008 to 2013 (the first few trips preceded this WRC project). The majority of springs in South Africa were visited at least once during the course of the research. Water temperatures, together with other physical parameters such as pH, electrical conductivity (EC) and Eh were measured as close to the issuing point as possible using portable multi-sensor meters, the Mettler Toledo SevenGo Duo Pro.

Water samples for chemical analyses were collected in separate 250 ml plastic bottles and kept in a cooler box for transportation to the laboratories for analysis. Samples collected for cation analysis by CGS team members were first filtered and acidified by HNO_3. The samples for anions were filtered. Some of the samples were analysed at the Council for Geoscience Laboratory in Pretoria and others at the accredited ARC (Institute of Soil, Climate and Water (ISCW) laboratories in Pretoria. Analytical techniques included ICP-MS and ICP-AES.

A summary of the physical characteristics and chemical composition of the thermal springs (excluding gases) was compiled and is included as Addendum A on the CD. Data include geographical coordinates, temperature, flow rates, EC, TDS, major ions and trace elements. However, close scrutiny of the results showed significant anomalies in the values of elements. The database was subsequently cleansed by removing outliers, and means calculated for each element (variable) for each spring using excel tools. This database (Addendum B) is considered to be final one and formed the basis for the analyses in Chapters 3 and 4.

Data on environmental isotopes provide critical information about sources of groundwater recharge, and the timing of recharge. Thus, in addition to the chemical analyses, 20 litres water samples were collected from 20 thermal springs and/or thermal boreholes in Limpopo using standard protocols and analysed for $\delta^{18}O$ and $\delta^{2}H$, carbon isotopes (^{14}C and ^{13}C) and tritium by a gas mass spectrometry technique at Ithemba Laboratory, Environmental Isotope Group (EIG), in Johannesburg, South Africa. Equilibration time for the water samples with hydrogen is about one hour and CO_2 is equilibrated with a water sample in about eight hours. The analytical precision is estimated at 0.1‰ for oxygen-18 and 0.5‰ for hydrogen-2 (Saeze, 2013).

Radiocarbon analyses were carried out on samples precipitated in the field as $BaCO_3$ from at least 50 litres of each sample water (the sample volume depends on the concentration of dissolved inorganic carbon (DIC) determined by alkalinity). The precipitate was induced by $BaCl_2$ solution in an alkaline environment (guaranteed by the addition of NaOH). Fourteen samples for carbon-14 and carbon-13 determination were subjected to this procedure. At Ithemba Laboratory, the dissolved inorganic carbon was extracted in precipitated water samples and its ^{14}C content was measured by liquid scintillation spectrometry and results expressed in per cent modern carbon (pmC). The $\delta^{13}C$ of Total Inorganic Carbon was measured using a mass spectrometry technique and reported in Vienna Pee Dee Belemnite (VPDB) (Saeze & Rikhotso, 2013; Deliverable 26).

Geophysical surveys were carried out in order to provide information on subsurface groundwater aquifers. Multiple geophysical methods were employed, including electrical resistivity tomography (ERT), electromagnetic conductivity profiling (ECP) and total magnetic profiling. Surveys were carried out along accessible areas in the vicinity of the hot spring eyes. The relative electrical conductivity and degree of magnetisation was deduced from the geophysical results.

Ground-based total field magnetic readings were recorded using a Geometrics model 856 and a Scintrex NaVmag Sm5 magnetometer. Diurnal variations at the base stations were monitored and recorded using a Geotron G5 magnetometer. A station spacing of 10 m was achieved along accessible and predominantly north to south oriented lines. The total field data were corrected for diurnal variations using the Geometrics Software package Magmap 2000. The corrected data were geo-referenced using coordinates that were recorded using a GPS during the survey. The survey data was despiked to remove the effects of cultural objects such as fences and was corrected for diurnal variations. Basaltic dykes and sills were mapped using the magnetic survey method.

Terrain conductivity measurements were carried out using a Geonics EM34-3, electrical conductivity unit. The reason for using this technique was to map variation of the terrain electrical conductivity. Fracture and shear zones are usually indicated by higher electrical conductivity values. The Geonics EM34-3, electrical conductivity meter unit was utilised with a 20 m dipole, transmitter – receiver separation and vertical coplanar coils that couple inductively with the ground. This geometry couples more with horizontal and sub horizontal layers. Data was collected along profiles at a station spacing of 10 m. The collected data was presented as profiles and gridded maps. Groundwater flow paths and water bearing zones were delineated from the high electrical conductivity zones.

Electrical resistivity data was recorded using a 72 channel multi-electrode, Iris Syscal Pro unit. The electrical resistivity method involves transmitting a direct current into the ground through stainless steel electrodes. The resultant voltages are measured for various potential electrode pairs along a profile. The electrodes were arranged in a dipole-dipole configuration for investigating lateral variations in resistivity or its reciprocal the electrical conductivity. A Wenner-Schlumberger array was used for investigating the variation of resistivity\electrical conductivity with depth. Electrode separations of 5 m and 10 m were used. There is a weathered and moisture bearing, low resistivity zone between the surface and a depth of 30 m. Possible faults and fractures were also mapped using the resistivity technique. High resistivity can be attributed to the presence of a basaltic sill or a dyke. The hot ground water could be exploiting faults or fractures in the basalt.

Ground geophysical surveys were carried out at several hot springs in the Limpopo and Eastern Cape provinces. The Limpopo hot springs comprised Dopeni, Evangelina, Mphephu, Sagole, Siloam, Soutini and Tshipise. The Eastern Cape hot springs were Aliwal North, Babsfontein and Polile Tshisa.

Detailed geophysical surveys utilising magnetic, electrical and electromagnetic methods were carried out at Sagole and Siloam Springs (Nyabeze, 2013). Articles and conference presentations that were produced as part of geophysical deliverables were as follows; No. 5. Geophysics of Limpopo Springs; No. 14. Geophysics of Artesian Springs; No. 15. Geophysics of natural and artesian thermal springs; No. 21. Geophysics of thermal springs. Within the framework of deliverable No. 16, the geophysics research team visited East African thermal springs in Ethiopia and Kenya to get an insight into geophysical methods that were being used to investigate deep aquifers. Full copies of these are included on the CD.

2.1.2 Location of thermal springs

2.1.2.1 Geographical distribution

Almost all of the thermal springs in South Africa are confined to a broad band (400 km wide) extending across more than half of the country from Piketberg in the Western Cape through KwaZulu-Natal, the Free State and Gauteng, up to the Soutpansberg in Limpopo (Kent, 1952). Kent (1949) mapped 74 of these (Fig. 1.7). However, in the course of this study nine 'new' springs were identified and the waters analysed. Seven of these, namely Tshalungwa, Tshipala, Maritumbe, Malahlapanga, Mafayini and Matiyavilla are located in the northern part of the Kruger National Park. Minwamadi, in the vicinity of the Nzhelele Dam, and Siloam, in the vicinity of the Siloam hospital, were previously mentioned by Winfield (1980), but no information was given on their characteristics. The distribution of all springs mentioned by Kent (1949) as well as the 'new' springs, are depicted in Figure 2.1.

At least 28 thermal springs and boreholes are located in the Limpopo Province. They occur in two main regions, namely the Waterberg in the south and the Soutpansberg in the north. Isolated springs are found in the extreme north-west of the province and to the east of the escarpment. Fourteen springs have been recorded in the Western Cape, 13 in Mpumalanga, 10 in the Eastern Cape, four in the Free State, five in KwaZulu-Natal and one in the Northern Cape. Unfortunately a number have dried up, including Winburg, Icon, Constantia and Masequa,

The location and characteristics of thermal springs can be explained by their tectonic setting and structural geology (Lumb In: Rybach & Muffler, 1981:82**)**

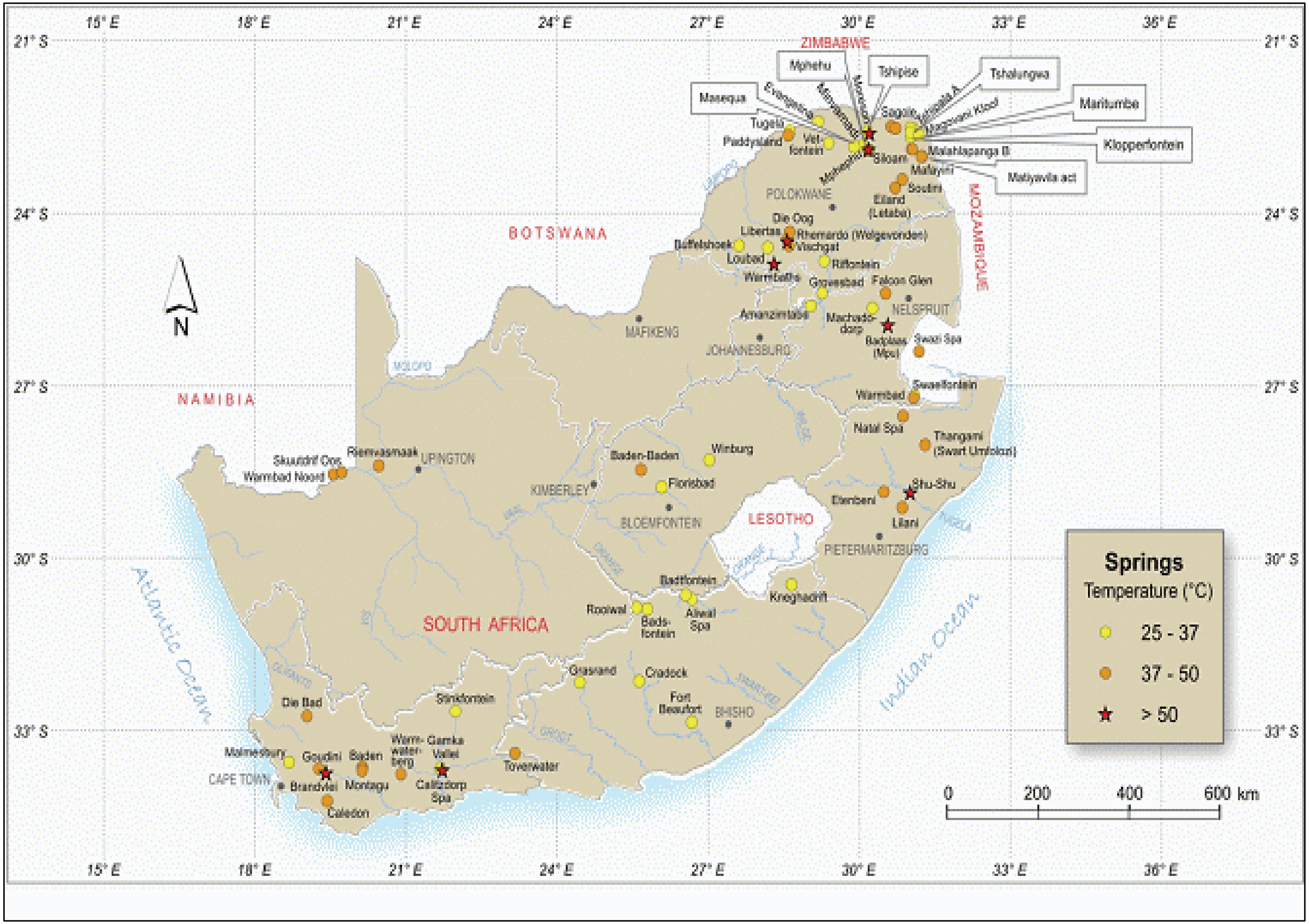


Fig. 2.1 Location of thermal springs in South Africa (Olivier et al., 2013)

2.1.2.2 *Geological controls*

The tectonic setting

McCarthy and Rubidge (2005) and Visser (1998) give detailed descriptions of the tectonic history of southern Africa (see Box 2.1). The two figures, (2.2 and 2.3), depict the tectonic setting of southern Africa and the geographical distribution of thermal springs.

BOX 2.1

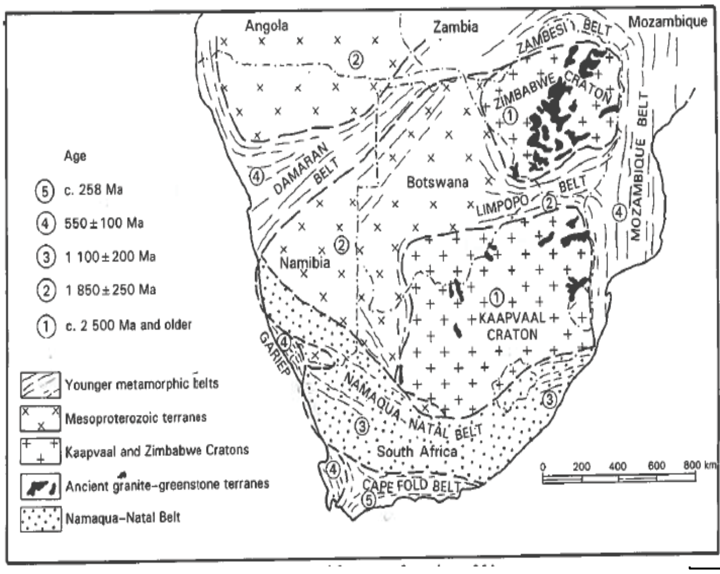
According to these authors, the geological history occurred in eight general steps. Island arcs amalgamated to form micro-continents, and these accreted to form the Kaapvaal Craton. It comprises mainly granites (granitoids) and greenstone belts (Visser, 1998). The Kaapvaal Craton stabilised approximately 3100 million years ago, and forms the nucleus of the southern African sub-continent.

Over the next 400 million years the Dominion Group and Witwatersrand Supergroup were deposited, and very importantly, the Limpopo Belt had formed. The Limpopo Belt separates the Kaapvaal Craton and the Zimbabwe Craton (Visser, 1998), comprising mainly gneisses (Johnson *et al*., 2006). The Limpopo Belt is further divided into the Southern Marginal Zone, the Central Zone and the Northern Marginal Zone (Johnson *et al.*, 2006).

From 2700 million years ago up until 1000 million years ago, a sequence of deposition, intrusion (such as the Bushveld Igneous Complex, and metamorphism occurred to form the Ventersdorp-,Transvaal- and Olifantshoek Supergroups, as well as the Waterberg and Soutpansberg Groups (McCarthy & Rubidge, 2005). During this period the Ubendian Belt was formed, which is seen as the zone between the Congo Craton and the Kaapvaal-Zimbabwe Craton. The Namaqua-Natal Belt is known as the zone of metamorphic rocks on the southern edge of the Kaapvaal Craton.

However, the Soutpansberg depositional basin was formed already around 1 800 million years ago as an east-west trending asymmetrical rift or half graben along the Palala Shear Belt. Deposition started with basaltic lavas, and was followed by sedimentary rocks. At this stage, there was a featureless landscape. After the sedimentation has ceased about 150 million years, the area was strongly block–faulted, and then uniformly tilted to the north. Approximately 60 million years of erosion formed the current morphology of the Soutpansberg Mountains.

The rocks which developed in the half graben subsided along a main border fault situated at about 20 km south of the Soutpansberg mountainous area. The area is dominated by igneous and metamorphic rocks. The rocks are mainly basalt, schist and granite. The geology is characterised by dykes and shear zones (Kent, 1949; 1969; 1986 www.soutpansberg.co.za).



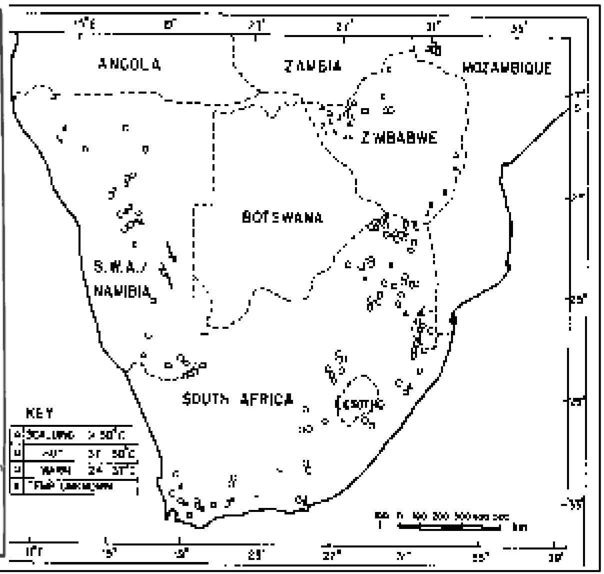
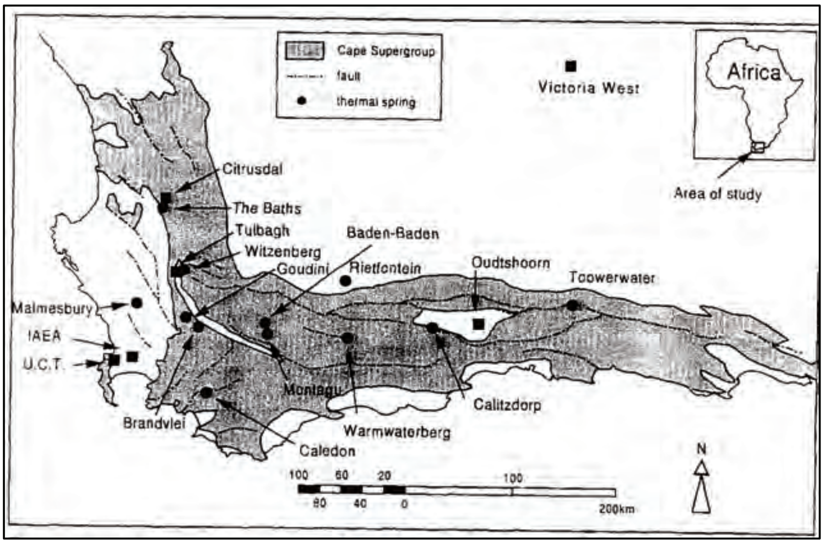


Fig. 2.2 Southern African tectonic settling (Visser, 1998)

Fig. 2.3 Spatial distribution of southern African thermal springs excluding Mozambique (Ashton & Schoeman, 1986)

Comparison of these two figures shows the close spatial coincidence between the thermal springs in South Africa and the edges of the Limpopo and Namaqua-Natal mobile belts. There appears to be some correspondence with the ancient granite-greenstone terranes (see Box 2.2).



BOX 2.2

The clear association between thermal springs in the Western Cape and the Cape Fold belt is illustrated in Figure 2.4.

Only Malmesbury and Rietfontein fall outside this belt.

Fig. 2.4 Thermal springs of the Cape Fold Belt (Diamond & Harris, 2000)

The role of structural geology

Geological studies have shown conclusively that the origin of each individual thermal spring in South Africa is associated with the local presence of deep geological structures, such as folds, faults and dykes. These structures provide continuously circulating artesian systems where rain and surface water descends to depth, is heated by the rocks, before rapidly returning to the surface without losing much heat (Kent, 1969). At many of the thermal springs, the water rises along fault zones or fissures associated with seismic activity, while other springs rise along wall-like bodies of impermeable rock (dykes) which impede the free movement of ground water (Ashton & Schoeman, 1986). These impermeable sections of fault zones, folds or dykes may restrict the direct percolation of water from the intake area to the spring eye, forcing the hot groundwater to the surface (Kent, 1969).

The springs in Limpopo (the province with most thermal springs) developed in the half graben in the Soutpansberg depositional basin that subsided along a main border fault situated at about 20 km south of the Soutpansberg mountainous area. The geology is thus characterised by dykes and shear zones (Kent, 1949; 1969). The second highest number of thermal springs is located in the Western Cape. These springs arise in the Cape Fold Belt (CFB) and include The Baths (near Citrusdal), Malmesbury, Witzenberg, Goudini, Brandvlei, Caledon, Avalon (Montagu), Baden-Baden, Warmwaterberg, Rietfontein, Calitzdorp, and Towerwater. The Cape Fold Belt is composed of rocks of the basement and the Cape Supergroup. These rocks include the Malmesbury Group, Cape Granites, the Table Mountain Group, Bokkeveld Group and Witteberg Group. Most of these springs fall within the Table Mountain Group

The most authoritative work on the geology of thermal springs was conducted by Kent (1949; 1962; 1969). The thermal springs and associated geology and structural controls of the KwaZulu-Natal springs are discussed by Molengraaff (1898 as quoted by Humphrey and Krige, 1932), Du Toit (1918; 1928), Gevers (1942; 1963); Hoole (2001). It appears that relatively little research has been conducted on the thermal springs in the Free State and Northern Cape, with the exception of Scott and Cooremans (1990) (Badsfontein, Aliwal Noord, Beersheba, Roodewal) and Douglas, 2001 (Florisbad).

Examples of the controlling influence of structural geology on thermal springs are shown in Figures 2.5 and 2.6 – one depicting the situation at springs in Limpopo and the other, on springs in the Western Cape – both from Kent (1949).

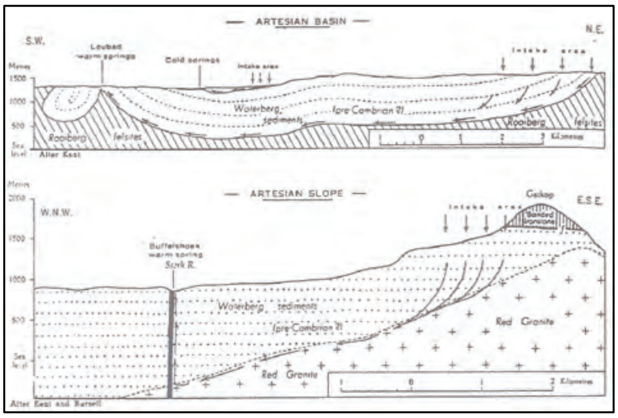


Fig. 2.5 Structural geology of Loubad and Buffelshoek

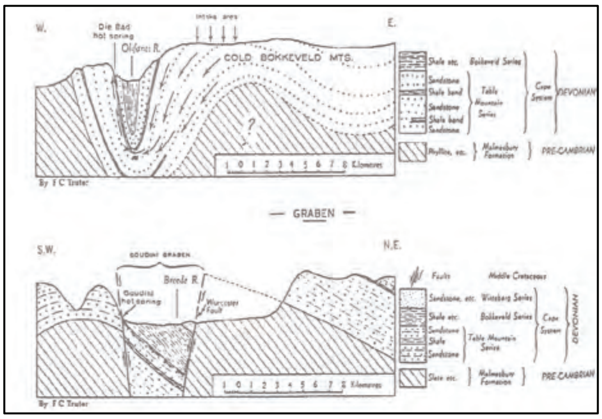


Fig. 2.6 Structural control at Die Bad (Citrusdal) and Goudini

Detailed research by Nyabeze *et al.* (2011) elucidated the structural controls of springs and groundwater geophysics at Sagole as follows: An east to west trending fault was inferred at Sagole Spring, based on ground magnetic data that was collected at stations spaced 10 m apart. The upwelling of hot groundwater probably exploits fractures. The fractures cross cut an inferred basaltic dyke or sill. Modelling of airborne magnetic data indicated that the heat source, Curie depth was an anticlinal structure at a depth range of 3 km to 5 km Nyabeze et al. (2013). Intersecting northwest and east to west trending lineaments were interpreted at the hot spring. Groundwater flow paths oriented south to north were mapped using the electromagnetic conductivity profiling technique, and electrical conductivity values in the range 50 mS/m to 100 mS/m were obtained, indicating the presence of water bearing zones or fractures. A 10 m dipole-dipole resistivity survey was carried out across the spring to confirm the electromagnetic conductivity results. The resistivity results show that the depth of weathering was approximately 30 m, the resistivity increases to about 1000 Ohm-m, due to the existence the inferred capping basaltic sill (Fig 2.7).

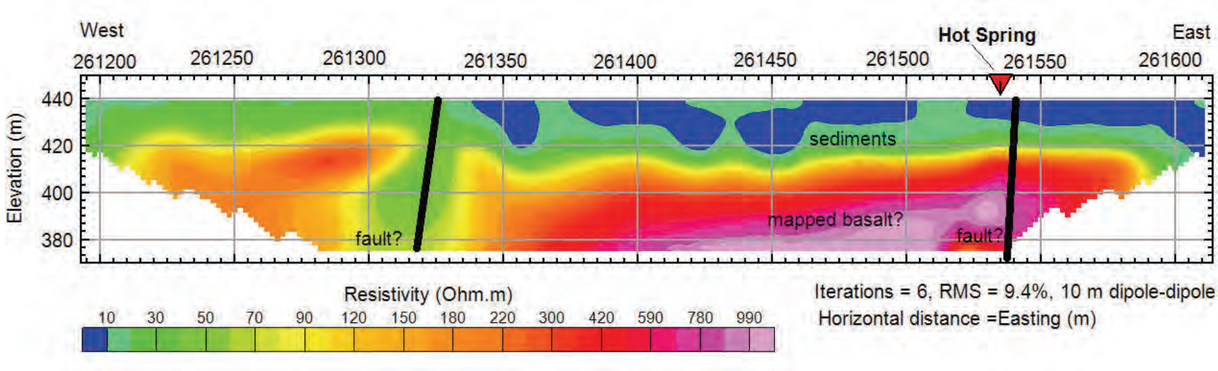


Fig. 2.7 A 10 m dipole-dipole resistivity survey across the Sagole spring showing interpreted fractures and the showing the high resistivity basaltic sill, possibly of the Soutpansberg Formation (Nyabeze, 2013)

2.1.3 Characteristics of thermal spring waters

While the location and depth of the thermal springs are controlled by the tectonic history and structural geology of the area, it is the type of rock and its mineral composition that control the chemistry of the thermal waters.

2.1.3.1 Physical characteristics

Temperature

Given the mostly warm climatic conditions prevailing throughout South Africa, a temperature of 25°C is generally used to distinguish thermal from non-thermal springs. The classification used for South Africa, as proposed by Kent in 1949, is as follows: 25-37°C = warm; 38-50°C = hot or hyperthermic; >50°C = scalding. The term 'tepid' is used for thermal waters with temperatures ranging between mean air temperature and 25°C.

Using these threshold temperatures, Kent (1949) classified 39 of the 74 South African springs as warm (25-37°C), 24 as hot (37-50°C) and six as scalding (>50°C). He did not have sufficient information to classify the remaining five. Although Brandvlei is usually considered to be the hottest spring (64°C), a spring near Siloam (Limpopo) was found to be 67.5°C in 2004. However, both the flow rate and the temperature of Siloam fluctuate over time – with the temperature varying from 63.5°C in 2008 and 71°C in 2012. The other scaldingly hot springs are: Tshipise (Limpopo, 57°C), Tugela Valley (KwaZulu-Natal, 52-53°C), Warmbaths (Limpopo, 52°C), Olifants Valley

(Western Cape; 50-51°C), and Badplaas (Mpumalanga, 50°C). Table 2.1 provides a summary of South African thermal spring temperatures.

TABLE 2.1: TEMPERATURES OF THERMAL SPRINGS							
Thermal spring	**Temp °C**	**Thermal spring**	**Temp °C**	**Thermal spring**	**Temp °C**	**Thermal spring**	**Temp °C**
LIMPOPO		**KNP**		**E CAPE**		**MPU**	
Tshipise	58	Tshalungwa	-	Aliwal	35	Badplaas	51
Sagole	46	Tshipala A	34	Cradock	29	Grovesbad	33
Evangelina	35	Maritumbe	29	Fish Eagle Spa	36	Machadodorp	28
Moreson	44	Magovani Hoof	26			Falcon Glen	42
Mphephu	44	Malahlapanga	38	**FREE STATE**		Amanzimtaba	33
Siloam	66	Malahlapanga B	38	Badsfontein	30	Sulphur spring	-
Warmbad	52	Mafayini	39	Florisbad	28		
Rhemardo	42	Matiyavila act	30	Baden Baden	21	**Swazi Spa**	42
Soutini	44						
Die Oog	39	**W CAPE**		**N CAPE**			
Vischgat	40	Brandvlei	63	Riemvasmaak	33		
Loubad	30	Citrusdal	46				
Buffelshoek	30	Caledon	49	**KZN**			
Minvamadi	33	Towerwater	45	Natal Spa	43		
Eiland source	41	Goudini	43	Lilani	40		
Lekkerrus	49	Calitzdorp	51	Thangami	39		
Libertas	45	Montagu	43	Shu-Shu	50		
				Warmbaths			
				Birlanyoni			

It is notable that the thermal characteristics of most springs have remained constant over the last 60 years (Olivier *et al.,* 2008).

Thermal controls

The source of heat may be related to adiabatic or diabatic processes, and a combination of these (see box 2.3).

BOX 2.3

Adiabatic processes: The temperature increases with crustal depth due to adiabatic heating (increased pressure) as reflected by the geothermal gradient. This is usually in the range of 2-3°C /100 m (Press & Siever, 1986). It is thus accepted that cold springs arise from shallow groundwater while thermal springs originate from depth.

Diabatic processes: In the absence of magma, the main heat producing elements are K, U and Th (Jones, 1992; Hartnady & Jones, 2007). These often occur in metamorphic rocks and granites.

Mazor and Verhagen (1983) found that some of the springs in the Cape Fold belt contain significant amounts of radiogenic He, accompanied by radiogenic Ar. However, the $^{4}He/^{40}Ar$ radiogenic values are in the range of 1-7 indicating common rocks as the origin rather than concentrates (ores) of U and Th. However, this does not appear to be the case in Limpopo where Nyabeze found subtle anomalies of background U in close proximity to Siloam and Mphephu.

The heat flow characteristics of rocks also play a role in the temperature of circulating groundwater (see box 2.4).

BOX 2.4

Heat flow in intrusive rocks such as gabbro and norite were found to have lower mean thermal conductivities in the range 5.2-5.3 mcal/cm sec ^{o}C (Carte & van Rooyen, 1969). Metamorphic rocks such as schists, phyllite, gneiss and granulite have mean values in the range 7.2-14.1 mcal/cm sec ^{o}C and sedimentary rocks such as sandstone and with higher values of 5.8-6.7 mcal/cm sec ^{o}C. Sedimentary rocks that are rich in organic matter such as carboniferous shales are often characterised by remarkably low thermal conductivity – lower by a factor of 2 or more than other common rock types (Nunn & Lin, 2002). This natural insulating effect produces elevated temperature gradients in organic-rich, fine-grained sediments. Consequently, underlying rocks will attain higher temperatures than would otherwise occur. Low geothermal gradients may also be due to heat advection into fracture zones. It thus seems that metamorphic terranes have the highest thermal conductivity values (Carte & van Rooyen, 1969).

It is important to note that the thermal conductivity may differ from one geological stratum to the next. Nevertheless, in springs of meteoric origin, the temperature of the thermal water reflects the depth of penetration and the rate at which it ascends to the surface (flow velocity) (Grasby & Hutcheon, 2001; LaMoreaux & Tanner, 2001).

Flow rates

The database (Addendum B) provides information on the flow rates of thermal springs. The majority of these were determined by Kent. Most springs that have been developed as resorts or for private use, have been fitted with pumps and it was thus not possible to determine flow rates.

South African thermal springs generally have low flow rates in comparison with volcanic countries where fumaroles and geyser type thermal springs occur (Kent, 1969). Brandvlei, in the Western Cape, which has the highest flow rate, is found in an area with an annual rainfall exceeding 600 mm (Kent, 1969). According to Kent (1969), the highest flow rates for South African thermal springs are in the region of 40 000 m^3/d (~460 l/s, i.e. magnitude 2). The flow rate at Brandvlei has remained constant over the last 50 to 60 years but this is not the case with a low-flowing spring such as Siloam. Here, a flow rate of 0.15 l/s was measured in 2004, decreasing to a mere trickle in 2008, and increasing to just over 1 l/s in 2012. Other springs such as Winburg (Free State), Icon, Constantia and Masequa (Limpopo) have dried up completely. The reason for this is not known, but may be due to decreased rainfall in catchment regions or increased groundwater extraction for domestic and agricultural purposes.

Although it was previously assumed that the hottest springs are those with the highest flow rates, this is not necessarily true. Hartnady and Jones (2007) explain that emergence temperatures of spring waters reflect the interaction between advective and conductive transport of heat in the host aquifer systems, aquifer permeability being the key factor. Where rock permeability is low, groundwater flow velocities are low, heat transport is dominantly conductive, and therefore spring temperatures are low. In rocks with high permeability, flow velocities are high and advective transport of heat is the dominant process. However, because high permeability also results in large volumes of circulating water, spring temperatures again remain low. The warmest springs generally occur for an intermediate range of permeability.

2.1.3.2 Chemical characteristics of thermal springs

As pointed out in chapter 1, minerals are generally more soluble in hot water and thus thermal springs are often enriched with trace elements. Certain minerals dissolve more readily than others and some rocks are richer in minerals than others. The pH of the solvent also affects the solubility of minerals. Hence, the specific chemical composition of spring water will depend largely on the composition of the rain water, its temperature and pH, the geology of the aquifer and the rocks through which the water circulates and rises to the surface.

Chemical classification

The defining publications on the chemical composition of South African thermal springs were those by Rindle (1916) and Kent (1949; 1952; 1969). Other chemical analyses were conducted on selected springs such as by Douglas (2001: Florisbad), Hoffman (1979: Lekkerrus and Libertas) and Winfield (1980: Mphephu Klein Tshipise (Sagole).

Different systems have been used to classify South African thermal springs according to their chemical characteristics. Rindle (1916) focused on the chemicals influencing their medicinal value (See Deliverable 1 on CD). However, the classification system used most frequently for South African thermal springs, is that devised by Bond in 1946. He divided thermal spring waters into five categories, as shown in Table 2.2**.**

TABLE 2.2 CLASSES OF THERMAL WATER IN SOUTH AFRICA ACCORDING TO BOND (1946)

Class	**Water**	**Chemical composition**
A	Highly mineralised chloride-sulphate water	TDS > 1 000 mg/l; Cl^- >27%; $SO_4^=$ >5%
B	Slightly saline chloride water	TDS 300-500 mg/l; Cl^- >27%; $SO_4^=$ <3%
C	Temporary hard carbonate water	TDS <800 mg/l; pH >7.6
D	Alkaline sodium carbonate water	TDS <1000 mg/l; Na_2CO_3 or $NaHCO_3$ >15% . No permanent hardness
E	'Pure' waters	TDS <150 mg/l; pH <7.1

Analysis of these variables (TDS, pH, SO_4, Cl and Na_2CO_3/$NaHCO_3$) indicate that the only 'pure' waters are those from the thermal springs in the Western Cape. Some – such as Evangelina and Eiland in Limpopo, Mafayini and Matiyavila in the Kruger National Park and Florisbad in the Free State – are highly mineralised chloride sulphate waters (A), but the majority of thermal spring waters fall in to C category – thus classified as being temporary hard carbonate waters. This agrees with findings by Kent (1969) and Ashton and Schoeman (1986) who state that the waters can be regarded as being slightly too highly mineralised.

Olivier *et al.* (2008) reanalysed thermal spring waters from eight thermal springs in the southern part of Limpopo to determine whether significant changes had taken place over time. These authors found that the chemical composition had not changed significantly over time. High levels of halogens are found in many springs in the country. Strontium is also plentiful. The minerals may have an impact on their fitness for consumption.

Gases such O_2, CO_2, CH_4, N_2, He, Ar, and H_2S were detected at some springs (Rindle, 1916; 1918, 1928; 1930; 1931; 1932; 1934; 1937; Kent, 1949).

Geochemical controls

The chemical characteristics of thermal springs are determined by regional differences in climate and geology. Of these, geology plays a dominant role. Figure 2.8 shows the location of thermal springs in South Africa and their associated geology

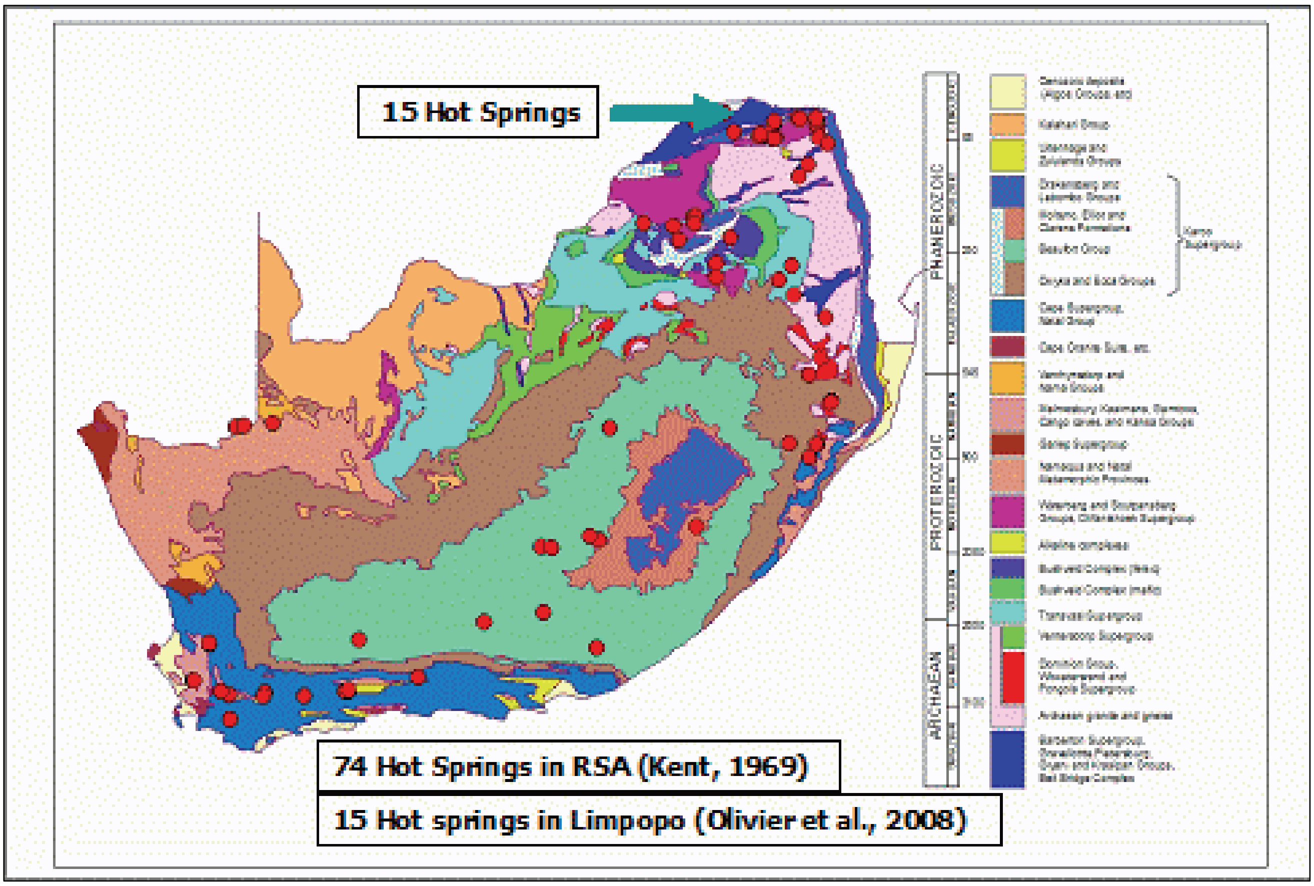


Fig. 2.8 Location of hot springs in South Africa and associated geology

Kent (1949; 1969) gave a comprehensive overview of the association between geology and the dominant and subdominant ions in thermal spring waters while Mazor and Verhagen (1983) studied 16 thermal spring waters from different parts of South Africa with respect to their salinity. They distinguished two salinity groups, namely a relatively saline group containing 936-2364 mg/l with NaCl as a dominant salt. These issue from crystalline terranes (Stober & Bucher, 2005: In Netili 2007) and include – in increasing order of salinity: Die Eiland, Malmesbury, Aliwal Noord, and Florisbad issuing from the Karoo sediments (Kent, 1969). Tshipise with almost 400 mg/l is also NaCl dominant and could be included in this group. The question of the salinity of the waters of Malmesbury and Die Eiland (Letaba), which are also NaCl dominated, is as yet unresolved. The other group comprises low saline thermal waters (90-432 mg/l) and with no specific ion dominance. These issue from sedimentary rocks and include Beersheba, Lilani, Warmbad, Natal Spa, Olifants, The Springs, Brandvlei & Goudini fall into this group.

Olivier *et al*. (2008, 2011) and Saeze and Rikhotso (2013) studied the chemical composition of thermal springs in Limpopo. Piper diagrams were used to assess the influence of geology on thermal waters (developed by Piper, 1944). These, together with a Gibbs plot (Gibbs, 1970) were used by Saeze & Rikhotos (2013) to determine geochemical processes affecting groundwater chemistry in Limpopo. They found that thermal springs in Limpopo can be subdivided into four groups according to the chemistry composition, i.e. springs emanating from gneissic rocks depict sea water type NaCl (Group I). The Group II springs originate from basalt rocks and their typical composition is $NaClHCO_3$. The third group (Group III) plots between fresh water (Group IV – $CaHCO_3$) and sea water type NaCl

(Group I). Weathering of aquifer material is the dominant process controlling the chemistry of this groundwater with the exception of three springs, Evangelina, Soutini and Die Eiland which seem to be controlled by crystallisation.

Saeze and Rikhotso's work are presented in Deliverable 26 while results obtained by Olivier *et al*. (2011) can be found as Deliverable 4.

The pH level of thermal springs is also influenced by geological formations and chemical composition. According to Kent (1969:156), of the thermal springs in Archean granite gneiss, eight are alkaline. Such springs include Lilani and Natal Spa. Some springs issuing from the Bushveld Igneous Complex are alkaline, with a similar chemical composition. Hot springs occurring in the Welgevonden reverse faults are also alkaline and are similar in chemical composition to springs in the igneous complex. Other alkaline springs are in the Precambrian Dominion Reef and Pongola systems, and some are associated with volcanoes of the Pretoria series. Alkaline springs of the Karoo system are said to receive their water from the upper part of the Beaufort series and higher strata (Kent, 1969). Springs such as those at Badfontein and Machadodorp, which are associated with sediments and volcanoes of the Pretoria Series, are weakly mineralised and alkaline. Thermal springs issuing from the quartzitic sandstone of the Table Mountain series of the Cape system are slightly acidic.

According to Kent (1969:157), gases discharged by springs fall into two categories. Springs from pre-Karoo (pre-Carboniferous) faults are dominated by N_2, with some He and Ar whereas springs originating from the Karoo system are dominated by CH_4. Diamond (1997) found that ^{13}C released at some springs in the form of CO_2 and CH_4 could come from near-surface bog environments, however at Malmesbury, where H_2S is also released, a possible geological source is indicated for the CO_2 and the CH_4 (Diamond, 1997). The H_2S at Malmesbury is possibly released from the rocks of the Malmesbury Group.

Although the chemistry of thermal spring waters give insight into the geology at depth – and thus the likely point depth of origin and hence the temperature – as well as the geochemical processes that occur there, isotope studies can add significant information on the age of the water, recharge processes and the origin of spring waters.

2.1.3.3 Origin and age of thermal spring waters

Since there is no evidence of recent volcanic activity in South Africa, it is generally assumed that all thermal springs in South Africa are of a meteoric origin (Rindle, 1916; Kent, 1949; Hoffmann, 1979; Ashton & Schoeman, 1986; Visser, 1989). However, isotope chemistry has been used to establish the origin of spring waters, recharge processes and the age of such waters (see box 2.5).

Using oxygen and hydrogen isotope geochemistry, Mazor and Verhagen (1983) and Diamond and Harris (2000) confirmed that the Cape Fold thermal springs are of meteoric origin and that the water is relatively young. Marzor and Verhagen (1983) indicate that water at The Baths had a residence time of around 2kyr. Plots of oxygen and hydrogen isotopes for Limpopo spring waters presented in figure. 2.9 show that there is no shift away from the GWML and hence these waters originated from local precipitation and no palaeoclimate effect or isotopic exchange with aquifer material is evident (Saeze & Rikhotso, 2013). This supports their findings for the thermal water age obtained by the radiocarbon method, which placed the recharge period of these waters in the Holocene.

BOX 2.5

The basic assumption here is that the δD and δ18O values for precipitation worldwide behave predictably, falling along the global scale that Craig (1961) defined as the Global Meteoric Water Line (GMWL), and mathematically is expressed as follows: δ2H = 8 δ18O + 10 (‰). The analyses of 2H and 18O can be used to identify the probable source of underground water.

Drever (1988) and various other studies have shown that if the isotopic composition of underground water plots close to the meteoric water line in a position similar to that of present-day precipitation in the same region, then the water is almost certainly meteoric. Thus, the stable isotopes (δ18O, δ2H) are known as conservative tracers and their original characteristics depend only on the local physical and atmospheric conditions prior to recharge (Dansgaard, 1964; Gat, 1971; Rozanskei et al., 1993 In: Saeze & Rikhotso, 2013; Deliverable 26)

Stable isotopes also provide information on the recharge processes of groundwater and help to answer questions relating to the origin, processes affecting recharged water, and residence times. For instance, the residence time of groundwater in actively circulating systems may range from tens to thousands of years and a changing climate should be recorded in palaeogroundwaters. Such climate changes are manifested by a shift in the stable isotope content of precipitation; the use of the isotopic method is then an important tool to distinguish Holocene waters and Pleistocene waters that could circulate in the deeper confined parts of the aquifer (Darling *et al*., 1997).

Late Pleistocene palaeogroundwaters will be isotopically depleted with respect to modern waters and shifted along the Global Meteoric Water Line (GMWL) towards negative values (Seaze & Rikhotso, 2013 Deliverable 26). Moreover, Tyson *et al*. (1998) indicated that if, in the course of climate change, surface temperatures become lower, the rainfall should increase. Actual evaporation rates will be lower, and consequently a higher recharge can be expected. This will increase hydraulic gradients towards springs, thus increasing deep subsurface flow and associated advective heat transport.

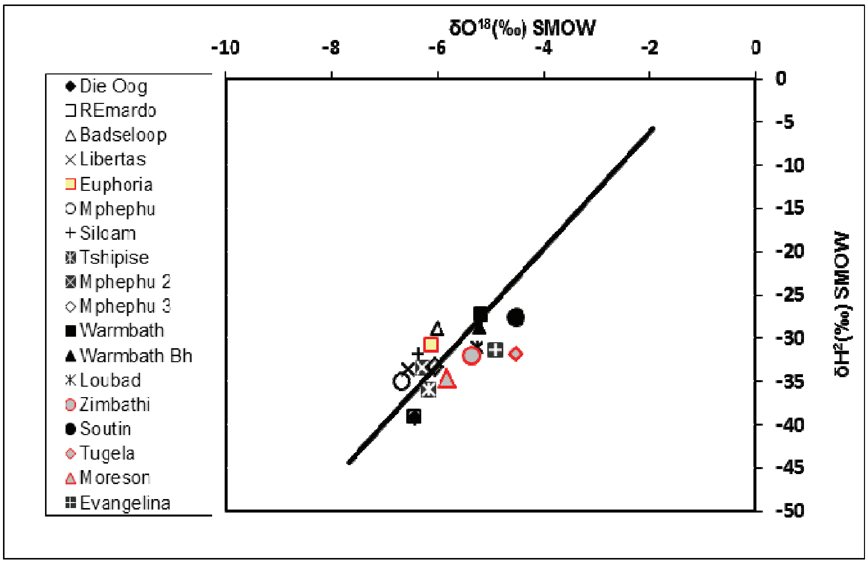


Fig. 2.9 Deuterium and oxygen-18 content of Limpopo thermal springs compared with Pretoria Meteoric Water Line

The meteoric origin of thermal spring waters thus implies that thermal springs are only likely to be found in areas with relatively high rainfall. Hoffman (1979) indicated that the thermal springs in South Africa occur only in areas with an annual rainfall in excess of 254 mm); the catchment area need not be geographically close to the spring; and the catchment area must be at a higher altitude than spring itself. It is therefore not surprising that most of the thermal springs originate in valleys or low-lying areas (Kent, 1952).

2.2 THE BIOLOGICAL SETTING

2.2.1 Introduction

Hartnady and Jones (2007) indicated at emergent thermal springs may have a significant impact on the surface water and associated ecology, but that have hitherto been largely neglected in scientific studies. Thermal springs exert significant control on ambient temperatures of wetland soils and surface-water streams in the discharge area. In some areas, thermal water issues from diffuse sources and mix unobstrusively with mountain stream flow in such a way as to cause a relatively sudden an anomalous elevation in the temperature of the surface water flow. Such emissions are often only detectable through along-channel mapping of water temperature, especially during mid-winter snowfall periods, when the contrast between the surface – water temp and the groundwater temperature is greatest.

In the Table Mountain Group terranes the fluid-mechanical advection and concentration of geothermal energy supports distinctive environmental regimes or niches that are largely buffered against extreme seasonal change, and which in turn allow characteristic microfaunal and microfloral populations to flourish. There is a dearth of hard information on what are these hot-spring microbial ecologies, and how higher floral and faunas elements in the wetland and riparian zones might depend for their nourishment on this geothermally-supported base. It might be suspected that vertebrates, such as endemic fish or amphibians, are sensitive to the range of water temp at certain times of the year (Hartnady & Jones, 2007).

Except for the research on sediments and pollen conducted at the Wonderkrater spring and Badsfontein and Aliwal North by Scott *et al*. (2003) and Scott & Cooremans (1990), respectively, no research has been conducted on the ecology/biodiversity in South African thermal springs. However, a thorough study of diatoms found in thermal springs in Namibia was conducted by Schoeman and Archibald in 1988.

A first attempt at identifying the microbiological diversity within South African thermal springs was undertaken as part of this project. This preliminary study focused on six thermal springs in Limpopo, namely Tshipise, Mphephu, Siloam, Soutini, Eiland and Sagole.

2.2.2 Identification of microbial diversity (Tekere *et al*. 2012; Deliverables 6 & 11)

2.2.2.1 Methodology

Sampling

Water samples for chemical, physical and microbial community studies were collected in August, 2010. The following water quality parameters were measured in situ using the relevant field meters (Mettler Toledo meters, UK): temperature, pH, electrical conductivity (EC), total dissolved solid (TDS) and dissolved oxygen (DO). The water was collected into sterile 2-litre bottles and placed into a cooler box for transportation to the laboratory for physico-chemical analyses and bacterial diversity studies.

DNA Extraction

The water samples were concentrated by both filtration for the clear water and centrifugation and DNA was extracted with the Genomic DNA Tissue Mini-Prep Kit (Zymo Research), as per protocol; with an additional DNA wash-step. See references Tekere *et al*. 2011; 2012 for further details.

PCR amplification

The PCR reaction was performed on the extracted DNA samples using universal degenerate primers 27F.1 and 1492R (De Santis *et al*. 2007). Each PCR reaction contained 5 µl of 10 Taq Buffer, 2 mM $MgCl_2$, 1.5 U Super-Therm DNA polymerase (Southern Cross), 0.25 mM deoxynucleosides triphosphates (dNTPs), 0.1 µM of each primer, 1 µl of extracted DNA and nuclease free water (NFW) up to the final reaction volume of 50 µl. After the amplification, 5 µl of the samples were run on a 1% agarose gel at 90 V for 30 min in order to verify amplification. The entire PCR reaction was loaded onto a 1% agarose gel and the correct band size (approximately 1500 bp) was excised. The DNA was recovered from the gel slices by using the GeneJET™ gel extraction kit (Fermentas). The DNA was subsequently re-amplified with two sets of primers in order to amplify two variable regions of the 16S rRNA gene (V1-3 and V4-7). These primers contained the appropriate adaptor and barcode sequences that were necessary for running the samples on the GS-FLX-Titanium (Roche). See references Tekere *et al*. 2011 and Tekere *et al*. 2012 for further details.

2.2.2.2 Results and discussion

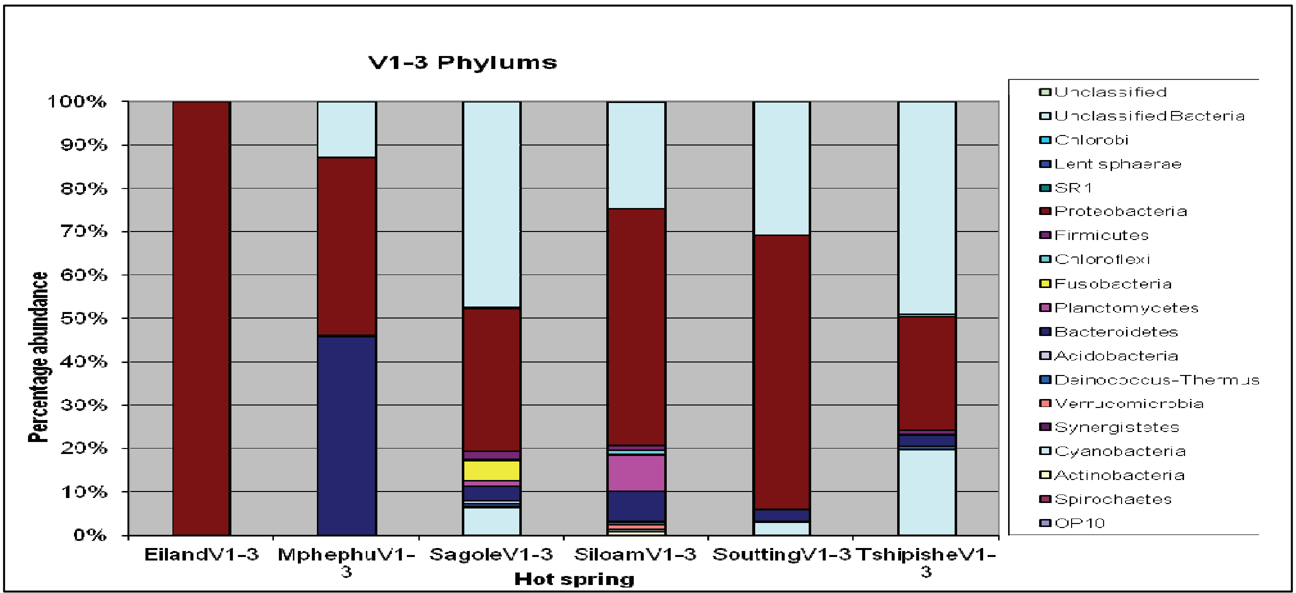
Details of the sequencing and the number of sequences found are given in Table 2.3 while a full list of bacterial genera found in these spring, is included as Addendum C.

TABLE 2.3: SUMMARY OF PYROSEQUENCING DATA FROM TSHIPISE, MPHEPHU, SAGOLE AND SILOAM

	Tshipise		Mphephu		Sagole		Siloam	
	V1-3	V4-7	V1-3	V4-7	V1-3	V4-7	V1-3	V4-7
Number of sequences	512	120	1117	721	1046	794	880	568
Total length of sequences	121287	42212	318167	255767	279690	297043	263930	208353
Average length of sequences	234	352	385	355	267	374	300	367

The V4-7 and the V1-3 hyper-variable regions had similar and overlapping efficacies; the V4-7 region was more effective in detecting genera which could not be detected and classified by the V1-3 region. A significant number of the sequences could not be assigned to any phyla, and this group might represent bacteria that have not yet been classified or detected before.

Very diverse bacterial genera representing all the different major bacterial phyla were detected in the hot water springs studied. Analysis of the community DNA revealed that the phyla Proteobacteria, Cyanobacteria, Bacteriodetes, Planctomycetes, Firmicutes, Deinococcus-Thermus, Fusobacteria, Acidobacteria, Chloroflexi and Verrucomicrobia dominated, and could be detected at varying abundances in the different hot springs (Fig. 2.10 a &b).



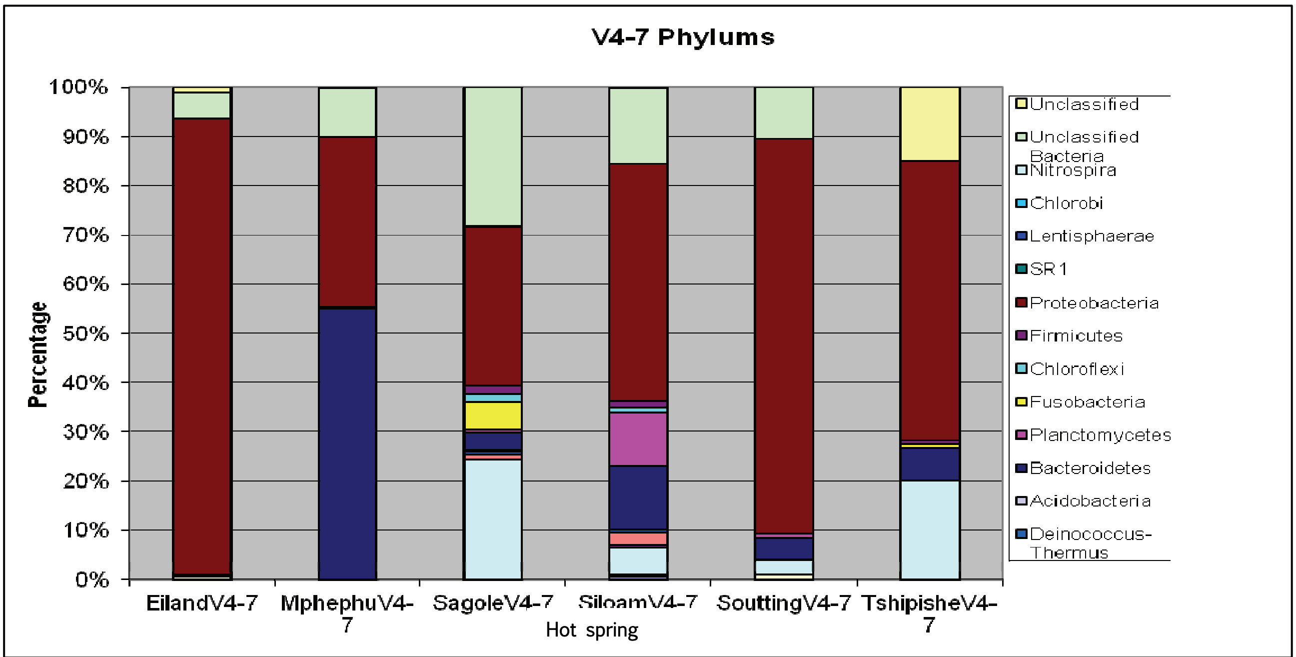


Fig. 2.10 a and b Microbial phyla detected at the hot spring by sequencing of the variable regions V1-3 and V4-7 of the 16S rRNA genes

The bacterial diversity obtained indicates that the hot water springs could harbour microorganisms of terrestrial as well as aquatic origin and bacteria known to be either mesophilic or thermophilic inhabitants. However, no attempt was made in this study to characterise the bacteria with respect to their thermophilic status. Contamination of the hot water spring by normal surface water, soil, and spores cannot be excluded, but it can, however, be concluded that the bacterial phylotypes detected can possibly all proliferate in this thermophilic environment.

Details of the studies on microbiological diversity in South African hot springs are captured as Deliverables 6 and 11 on the attached CD.

2.2.3 Algal diversity

Field trips were undertaken during 2010 to collect algae samples from six thermal springs in the northern part of Limpopo. The thermophylic algae mat was harvested from both hard and soft substrates where these were present. The samples were stored in cooler boxes before identification in the laboratory. Microscopic observations for identification purposes only on the algae were conducted within 24 hours from collection of samples at Resource Quality Services, Department of Water Affairs at Roodeplaat. Sub-samples were taken until no new species were encountered. Algae were identified with a Carl Zeiss inverted light microscope (magnification of 400 or 1000). Classification of algae was done from references in literature (Entwisle *et al*., 1997; Janse van Vuuren *et al.,* 2006).

Morpho-typical analysis revealed limited presence of phytoplankton groups. Algae from five different phyla, namely Cyanobacteria, Bacillariophyta, Chlorophyta, Euglenophyta and Dinophyta were identified from the selected thermal springs, and were dominated by Cyanobacteria. Figure 2.11 gives examples of some of the algae identified in the thermal springs in Limpopo Province, South Africa.

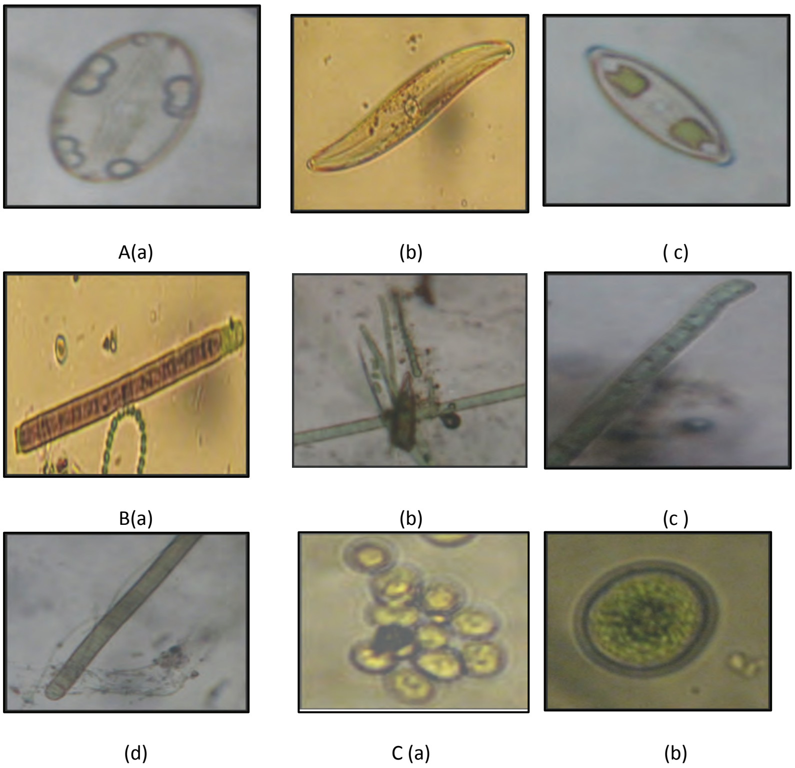


Fig. 2.11 Some algae from hot springs in northern Limpopo

A) Bacillariophyta (a) *Cyclotella Kutzing* sp. Cells are 5-30 µm in diameter, a common planktonic diatom found throughout the world, widespread in brackish water (Janse van Vuuren *et al*., 2006), (b) *Gyrosigma Hassall* sp. Cells are 60-400 µm long and 11-40 µm wide. Species within this genus are often found in dense algal mats on bottom of lakes. Genus may be found in brackish water (Janse van Vuuren *et al*., 2006); (c) *Craticula Grunow* sp. Cells are 9.5-170 µm long and 3-35 µm wide, species tend to be associated with fresh to brackish waters (Janse van Vuuren *et al*., 2006).

B) Cyanophyta (a) *Lyngbya Agardh ex Gomont* sp. Diameter of trichomes varies from 1-30 µm, inhibits fresh and brackish water. *Lyngbya* sp. has a firm, rigid sheet (Janse van Vuuren *et al*., 2006). Anterior cells have thickened terminal cap (Entwisle *et al*., 1997). (b) *Nostoc* sp. (c) *Phormidium* sp. (Entwisle *et al*., 1997; Janse van Vuuren *et al* , 2006) (d) *Oscillatoia* sp. (Entwisle *et al*., 1997).

C) Chlorophyta (a) *Coelastrum Nageli* sp. (Janse van Vuuren *et al*., 2006) (b)*Chlamydomonas* Ehrenberg sp. (Janse van Vuuren *et al*., 2006).

D) The blue green algae *Phormidium, Schizothrix, Microcystis, Oscillatori, and Lyngbya* and diatoms *Navicula, Nitzschia, Pinnularia*, especially widespread in thermal environments all over the world, were also noted in thermal springs in the Limpopo area.

The trace elements necessary for algal growth, namely copper, molybdenum, manganese, cobalt and vanadium are found in relatively low concentrations (or may even be absent) in many of the springs – the exceptions being Eiland and Soutini.

The Cyanophyta (*Phormidium*, *Microcystis*, *Oscillatoria*, *Nostoc*, *Nodularia*, *Lyngbya*, *Anabaena* and *Schizothrix*), Chlorophyta (*Oocystis*, *Chlorella* and *Spirogyra* spp.) and Bacillariophyta (*Pinnularia*) seem to be well adapted for survival in high fluoride concentrations in the different springs. The concentration of >4111 µg/l iodine, does not affect the algae living at Eiland. Clearly, Soutini and Eiland have exceptionally high concentrations of all macro-elements and anions.

It was interesting to note the algae, *Scenedesmus*, *Closterium*, *Chlamydomonas* (green algae), *Synedra*, *Aulacoseira*, *Nitzschia*, *Cyclotella*, *Gyrosigma* and *Craticula* (diatoms), occur exclusively at Soutini.

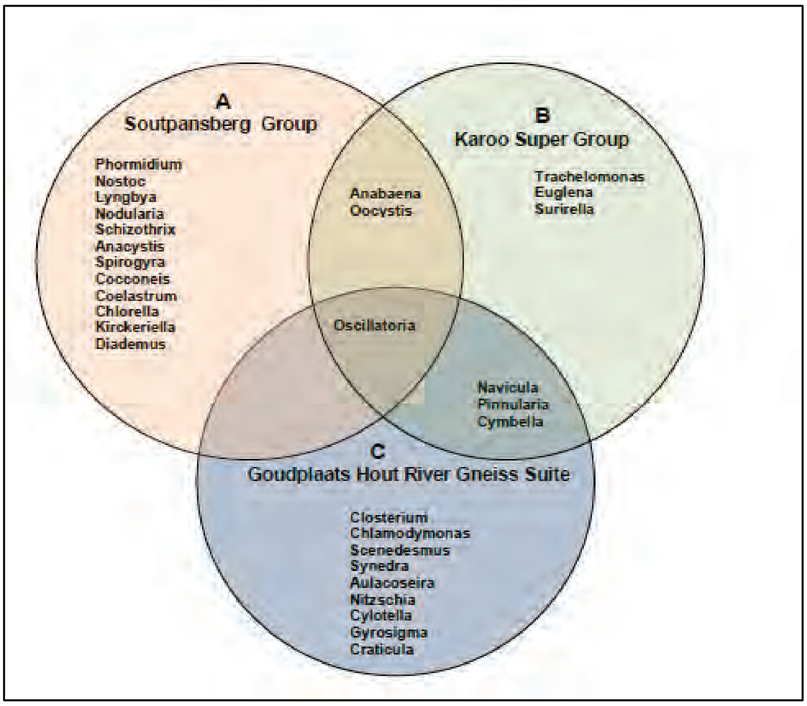


Fig. 2.12 Geological distribution of algae **(A=Mphephu & Siloam; B= Tshipisi & Sagole; C= Eiland & Soutini**

There was a high degree of specificity of the algae with regard to the geochemical environment (Fig. 2.12). Variations in temperature, pH and geochemistry of the lithostratigraphic units appear to be the governing determinant in community structure, the species abundance and distribution of the algae species. The community distribution of algae in the selected springs thus suggests not only the influences of geographical isolation due to the mineral content, but also probable human activity on species dominance in these environments.

Recreational or industrial interference in ecosystems of thermal springs may alter the natural biodiversity and promote the production of neurotoxic forming cyanobacterial isolates such as *Oscillatoria,* with consequential health risk implications to users. These will be discussed in more detail in Chapter 3.

CHAPTER 3: ASSESSMENT OF FITNESS FOR CURRENT USE

Olivier J, Jonker CZ & Tekere M

3.1 INTRODUCTION

By far the most popular use of thermal spring resources in South Africa is as resorts for leisure and tourism. As a whole, the use has remained essentially the same as was listed by Boekstein in 1998 (Refer to Table 1.2). Mabalingwe Spa is now called Amanzimtaba and falls within Mpumalanga rather than Gauteng; Die Oog is a retirement village but still allows camping and the use of some chalets for holidays. It is not known whether Forever Vaal Spa is a thermal spring resort or merely has heated swimming pools. Most resorts provide accommodation in the form of camping sites, self-catering chalets and, at more exclusive resorts, a hotel. Without exception, the facilities at resorts include one or more swimming pools (Fig. 3.1). At some, water is bottled and sold for therapeutic purposes and in other instances the thermal spring is the sole source of water for the entire resort.

Fig. 3.1 Visitors to resort at Warmbaths

The majority of visitors to such resorts comprise of older persons and families, often with small children. One of the principal reasons for visiting a resort is for the adults to relax in the warmth of the thermal pools while the children can participate in numerous activities in a safe environment. In undeveloped rural areas, this resource is frequently used by children and locals for bathing. Contrary to popular belief, not all spring water is safe.

It has been found that some thermal spring waters from resorts in other countries may be harmful or even dangerous to human and animal health, containing naturally occurring toxic minerals such as arsenic and mercury (Mandal & Suzuki, 2002; Romero *et al.,* 2003; Churchhill & Clinkenbeard, 2005), radio-active elements (Kempster *et al*., 1996; Baradcs *et al*., 2001) or pathogenic organisms such as the meningitis-causing *Naeglerias fowleri* (Sugita *et al.,* 1999; Izumiyama *et al*. 2003; Craun *et al.* 2005) and *Legionella pneumonia* (Miyamoto *et al.* 1997). Children and the aged are particularly susceptible to water borne diseases, skin and ear infections and carcinogenic risk.

Swimming and bathing invariably involves full-body contact with the water. Small quantities of thermal spring waters may also be swallowed, with the amount varying, but usually not 100 ml for any bathing event (DWAF 1996a). The effects of contaminants often manifest as irritation of the skin, eyes, ears or mucous membranes of the nose and mouth. Exposure pathways also include inhalation of potentially harmful gases present in and around the pools – especially where the pool or spa is enclosed.

Fig. 3.2   Enclosed spas at Eiland and Tshipise

Naturally occurring gases in South African thermal springs include hydrogen sulphide (H_2S) and methane (CH_4). The H_2S may be injurious at high concentrations and methane is highly flammable. Methane is also an asphyxiant and may displace oxygen in an enclosed space. Possible health effects of breathing in methane at high concentrations, resulting in oxygen deficiency, are increased breathing and pulse rates, lack of muscular coordination, emotional upset, nausea and vomiting, loss of consciousness, respiratory collapse and death ("Health Effects of Methane". Canadian Centre for Occupational Health & Safety. December 11, 2006).

Many resort owners have had the spring water tested for potability. Such tests do not necessarily provide information on potentially hazardous trace elements. The question that now arises is: are thermal spring waters safe for current uses?

3.2 POTENTIALLY HARMFUL EFFECTS OF CHEMICALS IN THERMAL WATERS

3.2.1 Human health

The DWAF (1996a) Water Quality Guidelines for Recreational Use were used as basis for the assessment of health 'risk'. This set of guidelines refers specifically to the effect of pH and microbiological contaminants. DWAF's (1996b) Guidelines for Domestic Use were used as standards for chemical contaminants. The term "Domestic Use", refers to water which is used 'in the domestic environment and includes water for drinking, food and beverage preparation, hot water systems, bathing and personal hygiene and washing' (DWAF 1996b). Guidelines for drinking water were obtained from SANS 241:2005. The 2011 version did not appear to differ significantly from the 2005 version with respect to minerals.

The comparison of the concentrations of sulphates, nitrate, nitrite, fluoride, sodium, potassium, magnesium, vanadium, chromium, manganese, zinc, uranium, cadmium, mercury, lead, selenium and arsenic in thermal spring waters with DWAF standards (Table 3.1) indicate that Evangelina and Riemvasmaak appear to have the worst water quality for recreational and bathing purposes – exceeding TWQR limits for more than five of the minerals.

According to the results of the analysis, only the Western Cape thermal springs and Loubad are fit for swimming and bathing. All other springs (barring those in the Western Cape and Sagole, Minvamadi and Loubad in Limpopo) contain unacceptably high concentrations of fluorides. Other minerals occurring in high concentrations are Na and Hg. In view of the high levels of F and Hg in the Kruger National Park thermal springs, it is perhaps fortunate that they will not be used for drinking purposes or for swimming purposes.

Since visitors at the developed resorts have only limited and intermittent contact with water for a short period of time, contaminants such as Na, SO_4 and NO_3 could, at most, cause skin or eye irritation and slight diarrhoea if excessive SO_4 occur. High levels of NO_3 have been associated with methaemoglobinaemia in infants and persons on sodium-restricted diets should take cognisance of the Na levels in the waters. Only two springs, namely Sagole and Warmbaths (KZN) have waters with a pH that falls outside specified limits. Fortunately none of the South African thermal springs contain high levels of the other potential carcinogens, Cd and Pb.

Comparison of mineral concentrations of thermal spring water with SANS drinking water standards (Table 3.2) shows the same general pattern as described above. Once again, it is the high concentrations of F that is the major cause of non-compliance. The inclusion of Mn in the SANS 241:2005 standards also eliminates Caledon, Towerwater and Calitzdorp as sources of drinking water. Only waters from Sagole, Loubad, Minvamadi in Limpopo and Brandvlei, Citrusdal and Goudini in the Western Cape conform to all standards and are thus fit for use for recreation and consumption.

IT THUS APPEARS THAT MOST SOUTH AFRICAN THEMAL SPRINGS CONTAIN ONE OR MORE ELEMENTS WHICH MIGHT BE INJURIOUS TO HUMAN HEALTH

TABLE 3.1: ASSESSMENT OF SUITABILITY: WATER QUALITY GUIDELINES FOR DOMESTIC USE (DWAF, 1996a)
Using final adjusted dataset

Springs	pH	SO_4	NO_3	NO_2	F	Na	K	Mg	V	Cr	Mn	Cu	Zn	U	Cd	Hg	Pb	Se	As
TWQR mg per litre	**6 to 9**	**200mg**	**6mg**	**6mg**	**1ug**	**100mg**	**50mg**		**100µg**	**50µg**	**50µg**		**3mg**	**70µg**	**5µg**	**1µg**	**10µg**	**20µg**	**10µg**
Health effects						**200mg**		**100mg**			**20mg**	**30mg**	**10mg**					**50µg**	
LIMPOPO																			
Tshipise	9	48	0	0	5	152	4	0	15	8	3	2	3	0	0	0	3	6	3
Sagole	9	17	0	0	1	66	1	0	3	4	3	1	15	0	0	1	2	2	3
Evangelina	7	210	9	0	4	355	6	27	91	23	5	11	26	30	1	1	3	31	22
Moreson	8	46	12	0	3	84	3	0	14	7	6	2	3	1	1	2	3	10	5
Mphephu	8	9	1	0	3	42	1	8	15	6	4	0	1	1	0	1	3	4	2
Siloam	9	10	0	0	6	61	3	0	18	1	1	0	6	2	0	0	0	1	0
Warmbad	8	12	0		19	126	4	2			1								
Rhemardo	7	12	1	0	6	35	4	2	4	3	10	6	38	0	2	0	4	4	1
Soutini	7	170		0	2	486	15	5	12	5	21	9		0					
Die Oog	7	10	1	0	6	42	4	2	4	6	20	6	9	1	1	0	6	2	4
Vischgat	7	97	1	0	6	58	6	2	3	3	12	6	13	1	1	1	5	0	4
Loubad	7	2	0	0	1	8	3	6	4	4	4	5	20	4	1	0	7	0	4
Buffelshoek	7	35	0		7	152	6	5											
Minvamadi	7	2	8	0	0	11	1	13	2	1	0	0	4	0	0	0	0	1	0
Eiland source	8	77	1	0	3	352	15	2	42	3	3	2	581	4	2	3	1	9	3
Lekkerrus	7	8			7	22	5	9	3	3	14	6	15	3	0	2	6	0	7
Libertas	7	8	0	0	5	22	3	2	5	3	49	30	43	0	0	0	5	3	1
KNP																			
Tshalungwa	7	26	1	0	1				7	2	4	0	42	1	0	3	6	1	3
Tshipala A	9	38			2	126	2		2	1	16	0	3	0	0	4	3	1	11
Maritumbe	8	24	0			35	32	9			150	30	110						
Magovani	7	9			0	25	5	15			230								
Malahlapanga	8	74			3	191	6		11	2	9	0	11	0	0	4	2	4	0
Malahlapnga B	6	159			3	231	9		15	11	104	4	8	0	0	1	4	5	0
Mafayini	8	355			1	562	14		10	0	5	1	3	0	0	3	3	15	0
Matiyavila	7	397	0			840	45		11	1	0	0	1	0	0	2	2	24	1

Springs	pH	SO_4	NO_3	NO_2	F	Na	K	Mg	V	Cr	Mn	Cu	Zn	U	Cd	Hg	Pb	Se	As
TWQR mg per litre	6 to 9	200mg	6mg	6mg	1ug	100mg	50mg		100µg	50µg	50 µg		3mg	70µg	5µg	1µg	10µg	20µg	10µg
Health effects						200mg		100mg			20mg	30mg	10mg					50µg	
W CAPE																			
Brandvlei	7	2	1	0	0	10	2	2	1	1	1	1	6	1	0	1	0	2	1
Citrusdal	6	2	1	0	0	8	2	2	1	1	4	0	26	0	0	0	0	2	0
Caledon	7	5	0	0	0	18	5	3	1	1	2635	0	0	0	0	0	0	1	1
Toverwater	7	4	0	0	0	13	7	3	0	0	946	0	0	1	0	0	0	0	0
Goudini	7	2	0	0	0	9	2	3	1	1	4	3	13	0	0	0	0	1	1
Calitzdorp	7	6	0	0	0	16	9	4	1	0	574	0	0	0	0	0	0	1	0
Montagu	7	6	1			10	4	3	1	3	3	4							1
E CAPE																			
Aliwal	9	6	0	0	4	331	2	0	13	0	1	0	5	0	0	2	0	11	2
Cradock	8	17	1	0	5	43	1	3	4	2	1	0	8	3		0	0	3	1
Fish Eagle Spa	9	10	1	0	4	335	3	0	14	0	3	0	2	0	0	1	0	6	1
FREE STATE																			
Badsfontein	7	4	0	0	4	316	2	0	11	0	1	0	1	0	0	1	0	4	1
Florisbad	8	89	3	0	5	681	10	1	22	1	3	0	1	0	0	1	0	8	1
Baden Baden	8	4	3	0	7	728	7	1	24	1	24	2	2	0	0	2	1	13	2
N CAPE																			
Riemvasmaak	8	612	6	0	4	913	17	19	16	1	0	0	1	307	0	1	0	27	11
KZN																			
Natal Spa	8	18	0	0	7	67	4	1	1	1	0	0	0	0	0	1	0	4	1
Lilani	9	41	1	0	9	81	3	3	1	98	16	13	1	0	0	2	0	2	0
Thangami	9	28	0	0	10	112	4	2	2	2	0	0	1	0	0	6	0	4	1
Shu-Shu	9	52	0	0	8	145	6	5	1	2	0	12	1	0	0	2	0	2	0
Warmbaths	10	10	0	0	8	64	4	5	0	1	0	0	0	0	0	2	0	1	1
Birlanyoni	8	24	3	1	20	69	6	5	1	2	26	1	2	0	0	0	0	2	1

Springs	pH	SO_4	NO_3	NO_2	F	Na	K	Mg	V	Cr	Mn	Cu	Zn	U	Cd	Hg	Pb	Se	As
TWQR mg per litre	**6 to 9**	**200mg**	**6mg**	**6mg**	**1ug**	**100mg**	**50mg**		**100μg**	**50μg**	**50 μg**		**3mg**	**70μg**	**5μg**	**1μg**	**10μg**	**20μg**	**10μg**
Health effects						**200mg**		**100mg**			**20mg**	**30mg**	**10mg**					**50μg**	
MPU																			
Badplaas	9	16	0		7	111	4	1		88	11	62	640		1		2	2	
Grovesbad																			
Machadodorp	8	3			3	60	2	3			18	59			1				
Falcon Glen	8	0			2	64				131	25	73	441		2				
Amanzimtaba	8	69	3	0	7	140	5	1	6	46	56	29	0	0	1	5	0	3	4
Sulphur spring	9	20	0	0	13	35	3	6	0	1	0	0	1	0	0	1	0	2	12
Swazi Spa	9	4			6	26	1	0	4	187	33	22						7	

TWQR = Target Water Quality Range	**No data**	**Conforms to Standards**	**Does not comply**

TABLE 3.2: DRINKING WATER STANDARDS (SANS 241:2005, 2011)

All A values	pH	Ca	Cl	F	Mg	NO3	NO2	K	Na	SO4	Zn	Al	Sb	As	Cd	Cr	Co	Cu	Pb	Mn	Hg	Ni	Se	V	TSS
	5 to 9.5	150	200	1	70	10	10	50	200	400	5000	300	10	10	5	100	500	1000	20	100	1	150	20	200	
Per litre		mg	mg	mg	mg	mg	mg	mg	mg	mg	µg	µg	µg	µg	µg	µg	µg	µg	µg	µg	µg	µg	µg	µg	
LIMPOPO																									
Tshipise	8.6	5	156	5.4	0	0	0	4	152	48	279	0	1	3	0	8	0	2	3	3	0.5	12	6	15	0
Sagole	9.3	2	43	0.9	0	0	0	1	66	17	80	0	1	3	0	4	0	1	2	3	0.5	0	2	3	2
Evangelina	7.4	78	507	4.0	27	9	0	6	**355**	210	926	1	1	22	1	23	1	11	3	5	1.1	0	31	91	0
Moreson	8.0	5	87	3.2	0	12	0	3	84	46	148	6	1	5	1	7	0	2	3	6	1.9	0	10	14	0
Mphephu	7.7	11	35	2.6	8	1	0	1	42	9	50	0	1	2	0	6	0	0	3	4	1.4	0	4	15	0
Siloam	8.7	6	44	5.7	0	0	0	3	61	10	124	0	7	0	0	1	0	0	0	1	0.3	0	1	18	0
Warmbad	8.5	10	88	18.5	2	0		4	126	12										1					0
Rhemardo	7.3	23	27	5.7	2	1	0	4	35	12	40		1	1	2	3	2	6	4	10	0.0	9	4	4	0
Soutini	7.2	86	680	2.2	5		0	15	486	170	0		0			5	17	9		21		16		12	0
Die Oog	7.3	25	26	5.8	2	1	0	4	42	10	10		0	4	1	6	3	6	6	20	0.0	17	2	4	0
Vischgat	6.9	37	34	6.0	2	1	0	6	58	97	2		1	4	1	3	3	6	5	12	0.9	12	0	3	0
Loubad	6.8	29	3	0.7	6	0	0	3	8	2	31	1	2	4	1	4	2	5	7	4	0.0	7	0	4	2
Buffelshoek	7.1	27	139	6.6	5	0		6	152	35		5													0
Minvamadi	7.3	9	19	0.1	13	8	0	1	11	2	39	0	0	0	0	1	0	0	0	0	0.0	0	1	2	2
Eiland source	8.0	34	546	3.3	2	1	0	15	352	77	1431	0	0	3	2	3	14	2	1	3	3.1	20	9	42	0
Lekkerrus	7.1	19	7	6.5	9			5	22	8	0		0	7	0	3	2	6	6	14	1.8	10	0	3	0
Libertas	6.9	24	8	5.2	2	0	0	3	22	8	38		0	1	0	3	4	30	5	49	0.3	6	3	5	0
KNP																									
Tshalungwa	7.3			0.9		1	0			26	218		0	3	0	2	0	0	6	4	2.6	0	1	7	0
Tshipala A	9.3	2	134	1.7				2	126	38	253		0	11	0	1	0	0	3	16	4.1	2211	1	2	0
Maritumbe	7.8	8	65		9	0		32	35	24		300						30		150					0
Magovani Hoof	7.4	16	44	0.3	15			5	25	9										230					0
Malahlapanga	8.4	19	270	2.9				6	191	74	713		0	0	0	2	0	0	2	9	3.9	4765	4	11	0
Malahlapanga B	6.1	33	328	3.1				9	231	159	868		0	0	0	11	4	4	4	104	1.5	72330	5	15	0
Mafayini	8.0	312	1166	1.2				14	562	355	2758		0	0	0	0	1	1	3	5	2.5	31150	15	10	0
Matiyavila act	7.3	486	1700			0		45	840	397	4248		0	1	0	1	0	0	2	0	1.6	0	24	11	0
W CAPE																									
Brandvlei	6.6	4	14	0.2	2	1	0	2	10	2	34	1	0	1	0	1	0	1	0	1	0.6	2	2	1	2

Citrusdal	6.2	2	16	0.2	2	1	0	2	8	2	43		0	0	0	1	0	0	0	4	0.0	1	2	1	2
Caledon	7.0	8	33	0.3	3	0	0	5	18	5	87		0	1	0	1	0	0	0	2635	0.0	0	1	1	0
Springs	**pH**	**Ca**	**Cl**	**F**	**Mg**	**NO3**	**NO2**	**K**	**Na**	**SO4**	**Zn**	**Al**	**Sb**	**As**	**Cd**	**Cr**	**Co**	**Cu**	**Pb**	**Mn**	**Hg**	**Ni**	**Se**	**V**	TSS
Toverwater	7.0	11	25	0.3	3	0	0	7	13	4	71	0	0	0	0	0	0	0	0	946	0.0	0	0	0	0
Goudini	6.6	9	10	0.2	3	0	0	2	9	2	39		0	1	0	1	0	3	0	4	0.0	0	1	1	2*
Calitzdorp	7.2	10	32	0.3	4	0	0	9	16	6			0	0	0	0	0	0	0	574	0.0	0	1	1	0
Montagu	6.6	7	15		3	1		4	10	6				1		3		4		3		1		1	2*
E CAPE																									
Aliwal	8.8	84	608	4.1	0	0	0	2	331	6	1034	4	0	2	0	0	0	0	0	1	1.8	0	11	13	0
Cradock	7.7	10	46	5.3	3	1	0	1	43	17	234	0	0	1		2	0	0	0	1	0.0	0	3	4	0
Fish Eagle Spa	8.3	76	853	4.0	0	1	0	3	335	10	834	30	0	1	0	0	0	0	0	3	0.7	0	6	14	0
FREE STATE																									
Badsfontein	7.3	72	684	4.2	0	0	0	2	316	4	975	0	0	1	0	0	0	0	0	1	1.1	0	4	11	0
Florisbad	7.9	96	1264	5.3	1	3	0	10	681	89	2394	0	0	1	0	1	0	0	0	3	0.9	0	8	22	0
Baden Baden	8.2	37	1375	6.9	1	3	0	7	728	4	2689	0	0	2	0	1	0	2	1	24	2.3	0	13	24	0
N CAPE																									
Riemvasmaak	7.8	142	1145	4.3	19	6	0	17	913	612	4538		0	11	0	1	0	0	0	0	1.3	0	27	16	0
KZN																									
Natal Spa	8.4	6	42	7.3	1	0	0	4	67	18	116	0	0	1	0	1	0	0	0	0	1.1	0	4	1	0
Lilani	9.2	5	29	8.7	3	1	0	3	81	41	61	0	0	0	0	98	2	13	0	16	2.4	208	2	1	0
Thangami	8.6	6	42	10.0	2	0	0	4	112	28	232	0	0	1	0	2	0	0	0	0	5.6	0	4	2	0
Shu-Shu	8.6	8	93	8.0	5	0	0	6	145	52	56	0	0	0	0	2	0	12	0	0	1.7	0	2	1	0
Warmbaths	10.0	9	16	8.0	5	0	0	4	64	10	55	0	0	1	0	1	0	0	0	0	1.8	0	1	0	0
Birlanyoni	8.0	6	47	19.6	5	3	1	6	69	24	68	0	0	1	0	2	0	1	0	26	0.4	1	2	1	0
MPU																									
Badplaas	8.6	6	131	6.8	1	0		4	111	16		181			1	88	2	62	2	11		128	2		0
Grovesbad																									*
Machadodorp	7.6	11	52	2.8	3			2	60	3					1		1	59		18		135			0
Falcon Glen	8.2		12	1.6					64	0					2	131	2	73		25		166			0
Amanzimtaba	8.0	28	298	7.4	1	3	0	5	140	69	514	0	2	4	1	46	0	29	0	56	4.9	0	3	6	0
Sulphur spring	8.6	7	17	13.1	6	0	0	3	35	20	30	0	0	12	0	1	0	0	0	0	1.2	0	2	0	0
Swazi Spa	8.7	4	6	5.6	0			1	26	4		73				187	3	22		33		349	7	4	0
	No data			**Complies to Standards**					**does NOT comply**					**Conductivity & TDS for aesthetics alone – not included**											

3.2.2 Animal health

Another possible source of concern is the use of thermal spring waters for domestic animals and wildlife. Many thermal springs are found on farms, on tribal land, in game reserves and ranching areas where the spring water flows into streams that are used by domestic animals, goats, game and wildlife as a source of water, especially during dry spells (Fig. 3.3). The potential risk of thermal springs needs to be assessed for this use.

Fig. 3.3 Thermal springs as a source of water for animals. (e.g. Goats at Sagole, fish at Eiland, dassies at Natal Spa, Wildlife footprints at thermal spring in KNP)

The Department of Water Affairs compiled Guidelines for Livestock Watering (DWAF 1996c). These are reflected in Table 3.3. These threshold values will probably also apply to wildlife. The degree to which thermal spring waters conform to these guidelines, are shown by means of colour shadings in Table 3.4.

TABLE 3.3: TWQR FOR LIVESTOCK			
Halogen	**Health impacts**	**TWQR (DWAF, 1996)**	**Springs which do not meet requirements**
Fluoride (F)	(+) Tooth and bone formation inhibits enzyme. activity of cariogenic bact. (-) Fluorosis; dental decay; osteoporosis; calcification tendons & ligaments; bone deformity; If >1 mg/l – poor conception/reproduction rate.	< 1.0 mg/l	Tshipise, Evangelina, Moreson, Mphephu, Siloam, Warmbad, Badplaas, Natal Spa, Rhemardo, Lilani, Die Oog, Vischgat; Aliwal Spa, Cradock, Buffelshoek, Riffontein, Machadodorp, Fort Beaufort, Stinkfontein, Paddispand, Eiland, Libertas, Riemvasmaak, Falcon-Glen, Tshipala A, Malahlapanga, Klopperfontein, Amanzimtaba, Swazi Spa, Thangami, Shu Shu, Badsfontein, Soutini.
Bromide (Br)	(-) Replace Cl in physiological functions. Cause goiter; exacerbated by high F & I; Toxic with long term exposure.	< 0.01 mg/l	Brandvlei, Tshipise, Sagole, Evangelina, Moreson, Mphephu, Siloam, Warmbad, Caledon, Towerwater, Rhemardo, Thangami, Die Oog, Vischgat, Aliwal Spa, Loubad, Cradock, Badsfontein, Minwamadi, Eiland, Riemvasmaak, Tshawungwa, Tshipala A, Malahlapanga, Matiyavila, Klopperfontein.
Iodide (I)	(+) Normal functioning of thyroid gland (-) Cumulative chronic toxin	<0.01 mg/l	Brandvlei, Tshipise, Evangelina, Moreson, Mphephu, Caledon, Warmwaterberg, Towerwater, Soutini, Aliwal Spa, Loubad, Cradock, Badsfontein, Machadodorp, Eiland, Libertas, Calitzdorp, Riemvasmaak, Tshalungwa, Tshipala A, Malahlapanga, Mafayini, Matiyavila, Klopperfontein.
Chloride (Cl)	(+) Circulatory system (-) Hypertension	< 200 mg/l	Evangelina, Tugela, Aliwal Noord, Aliwal Spa, Malmesbury, Badsfontein, Riffontein, Florisbad, Eiland, Riemvasmaak, Malahlapanga, Mafayini, Matiyavila, Amanzimtaba, Soutini
Br:I	(-) Replace I in thyroid hormones	Ave: 0.6:1 High: 3:1	Brandvlei, Tshipise, Sagole, Mphephu, Siloam, Citrusdal, Caledon, Towerwater, Rhemardo, Goudini, Die Oog, Aliwal Spa, Minwamadi, Eiland, Riemvasmaak, Tshalungwa, Tshipala A, Malahlapanga (53:1), Matiyavila, Mafayini.
TWQR = Target Water Quality Range for animal consumption (DWAF, 1996c)			

It is evident that Hg, Ni, Mo and the halogens (F, Cl, Br and I) are the greatest cause for concern since all spring except for those in the Western Cape, and Loubad and Minvamadi in Limpopo have values exceeding TWQR. The springs most at risk are those in the Kruger National Park (KNP), Riemvasmaak and those in Limpopo (except for Loubad and Minvamadi). Many springs are rich in the halogens and mercury, while few exceed the limits for Mo or Ni. Fluoride and bromine levels appear to be the most hazardous in the thermal springs.

High levels of fluoride are associated with dental fluorosis in young animals and skeletal fluorosis in more mature animals. This may increase the rates of bone fractures, decrease birth rates, increase rates of urolithiasis (kidney stones) and impair thyroid function (Fuge, 1988; Wessels *et al.,* 2010).

Bromine could possibly replace chlorine in some of the body functions and is concentrated in the thyroid gland in the absence of iodine. However, it cannot replace iodine in the synthesis of the thyroid hormones, thyroxin and triiodothryonine (Nielson, 1986: In Fuge, 1988). For this reason it is a potential goitrogen, (Meyer 2006: In Wessels *et al.,* 2010). Moreover, bromine salts are toxic and during lactation or when more water is consumed, passing the high bromine to calves is possible.

The ratio of bromine to iodine can be used as an indicator of the development of goiter in humans and animals. A bromine to iodine ratio of 3:1 (Wessels *et al.* 2010) is considered to be high and indicative of endemic goitre. This seems to be a real problem since a ratio of 25:1 was found in springs in the KNP. This shows that the animals that drink these spring waters on a prolonged basis are likely to develop endemic goitre with concomitant health implications (Olivier & Jonker, 2013, submitted).

TABLE 3.4: GUIDELINES FOR LIVESTOCK WATERING (DWAF, 1996c)																								
	TDS	F	Na	Mg	Mo	B	V	Cr	Mn	Co	Ni	Cu	Zn	Br	Cd	I	Hg	Se	As	Pb	NO_3	SO_4	Ca	Cl
Springs	mg/l	mg/l	mg/l	mg/l	µg/l	µg/l	µg/	µg/	µg/	µg/	µg/	µg/	µg/	µg/	µg/	µg/	µg/	µg/	µg/	µg/	mg/l	mg/l	mg/l	mg/l
All in mg/l except Hg & Se	3000	2	2000	500	0	5	1	1	10	1	1	0.5	20	0.01	0	0.1	1 ug/l	50 ug/l	1	0.1	100	1000	1000	3000 (1500)
LIMPOPO																								
Tshipise	436.2	5.4	151.8	0.1	1.9	161.1	15.0	7.9	3.3	0.1	12.4	1.7	2.5	278.5	0.0	74.4	0.5	6.0	3.4	2.7	0.4	47.5	4.5	155.8
Sagole	207.2	0.9	66.0	0.0	1.1	48.6	3.3	4.0	3.3	0.1	0.0	0.8	15.3	80.0	0.1	9.1	0.5	2.5	3.2	2.1	0.0	17.2	2.4	43.3
Evangelina	1329.9	4.0	355.4	26.6	15.3	297.9	91.3	23.0	5.1	1.1	0.5	10.5	25.7	925.6	0.8	2165.0	1.1	30.6	21.9	3.1	9.1	210.2	78.2	507.0
Moreson	334.5	3.2	83.9	0.2	1.3	56.7	13.7	7.4	6.3	0.1	0.0	1.7	3.1	148.2	0.9	580.9	1.9	10.1	4.9	2.6	12.1	46.0	4.8	86.9
Mphephu	186.5	2.6	41.8	8.3	1.2	33.3	14.7	5.6	3.6	0.1	0.0	0.4	0.6	50.3	0.2	219.8	1.4	3.8	2.0	2.9	1.0	8.8	11.2	35.4
Siloam	191.6	5.7	61.0	0.5	2.4	52.2	17.6	0.9	0.6	0.0	0.0	0.2	6.2	123.8	0.0	4.5	0.3	1.4	0.1	0.0	0.0	9.6	5.7	43.9
Warmbad	368.5	18.5	126.3	1.8	1.0	250.0			1.0												0.0	12.1	10.0	87.6
Rhemardo	207.5	5.7	35.4	2.1	9.7	47.6	3.7	2.8	9.6	2.1	8.8	6.0	37.5	39.6	1.8	15.9	0.0	3.8	1.4	3.7	0.9	11.8	23.3	26.8
Soutini		2.2	486.3	4.5	18.0	388.0	12.0	5.0	21.0	17.0	16.0	9.0		0.0								170.3	85.7	680.3
Die Oog	235.2	5.8	42.0	2.0	6.3	33.1	3.7	5.5	20.1	3.5	17.3	5.5	8.6	10.4	0.9	0.0	0.0	1.7	4.2	5.6	0.6	10.4	25.5	25.7
Vischgat	324.1	6.0	57.6	2.2	11.1	45.7	3.5	3.1	11.9	3.5	12.0	5.7	13.1	1.7	0.9	18.0	0.9	0.0	4.0	4.7	0.6	97.1	37.4	33.5
Loubad	164.1	0.7	7.9	6.0	11.1	47.0	4.3	3.5	3.5	1.6	7.1	5.0	19.5	31.4	1.2	7.8	0.0	0.0	4.5	7.0	0.3	2.2	28.7	2.9
Buffelshoek	450.0	6.6	151.6	4.7	1.0																0.0	35.1	27.1	138.5
Minvamadi	113.0	0.1	10.6	13.3	0.0	39.4	2.3	1.2	0.4	0.0	0.0	0.0	4.4	39.4	0.0	4.9	0.0	0.5	0.1	0.3	7.9	2.5	9.4	19.5
Eiland	1028.8	3.3	351.9	1.9	9.8	126.5	41.6	2.6	2.5	14.4	19.7	1.8	581.0	1430.5	2.4	591.3	3.1	9.4	3.3	0.9	1.1	76.7	33.8	546.1
Lekkerrus	162.0	6.5	22.0	8.5	12.5	43.8	3.2	3.4	14.2	2.2	10.2	5.8	14.6	0.0	0.0	20.1	1.8	0.0	6.6	5.7		8.0	19.0	7.0
Libertas	155.6	5.2	21.7	2.5	4.9	34.4	4.9	3.0	48.8	3.8	6.3	29.8	42.8	37.6	0.0	22.3	0.3	3.1	1.3	4.8	0.4	7.6	24.0	8.1
KNP																								
Tshalungwa	733.9	0.9			1.8	72.6	7.0	1.8	3.7	0.0	0.0	0.0	42.2	217.5	0.0	15.4	2.6	0.8	3.0	5.6	0.9	26.0		
Tshipala A		1.7	126.0		2.6	97.8	1.9	0.7	15.7	0.0	2211.0	0.0	2.6	252.9	0.0	28.8	4.1	0.9	11.0	3.0		38.0	2.0	134.0
Maritumbe	455.0		35.0	9.0		60.0			150.0			30.0	110.0								0.4	24.0	8.0	65.0

	TDS	F	Na	Mg	Mo	B	V	Cr	Mn	Co	Ni	Cu	Zn	Br	Cd	I	Hg	Se	As	Pb	NO_3	SO_4	Ca	Cl
Springs	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**µg/l**	**µg/l**	**µg/**	**µg/**	**µg/**	**µg/**	**µg/**	**µg/**	**µg/**	**µg/**	**µg/**	**µg/**	**µg/**	**µg/**	**µg/**	**µg/**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
All in mg/l except Hg & Se	**3000**	**2**	**2000**	**500**	**0**	**5**	**1**	**1**	**10**	**1**	**1**	**0.5**	**20**	**0.01**	**0**	**0.1**	**1 ug/l**	**50 ug/l**	**1**	**0.1**	**100**	**1000**	**1000**	**3000 (1500)**
Magovani H	210.6	0.3	25.0	15.0		40.0			230.0													9.0	16.0	44.0
Malahlap	721.5	2.9	191.0		3.2	88.8	11.3	1.9	9.0	0.2	4765.0	0.2	11.1	712.6	0.0	13.4	3.9	3.7	0.0	2.4		74.0	19.0	270.0
Malahla B	921.1	3.1	231.0		14.6	110.4	14.6	10.9	103.6	4.4	72330.0	4.4	8.2	868.1	0.1	21.6	1.5	4.9	0.0	4.3		159.0	33.0	328.0
Mafayini	2775.5	1.2	562.0		5.0	216.6	10.3	0.5	5.1	1.0	31150.0	0.8	3.1	2758.0	0.0	107.0	2.5	15.3	0.4	3.0		355.0	312.0	1166.0
Matiyv act	3984.5		840.0		18.2	259.9	10.6	1.1	0.0	0.5	0.0	0.0	0.5	4248.0	0.0	247.2	1.6	24.2	1.0	1.6	0.2	397.0	486.0	1700.0
W CAPE																								
Brandvlei	47.7	0.2	9.6	2.1	0.3	13.2	1.5	1.2	0.5	0.1	1.6	1.2	5.7	33.9	0.1	1.9	0.6	1.8	0.6	0.0	0.7	1.7	3.7	14.1
Citrusdal	75.4	0.2	8.3	1.7	0.0	21.1	1.2	1.1	4.4	0.0	0.5	0.0	26.1	43.2	0.0	0.9	0.0	2.1	0.3	0.0	0.7	1.5	2.1	15.7
Caledon	116.2	0.3	18.4	3.0	0.1	26.0	0.8	0.5	2634.7	0.3	0.0	0.0	0.0	87.0	0.0	6.7	0.0	1.5	0.8	0.1	0.0	5.2	7.6	32.6
Toverwater	112.7	0.3	13.1	3.3	1.3	19.8	0.4	0.4	946.2	0.1	0.0	0.0	0.1	71.3	0.0	20.7	0.0	0.3	0.5	0.0	0.0	3.8	11.4	25.0
Goudini	62.9	0.2	9.3	3.1	0.0	19.2	0.9	1.1	4.4	0.0	0.0	2.8	12.7	38.6	0.0	2.1	0.0	0.7	0.7	0.0	0.4	1.9	8.9	10.3
Calitzdorp	133.5	0.3	16.2	4.3	0.5	32.1	0.9	0.1	573.7	0.0	0.0	0.0	0.0		0.0	13.5	0.0	1.0	0.1	0.0	0.2	6.3	10.0	31.7
Montagu	83.7		9.9	2.6	1.0		1.0	3.0	3.0		1.0	4.0							1.0		0.5	5.5	7.2	14.6
E CAPE																								
Aliwal	1254.7	4.1	331.0	0.4	0.6	509.5	12.6	0.4	1.4	0.0	0.0	0.2	4.6	1033.9	0.0	229.3	1.8	11.2	1.9	0.1	0.3	5.8	84.0	607.9
Cradock	214.4	5.3	43.4	3.4	4.1	438.9	4.0	2.1	0.6	0.0	0.0	0.0	8.0	233.6		103.0	0.0	2.7	1.2	0.0	0.6	17.4	10.0	45.8
Fish Eagle	1293.1	4.0	335.4	0.4	0.5	580.0	14.2	0.4	2.9	0.1	0.0	0.4	1.6	833.7	0.0	474.9	0.7	6.3	1.3	0.0	0.5	10.0	75.9	853.0
FREE STATE																								
Badsfontein	1092.3	4.2	315.8	0.2	0.6	686.1	10.9	0.3	1.4	0.0	0.0	0.0	0.9	974.7	0.0	324.2	1.1	4.4	1.0	0.0	0.5	4.4	71.8	684.5
Florisbad	2108.3	5.3	680.8	0.6	0.4	531.3	22.2	1.1	2.8	0.1	0.0	0.3	1.0	2394.0	0.0	2877.0	0.9	7.8	1.3	0.0	3.0	88.9	95.6	1263.7
Baden Baden	2182.5	6.9	727.8	0.7	0.4	584.1	24.2	1.1	24.3	0.0	0.0	2.3	2.3	2689.0	0.0	3198.0	2.3	12.6	2.5	0.8	3.1	4.3	37.4	1375.1

	TDS	F	Na	Mg	Mo	B	V	Cr	Mn	Co	Ni	Cu	Zn	Br	Cd	I	Hg	Se	As	Pb	NO_3	SO_4	Ca	Cl
Springs	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**µg/l**	**µg/l**	**µg/**	**µg/**	**µg/**	**µg/**	**µg/**	**µg/**	**µg/**	**µg/**	**µg/**	**µg/**	**µg/**	**µg/**	**µg/**	**µg/**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
All in mg/l except Hg & Se	**3000**	**2**	**2000**	**500**	**0**	**5**	**1**	**1**	**10**	**1**	**1**	**0.5**	**20**	**0.01**	**0**	**0.1**	**1 ug/l**	**50 ug/l**	**1**	**0.1**	**100**	**1000**	**1000**	**3000 (1500)**
N CAPE																								
Riemvasmaak	3254.3	4.3	912.5	18.6	35.2	621.7	15.6	1.2	0.0	0.0	0.0	0.0	0.9	4538.0	0.0	228.1	1.3	27.1	11.0	0.0	5.5	612.4	142.4	1145.0
KZN																								
Natal Spa	228.7	7.3	67.3	1.2	6.5	9.7	0.7	1.0	0.0	0.1	0.2	0.0	0.0	115.9	0.0	30.3	1.1	4.2	0.7	0.1	0.0	17.8	5.6	42.2
Lilani	280.1	8.7	80.8	3.2	2.9	27.7	1.2	97.8	16.0	1.5	208.3	12.6	1.0	60.5	0.0	39.5	2.4	2.3	0.2	0.0	1.4	41.0	5.2	28.6
Thangami	397.8	10.0	112.4	1.8	3.4	34.4	1.8	2.4	0.0	0.0	0.1	0.0	1.0	231.9	0.0	133.4	5.6	3.8	1.0	0.0	0.5	28.3	5.8	42.2
Shu-Shu	723.6	8.0	145.2	5.0	3.7	24.0	1.2	1.7	0.0	0.0	0.1	11.5	1.0	56.2	0.0	47.2	1.7	1.8	0.0	0.0	0.2	51.7	8.4	92.7
Warmbaths	195.1	8.0	63.8	5.0	4.9	4.3	0.2	1.0	0.3	0.0	0.1	0.0	0.2	54.6	0.0	18.8	1.8	0.7	0.7	0.0	0.1	10.5	9.1	16.3
Birlanyoni	216.8	19.6	69.5	4.6	5.3	4.8	0.9	2.4	25.9	0.2	0.9	1.0	2.0	68.2	0.0	5.5	0.4	2.3	0.6	0.2	2.8	24.3	6.1	47.4
MPU																								
Badplaas	383.5	6.8	111.0	0.7	5.5			88.0	10.5	2.0	128.0	62.0	640.0		1.0			2.0		2.0	0.2	15.5	6.4	130.6
Grovesbad																								
Machadodorp	395.0	2.8	59.9	3.1	3.0	298.0			18.0	1.0	135.0	59.0			1.0							2.8	11.5	51.6
Falcon Glen	232.1	1.6	64.2		5.0			131.0	25.0	2.0	166.0	73.0	441.0		2.0							0.0		12.0
Amanzimtaba	699.4	7.4	139.8	0.6	5.7	205.2	6.5	46.0	56.1	0.0	0.1	29.0	0.0	513.6	0.5	222.2	4.9	3.0	4.5	0.0	3.4	69.3	28.0	298.1
Sulphur sp	152.0	13.1	34.6	6.3	3.2	2.3	0.1	1.3	0.0	0.0	0.2	0.0	0.8	29.5	0.0	6.5	1.2	2.0	12.1	0.0	0.0	20.2	7.2	16.7
Swazi Spa	124.2	5.6	26.1	0.3	18.0		4.0	187.0	33.0	3.0	349.0	22.0						7.0				3.9	3.8	6.0

Exceeds limits | **Conforms to guidelines** | **No data** | **Exceeds limits for monogastrics only**

3.3 POTENTIAL HEALTH RISK-BEARING MICROORGANISMS

3.3.1 Potentially harmful algae in thermal springs

Algae species appear to have very wide geographical distributions. Cyanobacteria (blue green algae) inhabit some of the planets harshest environments and commonly occur in thermophylic environments (Sompong *et al.,* 2005). These algae have adapted to high salinity or to high concentrations of certain ions. Blue-green algae are mainly concentrated in hot-spring waters with a pH of over 6 where they form conspicuous and often uni-algal matlike covers over submerged substrates (Castenholz, 1969). Cyanobacteria are particularly problematic because when their cells are ruptured they release toxic substances (cyanotoxins) into the water.

In the toxicity standards, algae biotoxins are considered supertoxic (Oberholtzer *et al.,* 2005). These biotoxins are water-soluble and heat stable. Cyanotoxins are also released from the algae by sulphur bacteria (Rand *et al.,* 1976).

The primary target organ of most cyanotoxins in mammals is the liver (i.e. they are hepatotoxic) but some cyanotoxins are neurotoxic (target the nervous system) and others are dermatotoxic (target the skin). Chronic exposure to low doses may promote the growth of liver and other tumours. Acute exposure to high doses may cause death from liver haemorrhage or liver failure. Other short term effects on humans include gastrointestinal and hepatic illnesses.

BOX 3.1

The primary types of cyanobacterial biotoxins include hepatotoxin (found as microcystins, nodularins and cylindrospermopsins), neurotoxin (anatoxins and saxitoxins) and dermatotoxins (lyngbyatoxin-A, aplysiatoxins, lipo poly-saccharides). Anatoxin-a are produced by species and strains of the genera *Anabaena* and *Oscillatoria* and is a secondary amine, 2-acetyl-9-azabicyclo (4.2.1) non-2-ene (Oberholtzer *et al.,* 2005). This alkaloid, a structural analogue of cocaine, is a potent post-synaptic cholinergic nicotinic agonist, which causes a depolarizing neuromuscular blockage, followed by fatigue and paralysis (Oberholtzer *et al.,* 2005). Various species of these blue green algae may have carcinogenic or mutagenic effects (Grabow, 1982). *Nodularia* can result in the death of stock or native animals. It produces hepatoxins that kill liver cells, leading to liver damage and gastroenteritis in humans (Entwisle *et al.,* 1997: 194).

Algae in Soutini thermal spring waters **Left** : *Phormidium* **Right** : *Nodularia*

Jonker *et al.,* 2013) found that the Cyanobacteria *Oscillatoria, Phormidium, Schizothrix, Microcystis, Oscillatoria*, and *Lyngby*a occur widely in Limpopo thermal springs with temperature ranging from 40°C to 60+°C.

Phormidium sp. dominated the 60+°C temperature zone, while Oscillatoria were found in most of the thermal springs and was distributed across the entire temperature range (40 to 67.5°C). *Oscillatoria, Anabaena, Phormidium, Nostoc* and *Lyngbya* thrive in waters with pH ranging from 7.5 to >9, however, *Nodularia, Schizothrix* and *Anacystis* occurred in highly alkaline waters (pH >9). The Cyanophyta (*Phormidium, Microcystis, Oscillatoria, Nostoc, Nodularia, Lyngbya, Anabaena* and *Schizothrix*) seem to be well adapted for survival in high fluoride concentrations in the different springs.

The use of chlorine to disinfect thermal swimming pools does not appear to be successful since the chlorination of these spring waters may have created ecological niche communities for algae, such as *Anabanea sp*. at Eiland and *Oscillatoria sp.* at Tshipise

The occurrence of potentially toxic Cyanobacteria has not been established in thermal spring in other provinces of the country. However, almost all cases of animal poisoning from algae in drinking water In South Africa, have been associated with *Microcystis aeruginos* which may render a potential health threat to rural domestic and agriculture users (Oberholtzer *et al.,* 2005).

3.3.2 Potentially harmful bacteria in thermal springs

The presence of microbial pathogens in thermal spring water poses a risk to public health for water used for domestic and recreational purposes. Although water quality criteria for recreational waters were established in the 1950s, there are still cases being reported of illnesses, such as gastroenteritis, arising from the ingestion of coliform bacteria in recreational waters (BonaDonna & Spica, 2010).

Numerous human diseases from bathing in naturally contaminated water are associated with the presence of opportunistic pathogens from *Pseudomonas, Aeromonas, Staphylococcus* and other microorganisms groups, being able to generate infections by contact with skin, mucous membrane, nosopharyngeal cavity, respiratory ducts, eyes, ears and urogenital passages (Niewolak & Tucholski, 1999)

Several bacterial pathogens, such as *Legionella* spp., *Aeromonas* spp., *Pseudomonas aeruginosa* and *Mycobacterium avium*, have a natural reservoir in the aquatic environment and soil.

Through metagenomic studies of the bacterial diversity of the thermal springs Siloam, Tshipise, Sagole, Eiland, Souting and Mphephu, genera with which some species that are known human pathogens were identified. Table 3.5 provides a list of some these genera and related diseases.

TABLE 3.5: SOME PATHOGENIC GENERA AT SELECTED STUDIED SOUTH AFRICAN HOT SPRINGS		
Pathogenic bacteria genus	**Disease linked to genus**	**Hot spring from which detected**
Clostridium	Gas gangrene, uterine infections, tetanus, Botulism, infant botulism, Antibiotic-associated diarrhea, pseudomembranous colitis	Sagole
Mycobacterium	TB, Leprosy	Eiland, Mphephu, Siloam, Soutini
Pseudomonas	Opportunistic infections, swimmer's ear, hot tub itch, cellulitis, pneumonia, more	Soutini
Aeromonas	Diarrhea	Soutini
Legionella	Legionnaires' disease	Siloam
Shigella/ Escherichia	hemorrhagic colitis; hemolytic uremic syndrome	Siloam
Vibrio	Cholera, wound infection, septicemia, gastrointestinal disease	Soutini
Enterococcus	Urinary tract infections, bacteremia, bacterial endocarditis, diverticulitis, and meningitis	Mphephu, Siloam
Flavobacteria	Pneumonia, Bacteremia	Soutini, Siloam, Mphephu
Stenotrophomonas	Pulmonary infections	Eiland, Mphephu, Siloam, Soutini

Thermal spring waters from Florisbad were incubated at 37 and 50°C to produce bacterial cultures as shown in Figure 3.4. The DNA sequence of microbial isolates was sequenced against the NCBI database.

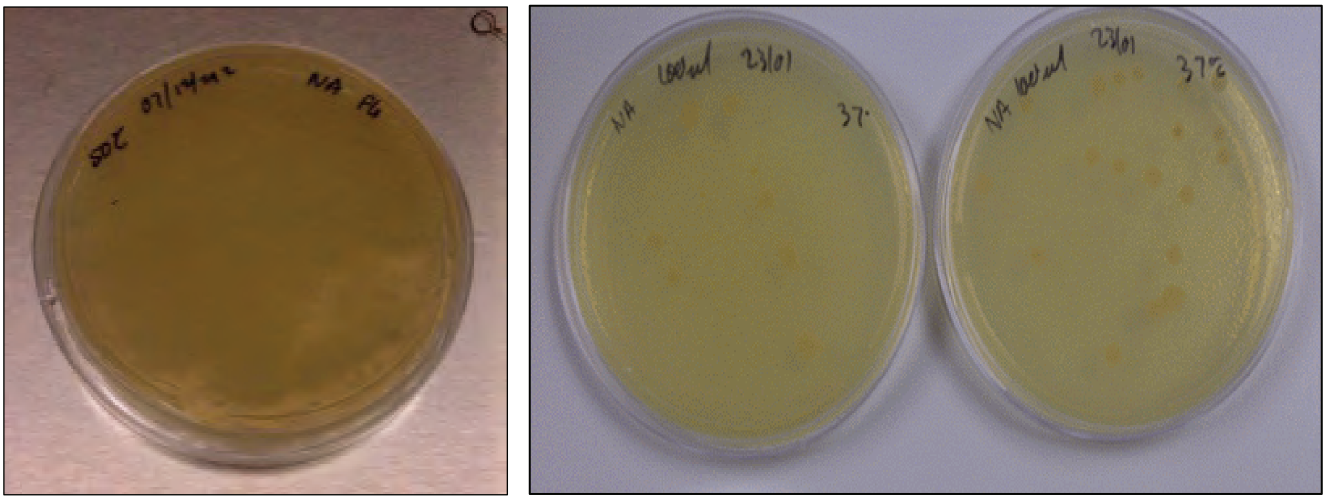


Fig. 3.4 Nutrient Agar (NA) plates incubated at 37 and 50°C.

The application of 16S ribosomal RNA gene sequencing isolated three different strains of *Bacillus subtilis* – namely OSS 42, N4 and BS-02 – from Florisbad waters.

TABLE 3.6: DESIGNATION OF UNIQUE ISOLATES FLORISBAD RESORT (SOURCE – DON COWAN DELIVERABLE 19)				
Isolate designation	**Highest Blast Result**	**GenBank accession number of highest Blast**	**No. of nucleotides used for alignment**	**% Identity**
TM1	*Bacillus subtilis* strain OSS 42 16S ribosomal RNA gene, partial sequence	EU124568.1	735	99 %
TM2	*Bacillus subtilis* strain N4 16S ribosomal RNA gene, partial sequence	JQ653049.1	710	99 %
TM3	*Bacillus subtilis* strain BS-02 16S ribosomal RNA gene, partial sequence	HM631974.1	757	99 %

BLAST results (Table 3.5) indicated that all 3 amplicons were closely affiliated to *Bacillus subtilis* isolates (see box 3.2).

BOX 3.2

Although *Bacillus* is included in the GRAS list (generally regarded as safe) of US Food and Drug Administration (USFDA) and hence are regarded as being harmless, some of these strains may pose a health risk to bathers and consumers of thermal spring waters. This applies specifically to the BS-02 strain, the plasmids of which have been found to carry florfenicol and chloramphenicol resistant genes. The carriage of a mobile *cfr* gene by Bacillus species and their common association with foods and environments may cause the spread of resistance to other bacterial organisms in various ecosystems, including animal hosts (Zeikus, 1979; Zhang, 2011).

It is thus clear that although some thermal springs might contain minerals that are potentially harmful, there is no concrete evidence that these elements arise from the groundwater. Contamination might be from pipes of other structural materials – although care was taken to try to obtain samples from as close to the point of issue as possible. It is thus important that the source of contamination is traced and remedial steps taken. In addition, it should be kept in mind that only little water is usually consumed during swimming and at these intake levels should not affect healthy visitors. The fact that vulnerable members of society – the very young and old – are exposed to such waters places a burden on the resort managers to introduce stringent safety standards. It is recommended that a thorough chemical analysis (including tests for potentially toxic trace elements) be conducted at each of the resorts and that microbial analysis be conducted at more regular intervals.

CHAPTER 4: ALTERNATIVE APPLICATIONS FOR THERMAL SPRINGS IN SOUTH AFRICA

Olivier J, Jonker CZ, Tekere M & Tshibalo AE

Chapter 1 discussed the global increase in variety of uses for thermal springs. As far as could be ascertained no investigations have been undertaken regarding the potential of these uses for South African thermal springs. This chapter identifies thermal springs that are suitable for 'alternative' uses beyond recreation, such as bottling, cosmetics, agriculture, aquaculture, hydro-mining and the generation of electricity.

4.1 METHODOLOGY

The sole criteria used for evaluation of fitness-for-use were the physical and chemical properties of thermal spring waters as given in Addendum B. A simple rating technique was devised to quantify the degree of suitability of each thermal spring for each particular use. This comprised the following steps:

- A literature study to identify all the criteria deemed necessary with respect to a particular use.
- The subdivision of these criteria into the essential criteria (A) (including threshold values for, e.g. toxicity) and non-essential criteria (B) – i.e. that could have additional beneficial properties.
- A value of 0 was assigned in the case of non-conformity (non-compliance) and a value of +1 if thermal spring properties conformed to requirements.
- A total suitability score (TSS) was then calculated as follows:

  TSS = A(A +B) where A = (a_1 x a_2 x a_3 x ….a_n) and B = ∑(b_1+ b_2 +…… b_n).

  This formula ensures that, in the event of an essential criterion not meeting the requirements a total suitability score of 0 will be given – indicating non-suitability.

Excel tools were used for statistical applications.

4.2 RESULTS – APPLICATIONS

4.2.1 Bottled water

Bottled water has become a pervasive global business, and its consumption continues to increase rapidly, particularly in countries where clean potable tap water is not available at low or no cost (Wilk, undated)(Fig 4.1). In 2006, global bottled water sales reached an estimated value of \$60 billion (~R500 billion) with more than 115 000 000 m^3 (3.0×10^{10} US gal) being consumed. In 2010, consumption figures had climbed to 183 billion (thousand million) litres with a value of more than $99 billion (R800 billion) (http//www.reportlinker.com). The US is the largest consumer followed by Mexico, China and Brazil (SANBWA, 2010).

The South African bottled water industry is very small when compared to the above. Despite this, it has shown a consistent positive growth rate over the last few decades. During 2012, 0.72 million m^3 were bottled, generating R3 550 million. The industry employs approximately 1 800 people (25 Degrees, 2012). Bottled water sells for prices ranging from R2 per 500 ml to almost R50 per 500 ml.

The Department of Health has drawn up legislation governing the bottled water industry. The industry is regulated by the South African National Bottled Water Association (SANBWA) using standards based on the 1963 international *Codex alimentarius*. In accordance with the Codex, three classes of bottled water are defined. These are *natural water*, *water defined by origin*, and *prepared water*. *Natural waters* are sourced from an underground aquifer and bottled at source. Natural mineral water and natural spring water fall into this class. *Water defined by origin* includes glacial, rain, mist and spring water. No chemical treatment is allowed that could affect the chemical composition of the water. *Prepared water* includes municipal, surface or groundwater that has been purified by treatments that change its chemical composition (Faurie *et al*., 2010). Reverse osmosis is the most popular technique used for purification.

If bottled, thermal spring water would be classified as either natural water or water defined by origin.

Fig. 4.1 Bottled thermal spring water

SANBWA standards for bottled water of untreated source water (as defined by origin), were used as the essential criteria for determining the suitability for bottling of thermal spring waters (SANBWA, 2010).

Since bottled water must conform to all standards, each of the minerals and chemical components of the water was deemed to be 'essential' (A) and not to be exceeded. The application of these standards to thermal waters is shown in Table 4.1. Each mineral in thermal spring waters was compared to the National Standards according to the arbitrary sequence of minerals as shown in Addendum B If the thermal waters tested exceeded any of the mineral standards the water was deemed be unfit for bottling, and no further comparison was conducted. Green shading was used to indicate conforming levels with orange shading for exceedance. A yellow colour was used to indicate the absence of data, while purple indicate criteria not included in SABWA. Springs for which no data were available were assumed to be unfit for bottling until such time as data became available.

TABLE 4.1: FITNESS FOR USE – BOTTLED WATER																									NICHE
SANBWA	pH	SO4	TDS	EC	NO3	NO2	F	Cl	Mo	B	Cr	Mn	Ni	Cu	Zn	Br	U	Cd	Sb	Ba	Hg	Pb	Se	As	Li
Criteria */l	5-9.5	250 mg	500 mg	150	50 mg	0.1 mg	5 mg	250 g	70 µg	5000	100	1000	150	1000	5000	6	0	5	10	700	2	50	20	50	
LIMPOPO																									
Tshipise	8.6	47.5	436.2	79.7	0.4	0.0	5.4	155.8	1.9	161	8	3.3	12.4	1.7	2.5	279	0.1	0.0	0.8	10.5	0.5	2.7	6.0	3.4	64.8
Sagole	9.3	17.2	207.2	35.4	0.0	0.0	0.9	43.3	1.1	48.6	4	3.3	0.0	0.8	15.3	80	0.2	0.1	0.8	5.0	0.5	2.1	2.5	3.2	20.7
Evangelina	7.4	210.2	1323	216	9.1	0.0	4.0	507	15.3	298	23	5.1	0.5	11	25.7	926	30	0.8	1.5	15.1	1.1	3.1	31	21.9	72.9
Moreson	8.0	46.0	334.5	56.5	12.1	0.0	3.2	86.9	1.3	56.7	7	6.3	0.0	1.7	3.1	148	0.8	0.9	1.2	26.3	1.9	2.6	10	4.9	40.1
Mphephu	7.7	8.8	186.5	35.2	1.0	0.0	2.6	35.4	1.2	33.3	6	3.6	0.0	0.4	0.6	50	0.9	0.2	1.3	37.2	1.4	2.9	3.8	2.0	6.9
Siloam	8.7	9.6	191.6	32.5	0.0	0.0	5.7	43.9	2.4	52.2	1	0.6	0.0	0.2	6.2	124	1.8	0.0	7.5	4.5	0.3	0.0	1.4	0.1	13.1
Warmbad	8.5	12.1	368.5	69.0	0.0		19	87.6	1.0	250		1.0								5.0					4.0
Rhemardo	7.3	11.8	207.5	42.0	0.9	0.0	5.7	26.8	9.7	47.6	3	9.6	8.8	6.0	37.5	39.6	0.0	1.8	1.0	9.5	0.0	3.7	3.8	1.4	79.5
Soutini	7.2	170.3		273		0.0	2.2	680	18.0	388	5	21.0	16.0	9.0		0.0	0.0		0						0.0
Die Oog	7.3	10.4	235.2	34.0	0.6	0.2	5.8	25.7	6.3	33.1	6	20.1	17.3	5.5	8.6	10.4	1.3	0.9	0	42.3	0.0	5.6	1.7	4.2	8.3
Vischgat	6.9	97.1	324.1	55.5	0.6	0.1	6.0	33.5	11	45.7	3	11.9	12.0	5.7	13.1	1.7	1.5	0.9	0.5	19.2	0.9	4.7	0.0	4.0	26.2
Loubad	6.8	2.2	164.1	25.0	0.3	0.0	0.7	2.9	11	47.0	4	3.5	7.1	5.0	19.5	31.4	4.1	1.2	2.5	13.3	0.0	7	0.0	4.5	47.1
Buffelshoek	7.1	35.1	450.0		0.0		6.6	138.5	1.0											5.0					4.0
Minvamadi	7.3	2.5	113.0	21.3	7.9	0.0	0.1	19.5	0.0	39.4	1	0.4	0.0	0.0	4.4	39.4	0.1	0.0	0.0	1.9	0.0	0.3	0.5	0.1	2.1
Eiland source	8.0	76.7	1029	194	1.1	0.0	3.3	546	9.8	128	3	2.5	19.7	1.8	581	1431	4.3	2.4	0.3	109	3.1	0.9	9.4	3.3	156
Lekkerrus	7.1	8.0	162.0	20.0			6.5	7.0	12.5	43.8	3	14.2	10.2	5.8	14.6	0.0	3.0	0.0	0.1	29.0	1.8	5.7	0.0	6.6	37.2
Libertas	6.9	7.6	155.6	23.7	0.4	0.0	5.2	8.1	4.9	34.4	3	48.8	6.3	29.8	42.8	37.6	0.2	0	0	29.6	0.3	4.8	3.1	1.3	0.0
W CAPE																									
Brandvlei	6.6	1.7	47.7	8.9	0.7	0.0	0.2	14.1	0.3	13.2	1	0.5	1.6	1.2	5.7	33.9	0.5	0.1	0	9.1	0.6	0	1.8	0.6	9.5
Citrusdal	6.2	1.5	75.4	9.1	0.7	0.0	0.2	15.7	0.0	21.1	1	4.4	0.5	0.0	26.1	43.2	0.1	0	0	4.9	0.0	0.0	2.1	0.3	3.7

SANBWA	pH	SO4	TDS	EC	NO3	NO2	F	Cl	Mo	B	Cr	Mn	Ni	Cu	Zn	Br	U	Cd	Sb	Ba	Hg	Pb	Se	As	Li
Criteria */l	5-9.5	250 mg	500 mg	150	50 mg	0.1 mg	5 mg	250 g	70 µg	5000	100	1000	150	1000	5000	6	0	5	10	700	2	50	20	50	
Caledon	7.0	5.2	116.2	23.3	0.0	0.0	0.3	32.6	0.1	26.0	1	2635	0.0	0.0	0.0	87.0	0.0	0	0.3	84.5	0.0	0.1	1.5	0.8	20.0
Toverwater	7.0	3.8	112.7	20.9	0.0	0.0	0.3	25.0	1.3	19.8	0	946.2	0.0	0.0	0.1	71.3	1.3	0	0.0	153	0.0	0	0.3	0.5	75.4
Goudini	6.6	1.9	62.9	10.6	0.4	0.0	0.2	10.3	0.0	19.2	1	4.4	0.0	2.8	12.7	38.6	0.1	0	0.0	3.8	0.0	0	0.7	0.7	9.3
Calitzdorp	7.2	6.3	133.5	26.0	0.2	0.0	0.3	31.7	0.5	32.1	0	573.7	0.0	0.0	0.0		0.0	0	0.3	86	0.0	0	1.0	0.1	38.0
Montagu	6.6	5.5	83.7	12.9	0.5			14.6	1.0		3	3.0	1.0	4.0						11				1.0	16.0
E CAPE																									
Aliwal spa	8.8	5.8	1254.7	195.3	0.3	0.0	4.1	607.9	0.6	510	1	1.4	0.0	0.2	4.6	1034	0.0	0.0	0.3	17.3	1.8	0.1	11.2	1.9	699
Cradock	7.7	17.4	214.4	37.2	0.6	0.0	5.3	45.8	4.1	439	2	0.6	0.0	0.0	8.0	234	2.7		0.0	8.5	0.0	0.0	2.7	1.2	111
Fish Eagle Spa	8.3	10.0	1294	196	0.5	0.0	4.0	853	0.5	580	0	2.9	0.0	0.4	1.6	834	0.0	0.0	0.3	20.4	0.7	0.0	6.3	1.3	603
FREE STATE																									
Badsfontein	7.3	4.4	1093	190.5	0.5	0.0	4.2	684.5	0.6	686	0	1.4	0.0	0.0	0.9	975	0.0	0.0	0.3	16.1	1.1	0.0	4.4	1.0	631
Florisbad	7.9	88.9	2109	357.5	3.0	0.0	5.3	1264	0.4	531	1	2.8	0.0	0.3	1.0	2394	0.0	0.0	0.1	128	0.9	0.0	7.8	1.3	611
Baden Baden	8.2	4.3	2183	322	3.1	0.0	6.9	1375	0.4	584	1	24.3	0.0	2.3	2.3	2689	0.0	0.0	0.0	266	2.3	0.8	12.6	2.5	1069
N CAPE																									
Riemvasmaak	7.8	612.4	3254	508	5.5	0.0	4.3	1145	35.2	621.7	1	0.0	0.0	0.0	0.9	4538	306.7	0.0	0.0	3.3	1.3	0.0	27.1	11.0	749.2
KZN																									
Natal Spa	8.4	17.8	228.7	34.7	0.0	0.0	7.3	42.2	6.5	9.7	1.0	0.0	0.2	0.0	0.0	115.9	0.0	0.0	0.0	0.0	1.1	0.1	4.2	0.7	84.7
Lilani	9.2	41.0	280.1	44.3	1.4	0.0	8.7	28.6	2.9	27.7	97.8	16.0	208.3	12.6	1.0	60.5	0.0	0.0	0.0	0.0	2.4	0.0	2.3	0.2	27.0
Thangami	8.6	28.3	397.8	63.0	0.5	0.0	10	42.2	3.4	34.4	2.4	0.0	0.1	0.0	1.0	231.9	0.0	0.0	0.0	0.0	5.6	0.0	3.8	1.0	133.6
Shu-Shu	8.6	51.7	723.6	111.5	0.2	0.0	8	92.7	3.7	24.0	1.7	0.0	0.1	11.5	1.0	56.2	0.0	0.0	0.0	0.0	1.7	0.0	1.8	0.0	25.7
Warmbaths	10.0	10.5	195.1	31.0	0.1	0.0	8	16.3	4.9	4.3	1.0	0.3	0.1	0.0	0.2	54.6	0.0	0.0	0.0	0.0	1.8	0.0	0.7	0.7	23.4
Birlanyoni	8.0	24.3	216.8	34.0	2.8	0.6	20	47.4	5.3	4.8	2.4	25.9	0.9	1.0	2.0	68.2	0.0	0.0	0.0	0.0	0.4	0.2	2.3	0.6	25.1

SANBWA	pH	SO4	TDS	EC	NO3	NO2	F	Cl	Mo	B	Cr	Mn	Ni	Cu	Zn	Br	U	Cd	Sb	Ba	Hg	Pb	Se	As	Li
Criteria */l	5-9.5	250 mg	500 mg	150	50 mg	0.1 mg	5 mg	250 g	70 µg	5000	100	1000	150	1000	5000	6	0	5	10	700	2	50	20	50	
MPU																									
Badplaas	8.6	15.5	383.5	60.5	0.2		6.8	130.6	5.5		88	10.5	128	62	640			1.0				2.0	2.0		147.5
Grovesbad																									
Machadodrp	7.6	2.8	395.0	40.3			2.8	51.6	3.0	298		18.0	135	59.0				1.0		95.0					33.7
Falcon Glen	8.2	0.0	232.1	35.7			1.6	12.0	5.0		131	25.0	166	73.0	441			2.0							138.0
Amanzimtaba	8.0	69.3	699.4	106	3.4	0.0	7.4	298.1	5.7	205	46	56.1	0.1	29.0	0.0	513.6	0.0	0.5	2.2	69.3	4.9	0.0	3.0	4.5	1187.5
Sulphur spring	8.6	20.2	152.0	22	0.0	0.0	13	16.7	3.2	2.3	1.3	0.0	0.2	0.0	0.8	29.5	0.0	0.0	0.0	0.0	1.2	0.0	2.0	12.1	17.7

No data | Conforms to Std | Does not conform to Standards | Not included in bottled water standards

All Standards in µg/l from Boron onwards

Table 4.1 indicates that none of the thermal springs in South Africa conform to all the essential criteria. The halogen content appears to be a major constraint – especially the high fluoride and bromide levels. Sagole, Moreson, Mphephu, Loubad, Minwamadi, Brandvlei, Goudini and Towerwater are the only springs where the fluoride levels do not exceed the limit of 1 mg/l and where sufficient data are available to make an assessment of suitability. Unfortunately, insufficient data were available for Riffontein, Paddisland and Masque in Limpopo; Warmbad Noord, Die Bad, Gamka Vallei, Montagu and Baden in the Western Cape; Knegnadrift, Grasrand and Rooiwal in the Eastern Cape; Skuifdrift Oos in the Northern Cape; and Grovesbad in Mpumalanga. Caledon and Montagu might be suitable for use since the concentration of a large number of chemical components do conform to SANBWA values. It is thus suggested that detail trace element analyses be conducted for these two springs.

It should be kept in mind that a number of springs might have the potential for a niche bottled water market even if the waters cannot be sold as conventional bottled water with the SANBWA accreditation, for example, thermal spring water rich in sodium and other electrolytes could be used to combat water intoxication. For years, healthcare and fitness professionals have stressed the importance of fluid intake and replacement in preventing dehydration. Therefore, the number of cases of dehydration has decreased in recent years.

Electrolyte-rich thermal spring water could be bottled to be specifically used for high performance exercise drinks provided that it does not contain toxic minerals. An example is water from Rhemardo in Limpopo. Although it exceeds allowable limits for SANBWA standards, it provides a good source of Na (1 186 mg/l). The relatively high vales of SO_4, F, Br, and U should not compromise health since the intake would be limited to sporadic events. Added benefits are the relatively high Li and Se concentrations that are known to have anti-depressant and skin benefitting effects.

4.2.2 Cosmetic purposes

The use of cosmetics is a practice that probably dates back to before the age of the Ancient Egyptians. Some of the early cosmetic practices include the use of kohl to line the eyes and berry salves to bring colour to the lips and cheeks. Very few women in the western world do not make use of cosmetics.

Fig. 4.2 Cleopatra (Wikipedia)

This industry is one of the largest in the world. In South Africa, the cosmetic industry is estimated to contribute R25 billion to the economy, without taking into account the informal sector, which also contributes to the economy.

BOX 4.1

'The Trade and Industry Deputy Minister Elizabeth Thabethe has encouraged SMMEs in the cosmetic industry to formalise and export their goods to other countries. "We hope that those SMMEs that are still mixing and producing from their backyards and selling informally will learn that they can become formal and penetrate the bigger market, and even export to other countries," said Thabethe on Thursday. The deputy minister was speaking at the first cosmetics sector workshop for SMMEs in Gauteng. "The growth in products that cater for the specific needs of the male market is an area of great opportunity for the local cosmetics and toiletries industry. The age of the metro-sexual male has taken off in the South African market," she said.' (SAnews.gov.za, 24/5/2013).

The boundary between the cosmetics and therapeutics industry has become increasingly blurred over the last few years. Many cosmetic companies claim that the application of their products) can have a therapeutic effect on diseases of the skin, including psoriasis, dermatitis, and fungal infections. Some cosmetic companies promote the healing of scars and other injuries through the use of their product enriched with minerals. The most popular minerals in cosmetics are those purported to come from the Dead Sea, but a few cosmetic houses have seen the opportunity to use minerals from thermal springs. A recently launched French skincare line has introduced a new range of creams, gels and cleansing products incorporating thermal spring minerals. The natural thermal spring water mineralised with I, Zn, Cd, Cr and Cu are claimed to have to soothing, anti-inflammatory, anti-irritant effect and are formulated to combat atopic dermatitis, eczema, psoriasis and burn-related problems. The low salt mineral content ($NaCl$ <266 mg/l) of certain thermal spring waters is purported to be suitable for sensitive skins by preventing dehydration. Most of these are imported to South Africa.

Currently none of the South African thermal spring waters is being used as an ingredient in cosmetic products. Thermal-cosmetics may provide a unique and innovative African product.

The compounds used in cosmetics in South Africa have been regulated since 27 March 2009 (Act 54 of 1972 (Amended by Act 32 of 1981 and Act 39 of 2007)). The cosmetic industry is controlled by the South African Bureau of Standards (SABS) and the Cosmetic, Toiletry & Fragrance Association of South Africa (CTFA) (www.ctf.co.za). Requirements for the industry have been developed by government, the CTFA and the SABS and are based on the EU Directive which classifies cosmetics containing lead, arsenic, cadmium, mercury and antimony as being of 'toxicological concern'. According to current standards, the concentrations of lead (Pb) should not exceed 10 ppm; arsenic (As) 3 ppm; cadmium (Cd) 3 ppm; mercury (Hg) 3 ppm and antimony (Sb) 5 ppm (http://ww.hc-sc.gc.ca/cps-spc/legislation/consultation/_cosmet/metal-metaux-consult-eng.php. 2011).

Some of the South African thermal spring waters may contain one or more of these minerals and the chemical characteristics of thermal spring waters may not be fit to be used in the cosmetic industry. Other springs may contain minerals beneficial for use in cosmetics. Table 4.2 indicates minerals that are prohibited in cosmetics, and are thus assumed to be essential criteria (A) for the selection of thermal spring waters, while others (B) may have beneficial effects in product for the cosmetic industry (Table 4.2). The evaluation of fitness-for-use is also shown on the table.

TABLE 4.2: FITNESS FOR USE – COSMETICS

Spring	As	Pb	Cd	Hg	Sb	A	Se	Na	Ca	Mg	B3	Ca	Mg	K		B	TSS
	<3 µg/l	<10 µg/l	<3 µg/l	<3 µg/l	<5 µg/l		>53 µg/l	<266 µg/l	>20 µg/l	>5 µg/l	[Ca x Mg]	>20	>5	>3	[Ca x Mg x K]		[A(A+B)]
	a1	a2	a3	a4	a5	A	b1	b2			b3				b4	B	
LIMPOPO																	
Tshipise	3	3	0	0	1	0	0	1	5	0	0	5	0	4	0	1	0
Sagole	3	2	0	1	1	0	0	1	2	0	0	2	0	1	0	1	0
Evangelina	22	3	1	1	1	0	0	0	78	27	1	78	27	6	1	2	0
Moreson	5	3	1	2	1	0	0	1	5	0	0	5	0	3	0	1	0
Mphephu	2	3	0	1	1	1	0	1	11	8	0	11	8	1	0	1	2
Siloam	0	0	0	0	7	0	0	1	6	0	0	6	0	3	0	1	0
Warmbad								1	10	2	0	10	2	4	0	1	
Rhemardo	1	4	2	0	1	1	0	1	23	2	0	23	2	4	0	1	2
Soutini					0			0	86	5	0	86	5	15	0	0	
Die Oog	4	6	1	0	0	0	0	1	25	2	0	25	2	4	0	1	0
Vischgat	4	5	1	1	1	0		1	37	2	0	37	2	6	0	1	0
Loubad	4	7	1	0	2	0	0	1	29	6	0	29	6	3	0	1	0
Buffelshoek								1	27	5	0	27	5	6	0	1	
Minvamadi	0	0	0	0	0	1	0	1	9	13	0	9	13	1	0	1	2
Eiland	3	1	2	3	0	0	0	0	34	2	0	34	2	15	0	0	0
Lekkerrus	7	6	0	2	0	0		1	19	9	0	19	9	5	0	1	0
Libertas	1	5	0	0	0	1	0	1	24	2	0	24	2	3	0	1	2
KNP																	
Tshalungwa	3	6	0	3	0	1	0										1
Tshipala A	11	3	0	4	0	0	0	1	2		0	2		2	0	1	0
Maritumbe								1	8	9	0	8	9	32	0	1	
Magovani H								1	16	15	0	16	15	5	0	1	
Malahlapga	0	2	0	4	0	0	0	1	19		0	19		6	0	1	0

Spring	As	Pb	Cd	Hg	Sb	A	Se	Na	Ca	Mg	B3	Ca	Mg	K		B	TSS
	<3 µg/l	<10 µg/l	<3 µg/l	<3 µg/l	<5 µg/l		>53 µg/l	<266 µg/l	>20 µg/l	>5 µg/l	[Ca x Mg]	>20	>5	>3	[Ca x Mg x K]		[A(A+B)]
	a1	a2	a3	a4	a5	A	b1	b2			b3				b4	B	
Malahlap B	0	4	0	1	0	1	0	1	33			33		9		1	2
Mafayini	0	3	0	3	0	1	0	0	312			312		14		0	1
Matiyavll act	1	2	0	2	0	1	0	0	486			486		45		0	1
W CAPE																	
Brandvlei	1	0	0	1	0	1	0	1	4	2	0	4	2	2	0	1	2
Citrusdal	0	0	0	0	0	1	0	1	2	2	0	2	2	2	0	1	2
Caledon	1	0	0	0	0	1	0	1	8	3	0	8	3	5	0	1	2
Toverwater	0	0	0	0	0	1	0	1	11	3	0	11	3	7	0	1	2
Goudini	1	0	0	0	0	1	0	1	9	3	0	9	3	2	0	1	2
Calitzdorp	0	0	0	0	0	1	0	1	10	4	0	10	4	9	0	1	2
Montagu	1							1	7	3	0	7	3	4	0	1	
E CAPE																	
Aliwal	2	0	0	2	0	1	0	0	84	0	0	84	0	2	0	0	1
Cradock	1	0		0	0		0	1	10	3	0	10	3	1	0	1	
Fish Eagle	1	0	0	1	0	1	0	0	76	0	0	76	0	3	0	0	1
FREE STATE																	
Badsfntein	1	0	0	1	0	1	0	0	72	0	0	72	0	2	0	0	1
Florisbad	1	0	0	1	0	1	0		96	1	0	96	1	10	0	0	1
Baden Baden	2	1	0	2	0	1	0	0	37	1	0	37	1	7	0	0	1
N CAPE																	
Riemvasmaak	11	0	0	1	0	0	0	0	142	19	1	142	19	17	1	1	2
KZN																	
Natal Spa	1	0	0	1	0	1	0	1	6	1	0	6	1	4	0	1	1
Lilani	0	0	0	2	0	1	0	1	5	3	0	5	3	3	0	1	1
Thangami	1	0	0	6	0	0	0	1	6	2	0	6	2	4	0	1	0
Shu-Shu	0	0	0	2	0	1	0	1	8	5	0	8	5	6	0	1	1
Warmbaths	1	0	0	2	0	1		1	9	5	0	9	5	4	0	1	1
Birlanyoni	1	0	0	0	0	1	0	1	6	5	0	6	5	6	0	1	1
MPU																	
Badplaas		2	1				0	1	6	1	0	6	1	4	0	1	
Grovesbad																	
Machadodorp			1					1	11	3	0	11	3	2	0	1	
Falcon Glen			2					1								1	
Amanztaba	4	0	1	5	2	0	0	1	28	1	0	28	1	5	0	1	0
Sulphur S	12	0	0	1	0	0	0	1	7	6	0	7	6	3	0	1	0

Spring	As	Pb	Cd	Hg	Sb	A	Se	Na	Ca	Mg	B3	Ca	Mg	K		B	TSS
	<3 µg/l	<10 µg/l	<3 µg/l	<3 µg/l	<5 µg/l		>53 µg/l	<266 µg/l	>20 µg/l	>5 µg/l	[Ca x Mg]	>20	>5	>3	[Ca x Mg x K]		[A(A+B)]
	a1	a2	a3	a4	a5	A	b1	b2			b3				b4	B	
Swazi Spa							1	1	4	0	0	4	0	1	0	1	

No data		a,b=0			Suitable for cosmetics			
A or B=0		a,b=1			Not suitable			

It was found that the thermal springs that are suitable for use are Mphephu Rhemardo, Minwamadi, Aliwal, Fish Eagle, all those in the Free State, all in KZN (barring Thangami), all in the Western Cape, except for Montagu for the mineral dataset is incomplete. Of these, Mphephu Rhemardo, Minwamadi, Libertas, Riemvasmaak and the Western Cape spring (except for Montagu) have the highest TSS values. Although the springs in the Free State and adjacent parts of the Eastern Cape, are suitable for the cosmetic industry, they have low TSS values since they do not have many non-essential (beneficial) properties. All other thermal springs in South Africa have unacceptably high levels of at least one of criterion of the minerals, As, Pb, Hg, Cd and Sb and thus not suitable for the use in the cosmetic industry.

4.2.3 Agriculture use

Food production is becoming more expensive, largely due to the mounting cost of electricity. Many countries have explored the use of geothermal energy as a source for heating for greenhouses, dairy farming, egg incubation and poultry farming, among numerous others and for crop drying (Christopher & Armstead, 1978; Mohamed, 2002; Lund & Lienau, 1992; Carella & Sommaruga, 2000; Swarieh, 2000; Lund & Freeston, 2001; Gill, 2004. Temperatures required for various agricultural activities are presented in Table 4.3.

TABLE 4.3 TEMPERATURES REQUIRED FOR VARIOUS AGRICULTURAL ACTIVITIES

Use	Temperatures in °C
Soil heating	20-35
Heating greenhouses	35-95
Food processing	35-95
Aquaculture (including fish and algae production)	20-40
Biogas processing	35-50
Mushroom cultivation	45-65
Drying fruits and vegetables	65-95
Pasteurisation	50-70
Beet sugar extraction	60-85
Blanching and cooking	70-100
Sugar pulp drying	110-125

Source: Popovski & Vasilevska, 2003

Chevallier and Musekiwa (2010) also includes beet sugar extraction (60-85°C) and pasteurization (50-75°C) in this list.

Although some of the activities mentioned in Table 4.3 are excluded due to temperature constraints, South African thermal springs lend themselves to crop drying, aquaculture (i.e. fish farming and algae and oyster cultivation), mushroom farming, heating greenhouses, biogas processing. Water from thermal springs could also be used for irrigation provided that the flow rate and reserve are high and the chemical composition is suitable for crop production.

4.2.3.1 Heating greenhouses and irrigation

Greenhouses are used worldwide for the production of vegetables including the cultivation of tomatoes, cucumbers, other vegetables, and flowers and most large nurseries have greenhouses for the cultivation of seedlings.

An advantage of using heat from thermal waters is that the temperature can be kept constant throughout the day and night. Figures 4.3 a-f indicate the wide variety of installations possible for geothermal greenhouse heating (Popovski & Popovska-Vasilevska, 2001).

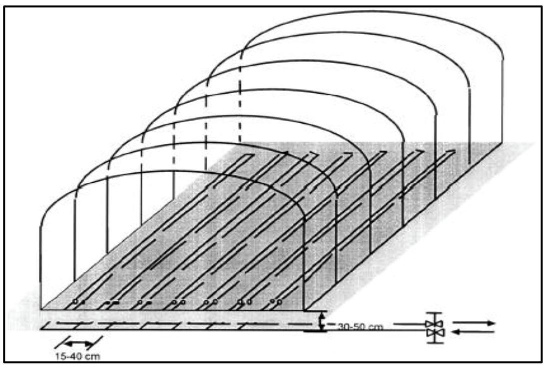


Fig. 4.3a Soil heating installation

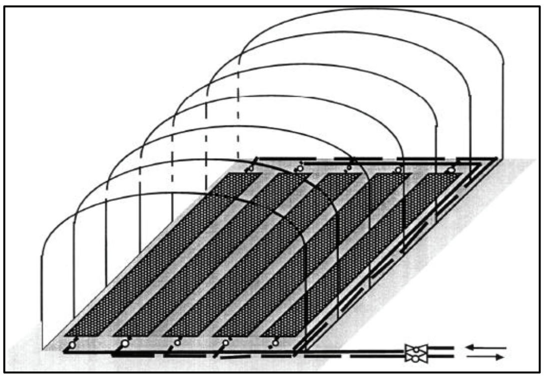


Fig. 4.3b Installation on ground

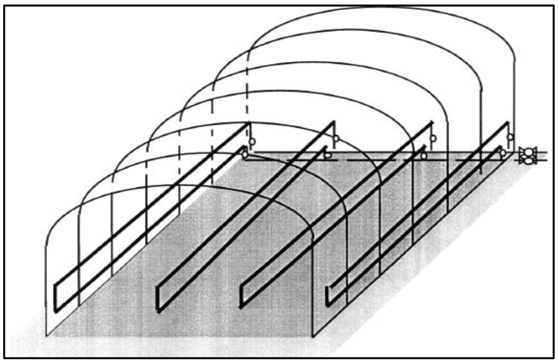


Fig. 4.3c   Free convection pipe heating installation

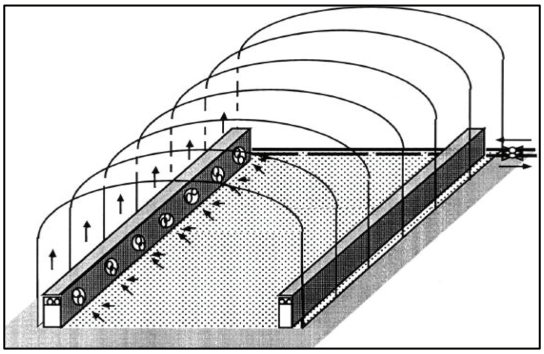


Fig. 4.3d   Fan heating installation

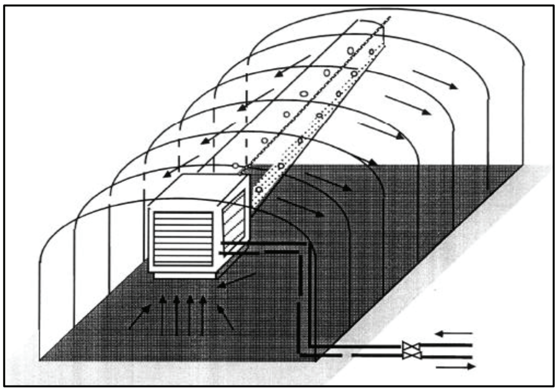


Fig. 4.3e   Horti-therm heating system

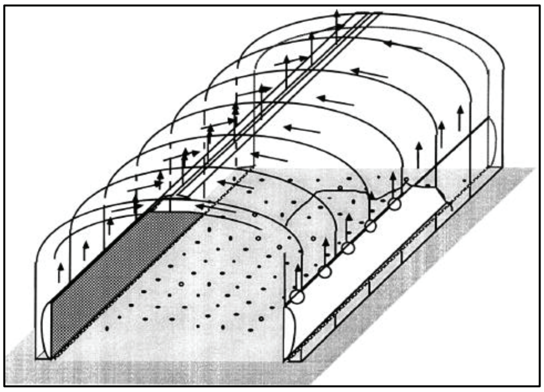


Fig. 4.3f   Long temperature roof heating

Climate control is thus easy and expensive thermal control equipment is not as crucial as when using other sources of heat. Greenhouses are essential for production during seasons when the ambient temperature is too low for conventional open field farming. The possible benefits of using geothermal water are is that it leads to higher productivity, and better quality crops as they are protected from external climate factors such as heavy rains, strong winds and severe cold or snow. Internal climate control can shorten the normal growing period leading to the economic competitiveness especially in colder climates (Lund & Boyd, 2003:14-15).

Countries that make use of geothermal energy for heating greenhouses include China, Georgia, Hungary, Iceland, Italy, Russia, the United States of America, Greece, Slovenia, New Zealand, Spain and Israel (Lund & Freeston, 2000). As far as is known, only two African countries use geothermal energy for greenhouse heating. One is Tunisia and the other, Kenya (see box 4.2. Kenya is the 4th largest supplier of flowers in the world, with exports amounting to 110 000 tons (Price, Radio Sonder Grense, 24 August 2013, 12:58). The flower industry is the country's second-highest source of income. An experiment conducted in Tunisia using geothermal water for heating greenhouses was very encouraging. Crops produced included cucumbers, tomatoes, melons, watermelons and peppers.

Box 4.2

Mr Peter Nyabeze in Olkaria (Kenya) on a field trip to the East African Rift Valley. Oserian's greenhouse heating uses geothermal steam (2011)

In South Africa too, geothermal energy could be used for heating greenhouses and thus the continuous (and out of season) production of vegetables and flowers. Many parts of the country experience cold winters with either snow or frost and thus all thermal springs could be used for this purpose. The type of crop to be produced will depend upon the temperature of the spring waters. Not only could this provide food security but could allow sub-tropical or tropical exotic 'crops' to be cultivated in areas not normally suitable for this purpose, generating income and creating jobs. Geothermal water is also used for irrigation this is dependent on the SAR and chemical composition of the water. Continuous irrigation with SAR of more than 2 could induce sodic soil conditions. This will affect the growth of sodium sensitive plants. In addition, the quality of produce may also be affected by SAR values. For example, in South Africa the sodium content of wine is restricted to 100 mg/l. The suitabilities of springs for irrigation are presented as Table 4.4.

TABLE 4.4: FITNESS FOR USE – AGRICULTURAL USE: IRRIGATION

ALL A	flow rate l/s	pH	pHs	Langelier	SAR	EC mS/m	F	Cl	Na	Mo	Be	B	V	Cr	Mn	Co	Ni	Cu	Zn	Li	U	Cd	Pb	Se	As	TSS	Non conform
							mg/l			µg /l																	
DWAF 1996d (mg/l)		6.5 - 8.4		+0.2 to -0.2	< 2	40	2	100	70	0.01	0.1	0.50	0.1	0.10	0.02	0.05	0.20	0.2	1	2.5	0.01	0.01	0.2	0.02	0.1		
Convert µg/l										10	100	500	100	100	20	50	200	200	1000	2500	10	10	200	20	100		
LIMPOPO																											
Tshipise	10	9	9	0	19	80	5	156	152	2	0	161	15	8	3	0	12	2	3	65	0	0	3	6	3	0	6
Sagole	7	9	9	0	12	35	1	43	66	1	0	49	3	4	3	0	0	1	15	21	0	0	2	2	3	0	3
Evangelina		7	8	0	9	216	4	507	355	15	0	298	91	23	5	1	0	11	26	73	30	1	3	31	22	0	8
Moreson		8	9	-1	12	57	3	87	84	1	0	57	14	7	6	0	0	2	3	40	1	1	3	10	5	0	5
Mphephu	6	8	8	-1	2	35	3	35	42	1	0	33	15	6	4	0	0	0	1	7	1	0	3	4	2	0	3
Siloam	0	9	9	0	9	33	6	44	61	2	0	52	18	1	1	0	0	0	6	13	2	0	0	1	0	0	3
Warmbad	2	8				69	19	88	126	1		250			1					4						0	4*
Rhemardo	7	7	8	-1	2	42	6	27	35	10	1	48	4	3	10	2	9	6	38	80	0	2	4	4	1	0	3
Soutini		7				273	2	680	486	18		388	12	5	21	17	16	9		0	0					0	6*
Die Oog	38	7	8	-1	2	34	6	26	42	6	0	33	4	6	20	3	17	6	9	8	1	1	6	2	4	0	3
Vischgat		7	8	-1	2	56	6	34	58	11	1	46	3	3	12	3	12	6	13	26	1	1	5	0	4	0	5
Loubad	22	7	8	-1	0	25	1	3	8	11	1	47	4	4	4	2	7	5	20	47	4	1	7	0	4	0	2
Buffelshoek		7					7	139	152	1										4						0	3*
Minvamadi	3	7	9	-1	1	21	0	19	11	0	0	39	2	1	0	0	0	0	4	2	0	0	0	1	0	0	1
Eiland	2	8	8	0	19	194	3	546	352	10	0	126	42	3	3	14	20	2	581	156	4	2	1	9	3	0	5
Lekkerrus	19	7				20	7	7	22	12	1	44	3	3	14	2	10	6	15	37	3	0	6	0	7	0	2*
Libertas	10	7	8	-1	1	24	5	8	22	5	0	34	5	3	49	4	6	30	43	0	0	0	5	3	1	0	3
KNP																											
Tshalunga		7				113	1			2	0	73	7	2	4	0	0	0	42	22	1	0	6	1	3	0	1*
Tshipala A		9					2	134	126	3	0	98	2	1	16	0	2211	0	3	31	0	0	3	1	11	0	4*
Maritumbe		8				70		65	35			60			150			30	110							0	2*
Magovani		7				32	0	44	25			40			230											0	1*
Malahlapanga		8				111	3	270	191	3	0	89	11	2	9	0	4765	0	11	98	0	0	2	4	0	0	5*
Malahlapanga B		6				142	3	328	231	15	0	110	15	11	104	4	72330	4	8	133	0	0	4	5	0	0	8*
Mafayini		8				427	1	1166	562	5	0	217	10	0	5	1	31150	1	3	295	0	0	3	15	0	0	4*
Matiyavila		7				613		1700	840	18	0	260	11	1	0	0	0	0	1	403	0	0	2	24	1	0	5*
W CAPE																											
Brandvlei	127	7	10	-3	1	9	0	14	10	0	0	13	1	1	1	0	2	1	6	9	1	0	0	2	1	0	1
Citrusdal	22	6	10	-4	1	9	0	16	8	0	0	21	1	1	4	0	1	0	26	4	0	0	0	2	0	0	2

ALL A	flow rate l/s	pH	pHs	Langelier	SAR	EC mS /m	F	Cl	Na	Mo	Be	B	V	Cr	Mn	Co	Ni	Cu	Zn	Li	U	Cd	Pb	Se	As	TSS	Non conform
							mg/l	µg /l																			
DWAF 1996d (mg/l)		6.5 - 8.4		+0.2 to -0.2	< 2	40	2	100	70	0.01	0.1	0.50	0.1	0.10	0.02	0.05	0.20	0.2	1	2.5	0.01	0.01	0.2	0.02	0.1		
Convert µg/l										10	100	500	100	100	20	50	200	200	1000	2500	10	10	200	20	100		
Caledon	9	7	9	-2	1	23	0	33	18	0	1	26	1	1	2635	0	0	0	0	20	0	0	0	1	1	0	2
Toverwater	9	7	9	-2	1	21	0	25	13	1	0	20	0	0	946	0	0	0	0	75	1	0	0	0	0	0	2
Goudini	3	7	9	-2	1	11	0	10	9	0	0	19	1	1	4	0	0	3	13	9	0	0	0	1	1	0	1
Calitzdorp		7	9	-2	1	26	0	32	16	1	0	32	1	0	574	0	0	0	0	38	0	0	0	1	0	0	2
Montagu	6	7				13		15	10	1			1	3	3		1	4		16					1	0	0*
E CAPE																											
Aliwal	43	9	8	1	10	195	4	608	331	1	0	510	13	0	1	0	0	0	5	700	0	0	0	11	2	0	7
Cradock	1	8	9	-1	3	37	5	46	43	4	0	439	4	2	1	0	0	0	8	111	3		0	3	1	0	3
Fish Eagle		8			11	196	4	853	335	0	0	580	14	0	3	0	0	0	2	603	0	0	0	6	1	0	6*
FREE STATE																											
Badsfontein	3	7	8	-1	10	191	4	684	316	1	0	686	11	0	1	0	0	0	1	631	0	0	0	4	1	0	7
Florisbad		8	8	0	18	358	5	1264	681	0	0	531	22	1	3	0	0	0	1	611	0	0	0	8	1	0	7
Baden Bn		8	8	0	32	322	7	1375	728	0	0	584	24	1	24	0	0	2	2	1069	0	0	1	13	2	0	8
N CAPE																											
Riemvasmaak	1	8	7	1	21	508	4	1145	913	35	1	622	16	1	0	0	0	0	1	749	307	0	0	27	11	0	9
KZN																											
Natal Spa	3	8	9	0	6	35	7	42	67	7	0	10	1	1	0	0	0	0	0	85	0	0	0	4	1	0	2
Lilani	3	9	8	1	5	44	9	29	81	3	0	28	1	98	16	2	208	13	1	27	0	0	0	2	0	0	7
Thangami		9	8	0	6	63	10	42	112	3	0	34	2	2	0	0	0	0	1	134	0	0	0	4	1	0	6
Shu-Shu		9	8	0	6	112	8	93	145	4	0	24	1	2	0	0	0	12	1	26	0	0	0	2	0	0	5
Warmbaths		10	8	2	4	31	8	16	64	5	0	4	0	1	0	0	0	0	0	23	0	0	0	1	1	0	4
Birlanyoni		8	9	-1	5	34	20	47	69	5	0	5	1	2	26	0	1	1	2	25	0	0	0	2	1	0	4
MPU																											
Badplaas	10	9				61	7	131	111	6				88	11	2	128	62	640	148		1	2	2		0	5*
Grovesbad																										*	*
Machadodorp	2	8				40	3	52	60	3		298			18	1	135	59		34		1				0	1*
Falcon G	6	8				36	2	12	64	5				131	25	2	166	73	441	138		2				0	2*
Amanziaba		8	8	0	8	106	7	298	140	6	0	205	6	46	56	0	0	29	0	1188	0	1	0	3	4	0	6
Sulphur S		9	9	0	3	22	13	17	35	3	0	2	0	1	0	0	0	0	1	18	0	0	0	2	12	0	3
Swazi Spa	14	9				19	6	6	26	18			4	187	33	3	349	22		47				7		0	6*

Not suitable		Suitable		No data	

Most thermal springs except those of the Western Cape and a few in Limpopo have SAR values exceeding 2. Some South African thermal springs have high concentrations of sodium, fluoride chlorides, molybdenum, manganese and nickel. These may inhabit the growth of sensitive plants.

4.2.3.2 Agricultural crop drying

At present, geothermal energy is used in many countries for drying various grains, vegetables (e.g. tomatoes, onions and garlic, fruit crops such as coconut and timber. There is great potential for the use of geothermal energy to dry crops in tropical and sub-tropical regions where field spoilage occurs rapidly (Lund & Freeston, 2001; Andritsos, Dalampakis & Kolios, 2003; Bang, 2004; Lund, 2005). Here too, the use of geothermal heat could be cost effective. The table below compares the cost of dehydrating fruits by the conventional heating system versus geothermal heat.

TABLE 4.5: THE COST OF DEHYDRATING FRUITS USING CONVENTIONAL OR GEOTHERMAL HEAT

Product	Capacity (kg)	Time (hrs)	Heat cost (in US$) for geothermal system	Heat cost (in US$) for conventional system
Pineapple	800	18	19	104
Apple slices	700	16	17	93
Apple cubes	900	16	17	93
Banana	800	24	27	125
Plantain	700	30	31	135

Courtesy: M/s Eco Fruit Agro Industry, Guatemala, Central America: Costs in US$ (Chandrasekharam (2001:9)).

According to Table 4.5 several vegetable and fruit products can be dried with temperatures ranging from 65-95°C. There is thus real potential for the warmer springs, such as Siloam and Brandvlei to be used to dry locally produced fruits and vegetables.

4.2.3.3 Mushroom farming

“It is easy to despise gold and silver but exceedingly difficult to refuse a plate of mushrooms” (Levin *et al.* 1985:8 quoting Martial (38-103 AD).

Mushrooms have important medicinal value for the reduction of high cholesterol levels in blood, tumour inhibition and stimulation of the body’s immune system. They have been used to treat patients with cancer and to boost the immune system of people living with HIV and AIDS. Nutritionally mushrooms rank above most vegetables and legumes in protein content. Mushrooms have high fibre content and are good sources of vitamins B, C, thiamin, niacin and riboflavin. They have a very low fat content that is very desirable for people with high blood pressure. However, they are grown more for their flavour than nutritional value. They are marketed as fresh, dried or canned. Dried mushrooms is a relatively 'new' product in South Africa, but widely used in European countries as the product can be stored for very long times. The size of the South African dried mushroom market is not known. To date, it is only available at exclusive food outlets.

Some of the advantages of mushroom cultivation are that they are relatively easy to cultivate, can produce 3 to 4 harvests per 15 kg substrate, and is affordable (Staments, 1998; Beyer *et al*. 1999; Culver, 2004). In addition to being used as a food source, the used substrate can be used as compost for other agricultural activities. Moreover, due to their ability to bio-accumulate heavy metals mushrooms are increasingly being used for reclamation of mined land.

Commercial mushrooms production is a lucrative business all over the world with millions of tonnes being cultivated each year. The most popular mushrooms are white and brown button mushrooms (*Agaricus bisporus*), Shiitake (*Lentinus edodes*), Oyster *(Pleurotus ostreatus*), King and Porcini. Countries producing mushrooms commercially include Belgium, Denmark, France, Germany, the UK, Ireland, Italy, Poland, Spain, China, India, Japan, Korea, Canada and the USA, Australia and South Africa (Kues & Liu, 2000).

Basic requirements for mushroom farming are ability to control temperature and moisture and to inhibit the growth of competing, undesirable mushrooms which can contaminate the product (Rangel, 1998:14). Different temperatures are required during the production cycles. Firstly, pasteurisation of the growth medium requires temperatures of around 90^{o}C. During the growth stages, most mushrooms require temperature of around 25^{o}C – depending upon the type of mushroom cultivated. For example, straw mushrooms require temperatures of 35-37°C while Oyster mushrooms need temperatures of 30-35°C during incubation.

Geothermal energy could be used for heating in South Africa thereby reducing the electricity production costs during the incubation. For thermal springs with very high temperatures, the heat energy could first be used for other purposes, with the slightly cooled water employed for mushroom production.

4.2.4 Aquaculture

4.2.4.1 Fish farming

Aquaculture is the production and sale of farm-raised aquatic plants and animals. Geothermal energy has been used to raise, for example, cat fish, shrimp, tilapia, eels, lobster, crabs, crayfish, prawns and tropical fish (Lund & Lienau, 1992; Lund & Boyd, 2003; Gill, 2004). Tilapia, especially, is being cultivated in a number of African countries such as Egypt, Zimbabwe, Zambia and Malawi as a means to provide high-quality protein (El-Gayar & Leung 2001 In Lapere, 2010 p2). One of the major constraints in open pond aquaculture production is low temperature. The use of geothermal heat allows better control of pond temperature and optimises fish growth (Fig. 4.4a-b). With only a slight increase in temperature, 'crops' can be produced faster than by the conventional method.

Fig. 4.4a Geothermal water use for aquaculture (Direct application at Gila Bend Shrimp Farm, US) http://arizonaexperience.org/land/geothermal-energy

Fig, 4.4b Geothermal heat used for aquaculture. Israeli desert aquaculture at Kibbutz Ketura Israel, Geothermal water is passing through fish culture raceways, and is being used for irrigation of crops (Wikipedia)

Currently no fish are grown in thermal spring waters in South Africa.

In his thesis Tshibalo (Deliverable 18) investigates the potential of using thermal spring at Sagole for tilapia farming. Ideally, water temperatures for tilapia are 21^{o} to 27^{o}C (Lund & Lienau, 1992). The water quality including dissolved oxygen, total ammonia-nitrogen (ionized and unionised), pH, alkalinity, hardness, chlorine, carbon dioxide, salinity, and hydrogen sulphide may also affect the growth of tilapia in thermal springs (Buttner *et al.*, 1993, Lapere, 2010). These factors can thus be used for a suitability analysis for tilapia production in thermal springs as shown in Table 4.6

TABLE 4.6: FITNESS FOR USE – TILAPIA PRODUCTION

Lapere (2012)	pH	Temp	NO2	Cl
	6 to 8	24-33	<1 mg/l	>200 mg/l
LIMPOPO				
Tshipise	8.64	57.90	0.00	155.82
Sagole	9.33	46.30	0.00	43.31
Evangelina	7.45	35.13	0.00	506.95
Moreson	8.01	44.00	0.00	86.87
Mphephu	7.68	43.50	0.00	35.44
Siloam	8.68	66.10	0.00	43.90
Warmbad	8.48	51.97		87.60
Rhemardo	7.27	42.00	0.00	26.82
Soutini	7.22	43.90	0.00	680.33
Die Oog	7.34	38.83	0.20	25.73
Vischgat	6.88	40.05	0.06	33.52
Loubad	6.81	30.00	0.00	2.91
Buffelshoek	7.10	30.05		138.50
Minvamadi	7.35	33.40	0.00	19.47
Eiland source	7.99	40.77	0.03	546.06
Lekkerrus	7.10	49.00		7.00
Libertas	6.89	45.00	0.00	8.08
KNP				
Tshalungwa	7.27		0.10	
Tshipala A	9.28	34.00		134.00
Maritumbe	7.81	28.50		65.00
Magovani Hoof	7.42	26.30		44.00
Malahlapanga	8.35	38.00		270.00
Malahlapanga B	6.14	38.00		328.00
Mafayini	8.04	38.50		1166.00
Matiyavila act	7.26	29.50		1700.00
W CAPE				
Brandvlei	6.63	63.05	0.00	14.14
Citrusdal	6.24	46.10	0.00	15.72
Caledon	7.00	49.00	0.00	32.61
Toverwater	6.98	45.15	0.00	24.95
Goudini	6.60	43.05	0.00	10.28
Calitzdorp	7.15	51.00	0.00	31.72
Montagu	6.57	42.50		14.60
E CAPE				
Aliwal	8.82	35.13	0.00	607.91
Cradock	7.70	29.10	0.00	45.84
Fish Eagle Spa	8.30	35.70	0.00	853.00

FREE STATE				
Badsfontein	7.32	30.40	0.00	684.45
Florisbad	7.88	27.80	0.00	1263.73
Baden Baden	8.20	20.70	0.00	1375.08
N CAPE				
Riemvasmaak	7.80	33.00	0.00	1144.96
KZN				
Natal Spa	8.39	43.20	0.00	42.16
Lilani	9.24	39.50	0.00	28.57
Thangami	8.56	38.50	0.00	42.18
Shu-Shu	8.64	50.00	0.00	92.70
Warmbaths	9.99		0.00	16.32
Birlanyoni	7.98		0.58	47.43
MPU				
Badplaas	8.61	50.67		130.63
Grovesbad		32.80		
Machadodorp	7.55	28.00		51.60
Falcon Glen	8.19	42.00		12.00
Amanzimtaba	8.03	32.50	0.00	298.06
Sulphur spring	8.64		0.00	16.70
Swazi Spa	8.72	42.00		6.00
Conforms to requirements			**Does not conform**	

According to this table, the thermal springs in the Free State as well as Amanzimbata and Riemvasmaak appear to be the most suited with respect to water quality for tilapia farming. However, even at thermal springs where the water quality is not suitable, the heat could be used to provide optimal water temperatures by piping hot water around and under the fish ponds. Where the spring water temperature is too high, it would be a simple matter to cool it down to acceptable limits. It should also be noted that fish in an aquaculture environment are highly susceptible to diseases. Thus the biological water quality must be monitored on a regular basis.

4.2.4.2 Oysters and pearls

Oysters are not just popular as a delicacy, but are vital for the cultivation of pearls. Most of the pearls are produced from the genus *Pinctada.* These range from the exotic South Sea pearls (*Pinctada maxima*) to the classic Akoya pearls (*Pinctada fucata*) (Fig 4.5). Pearls are a valuable commodity. This industry is worth ~US$ 625 million annually (Jerry, 2011). In French Polynesia alone, 14 tonnes of Tahitian pearls are produced annually, with a total value of US$ 130 million. Wild harvested, natural pearls account for less than 1/1000th of a percent of the pearls on the market today, with cultured pearls from saltwater and freshwater making up nearly the rest.

Fig. 4.5 Pearls (http://www.pearl-guide.com)

Much research has been conducted on the chemical composition, temperature variation and pH of waters that may influence the production of pearls. It is, for instance, known that the minerals and trace elements in the water influence the colour of pearls. The golden and cream coloured pearls contain more copper and silver, while skin coloured and pink pearls contain more sodium and zinc. The golden coloured pearls contain more metallic elements than green pearls (FAO, 2013).

In South Africa, oysters are not used for the production of pearls, but rather as a culinary delight. The oyster banks stretch along the coast of Mozambique from the Island of Bazaruto to False Bay, near Cape Town.

The most commonly occurring oyster is *Pinctada capensis* and is found only on the eastern and southern coasts of Africa in the vicinity of Algoa Bay and False Bay. Pearls are rarely found from this oyster, and if they are, they are usually non-uniform in shape and less lustrous than the commercial available pearls (http://www.pearl-guide.com).

A number of oyster farming projects have recently been initiated in South Africa. In 2010, the oyster production was 276 tons. During this period, 15 947 200 oyster spat were imported from Chile, Guernsey and Namibia to be raised for international markets which prefer oysters weighing between 65 g and 120 g.

Although mariculture is used most often for the cultivation of oysters, this is indeed as risky business due to the unpredictability of the sea and stormy and rough weather may cause significant – at time total – loss of the entire oyster bed. For this reason, aquaculture may be a viable option.

Fig. 4.6   Oysters (Wikipedia)

Water temperature plays a critical role in oyster production and should rarely, if ever, fall below 20°C. Ideally a constant water temperature of 27°C is required. In warmer waters, the shells are generally larger and the oyster grows faster. Thermal spring water may thus be a viable option for production. The best pH values are in the region of pH=7.6 to pH=8.2.

International research shows that the production of high-quality oysters is significantly higher in waters with higher total dissolved solids than in the sea (Atsumi *et al*., 2011). However, little is known about the requirements of indigenous oyster species. New research is being undertaken at the Department of Zoology and Botany at the University of Stellenbosch. According to local gourmets, the South African oysters are superior in taste to exotics. This is a factor that should be kept in mind if oyster cultivation is considered at thermal springs. In the absence of more detailed information about cultivation requirements, the concentration of sea water is used to evaluate the suitability of thermal springs for oyster production. All factors are assumed to be non-essential (B) (Table 4.7).

Eleven thermal springs (excluding those in the Kruger National Park) conform to the pH requirements. These springs are Moreson, Mphephu and Eiland in Limpopo; Cradock in the Eastern Cape; Baden Baden and Florisbad in the Free State; Riemvasmaak in the N Cape, Birlanyoni in KZN and Falcon Glen, Machadodorp and Amanzimtaba in Mpumalanga.

The TDS values for South African springs are at least a factor of 10 less that optimally required. However, these can be corrected with the addition of chemicals – although this factor will affect the price of production.

sea water		TABLE 4.7 FITNESS FOR USE – OYSTERS AND PEARLS																						TSS
Spring	pH	TDS	Na	K	Ca	Mg	Cl	Mo	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	Li	Cd	Ba	Tl	Pb	Sn	U	
	7.6-8.2	33 000	10 600	392	411	1290	18 980	10	1	2	0.2	0.4	0.4	7	0.9	5	178	0.1	21	$4E^{4}$	0.03	0.3	3	
ALL B (non-esst)		mg/l						µg/l																
LIMPOPO																								
Tshipise	8.6	436.2	151.8	4.0	4.5	0.1	155.8	1.9	31.9	15.0	7.9	3.3	0.1	12.4	1.7	2.5	64.8	0.0	10.5	0.1	2.7	0.0	0.1	1
Sagole	9.3	207.2	66.0	1.3	2.4	0.0	43.3	1.1	12.5	3.3	4.0	3.3	0.1	0.0	0.8	15.3	20.7	0.1	5.0	0.1	2.1	0.6	0.2	3
Evangagelina	7.4	1329.9	355.4	6.1	78.2	26.6	507.0	15.3	292	91.3	23	5.1	1.1	0.5	11	25.7	72.9	0.8	15.1	0.2	3.1		29.9	0
Moreson	8.0	334.5	83.9	3.2	4.8	0.2	86.9	1.3	27.4	13.7	7.4	6.3	0.1	0.0	1.7	3.1	40.1	0.9	26.3	0.2	2.6		0.8	3
Mphephu	7.7	186.5	41.8	1.2	11.2	8.3	35.4	1.2	19.4	14.7	5.6	3.6	0.1	0.0	0.4	0.6	6.9	0.2	37.2	0.2	2.9	0.1	0.9	2
Siloam	8.7	191.6	61.0	2.8	5.7	0.5	43.9	2.4	18.1	17.6	0.9	0.6	0.0	0.0	0.2	6.2	13.1	0.0	4.5	0.0	0.0	11.4	1.8	4
Warmbaths	8.5	368.5	126.3	4.5	10.0	1.8	87.6	1.0				1.0					4.0		5.0					0
Rhemardo	7.3	207.5	35.4	3.8	23.3	2.1	26.8	9.7	229	3.7	2.8	9.6	2.1	8.8	6.0	37.5	79.5	1.8	9.5	0.8	3.7		0.0	2
Soutini	7.2		486.3	15	86	4.5	680.3	18.0	40	12.0	5.0	21.0	17.0	16.0	9.0		0.0						0.0	0
Die Oog	7.3	235.2	42.0	3.8	26	2.0	25.7	6.3	179	3.7	5.5	20.1	3.5	17.3	5.5	8.6	8.3	0.9	42.3	0.4	5.6		1.3	2
Vischgat	6.9	324.1	57.6	6.0	38	2.2	33.5	11.1	185	3.5	3.1	11.9	3.5	12.0	5.7	13.1	26.2	0.9	19.2	0.6	4.7		1.5	4
Loubad	6.8	164.1	7.9	2.9	29	6.0	2.9	11.1	144	4.3	3.5	3.5	1.6	7.1	5.0	19.5	47.1	1.2	13.3	0.7	7.0		4.1	5
Buffelshoek	7.1	450.0	151.6	5.7	27	4.7	138.5	1.0									4.0		5.0					0
Minvamdi	7.3	113.0	10.6	1.0	9.4	13.3	19.5	0.0	1.0	2.3	1.2	0.4	0.0	0.0	0.0	4.4	2.1	0.0	1.9	0.0	0.3	0.0	0.1	4
Eiland	8.0	1028.8	351.9	15	34	1.9	546.1	9.8	6.1	41.6	2.6	2.5	14.4	19.7	1.8	581	156	2.4	109	0.3	0.9	0.0	4.3	5
Lekkerrus	7.1	162.0	22.0	5.0	19	8.5	7.0	12.5	142	3.2	3.4	14.2	2.2	10.2	5.8	14.6	37.2	0.0	29.0	0.4	5.7		3.0	4
Libertas	6.9	155.6	21.7	3.2	24	2.5	8.1	4.9	67.4	4.9	3.0	48.8	3.8	6.3	30	42.8	0.0	0.0	29.6	1.0	4.8		0.2	4
KNP																								
Tshalungwa	7.3	733.9						1.8	2.9	7.0	1.8	3.7	0.0	0.0	0.0	42.2	22.5	0.0	80.0	0.2	5.6	14.5	0.9	2
Tshipalala	9.3		126.0	2.3	2		134.0	2.6	4.8	1.9	0.7	16	0.0	2211	0.0	2.6	30.5	0.0	39.0	0.0	3.0	22.0	0.0	3

Spring	pH	TDS	Na	K	Ca	Mg	Cl	Mo	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	Li	Cd	Ba	Tl	Pb	Sn	U	
	7.6-8.2	33 000	10 600	392	411	1290	18 980	10	1	2	0.2	0.4	0.4	7	0.9	5	178	0.1	21	0.0004	0.03	0.3	3	
ALL B (non-essential		**mg/l**						**ug/l**																
Magovani	7.4	210.6	25.0	4.9	16	15	44.0					230							40.0					0
Malahlapanga	8.4	721.5	191.0	5.7	19		270.0	3.2	39.4	11.3	1.9	9.0	0.2	4765	0.2	11.1	97.7	0.0	21.9	0.2	2.4	5.6	0.0	1
Malahpanga b	6.1	921.1	231.0	8.7	33		328.0	14.6	176	14.6	11	104	4.4	72330	4.4	8.2	133	0.1	31.3	0.5	4.3	6.2	0.0	3
Mafayini	8.0	2775.5	562.0	14	312		1166	5.0	4.5	10.3	0.5	5.1	1.0	31150	0.8	3.1	295	0.0	41.6	0.1	3.0	3.0	0.0	4
Matiyavi	7.3	3984.5	840.0	45	486		1700	18.2	5.4	10.6	1.1	0.0	0.5	0.0	0.0	0.5	403	0.0	61.0	0.2	1.6	2.4	0.0	3
W CAPE																								
Brandvlei	6.6	47.7	9.6	2.4	3.7	2.1	14.1	0.3	4.3	1.5	1.2	0.5	0.1	1.6	1.2	5.7	9.5	0.1	9.1	0.0	0.0	0.0	0.5	6
Citrusdal	6.2	75.4	8.3	2.2	2.1	1.7	15.7	0.0	2.5	1.2	1.1	4.4	0.0	0.5	0.0	26.1	3.7	0.0	4.9	0.0	0.0		0.1	3
Caledon	7.0	116.2	18.4	5.4	7.6	3.0	32.6	0.1	4.7	0.8	0.5	2635	0.3	0.0	0.0	0.0	20.0	0.0	84.5	0.3	0.1	0.8	0.0	4
Toverwater	7.0	112.7	13.1	7.3	11	3.3	25.0	1.3	2.1	0.4	0.4	946	0.1	0.0	0.0	0.1	75.4	0.0	153	0.3	0.0	0.0	1.3	2
Goudini	6.6	62.9	9.3	2.4	8.9	3.1	10.3	0.0	3.1	0.9	1.1	4.4	0.0	0.0	2.8	12.7	9.3	0.0	3.8	0.0	0.0	0.0	0.1	3
Calitzdorp	7.2	133.5	16.2	8.9	10	4.3	31.7	0.5	3.2	0.9	0.1	574	0.0	0.0	0.0	0.0	38.0	0.0	86.3	0.2	0.0	0.0	0.0	3
Montagu	6.6	83.7	9.9	4.3	7.2	2.6	14.6	1.0		1.0	3.0	3.0		1.0	4.0		16.0		11.0					1
E CAPE																								
Aliwal	8.8	1254.7	331.0	2.2	84	0.4	607.9	0.6	1.5	12.6	0.4	1.4	0.0	0.0	0.2	4.6	700	0.0	17.3	0.0	0.1	0.0	0.0	5
Cradock	7.7	214.4	43.4	1.0	10	3.4	45.8	4.1	2.8	4.0	2.1	0.6	0.0	0.0	0.0	8.0	111		8.5	0.2	0.0	0.2	2.7	7
Fish Eagle	8.3	1293.1	335.4	2.6	76	0.4	853.0	0.5	0.0	14.2	0.4	2.9	0.1	0.0	0.4	1.6	603	0.0	20.4	0.0	0.0	0.0	0.0	4
Badsfontein	7.3	1092.3	315.8	2.2	72	0.2	684.5	0.6	1.4	10.9	0.3	1.4	0.0	0.0	0.0	0.9	631	0.0	16.1	0.0	0.0	0.0	0.0	3
Florisbad	7.9	2108.3	680.8	9.6	96	0.6	1264	0.4	0.4	22.2	1.1	2.8	0.1	0.0	0.3	1.0	611	0.0	128	0.0	0.0	0.0	0.0	2
Baden Baden	8.2	2182.5	727.8	6.8	37.4	0.7	1375	0.4	0.2	24.2	1.1	24.3	0.0	0.0	2.3	2.3	1069	0.0	266	0.1	0.8	4.1	0.0	3
N CAPE																								
Riemvasmaak	7.8	3254.3	912.5	16.7	142	18.6	1145	35.2	4.5	15.6	1.2	0.0	0.0	0.0	0.0	0.9	749	0.0	3.3	1.2	0.0	0.0	307	3

Spring	pH	TDS	Na	K	Ca	Mg	Cl	Mo	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	Li	Cd	Ba	Tl	Pb	Sn	U	
	7.6-8.2	33 000	10 600	392	411	1290	18 980	10	1	2	0.2	0.4	0.4	7	0.9	5	178	0.1	21	0.0004	0.03	0.3	3	
ALL B (non-essential		**mg/l**						**ug/l**																
KZN																								
Natal Spa	8.4	228.7	67.3	3.6	5.6	1.2	42.2	6.5	7.5	0.7	1.0	0.0	0.1	0.2	0.0	0.0	84.7	0.0	0.0	0.0	0.1	0.0	0.0	2
Lilani	9.2	280.1	80.8	3.0	5.2	3.2	28.6	2.9	7.2	1.2	97.8	16	1.5	208	13	1.0	27.0	0.0	0.0	0.0	0.0	0.0	0.0	2
Thangami	8.6	397.8	112.4	3.5	5.8	1.8	42.2	3.4	3.0	1.8	2.4	0.0	0.0	0.1	0.0	1.0	134	0.0	0.0	0.0	0.0	0.1	0.0	1
Shu-Shu	8.6	723.6	145.2	5.5	8.4	5.0	92.7	3.7	7.6	1.2	1.7	0.0	0.0	0.1	11.5	1.0	25.7	0.0	0.0	0.0	0.0	0.0	0.0	1
Warmbath	10.0	195.1	63.8	4.4	9.1	5.0	16.3	4.9	7.4	0.2	1.0	0.3	0.0	0.1	0.0	0.2	23.4	0.0	0.0	0.0	0.0	0.2	0.0	1
Birlanyoni	8.0	216.8	69.5	6.5	6.1	4.6	47.4	5.3	15.2	0.9	2.4	26	0.2	0.9	1.0	2.0	25.1	0.0	0.0	0.0	0.2	0.0	0.0	4
MPU																								
Badplaas	8.6	383.5	111.0	4.0	6.4	0.7	130.6	5.5			88	11	2.0	128	62	640	148	1.0			2.0			0
Grovesbad																								0
Machadodorp	7.6	395.0	59.9	2.4	11.5	3.1	51.6	3.0				18	1.0	135.0	59		33.7	1.0	95.0					2
Falcon Glen	8.2	232.1	64.2				12.0	5.0			131	25	2.0	166	73	441	138	2.0						1
Amanztababi	8.0	699.4	139.8	4.8	28	0.6	298.1	5.7	2.6	6.5	46	56	0.0	0.1	29	0.0	1188	0.5	69.3	0.1	0.0	0.0	0.0	4
Sulphur Spring	8.6	152.0	34.6	2.7	7.2	6.3	16.7	3.2	4.8	0.1	1.3	0.0	0.0	0.2	0.0	0.8	17.7	0.0	0.0	0.0	0.0	0.0	0.0	0
Swazi spa	8.7	124.2	26.1	1.2	3.8	0.3	6.0	18.0		4.0	187	33	3.0	349	22		47.0							1

No data		< sea water		> than sea water		Approximate sea water	

4.2.4.3 Growing micro-algae (Spirulina)

There are many species of micro-algae that are currently produced for commercial purposes, such as the manufacture of biofuels, pharmaceutical products, cosmetics, dyes and food. These species include *Isochrysis, Chaetoceros, Chlorella, Dunaliella and Arthrospira* (*Spirulina)* (Fig. 4.7).

Fig. 4.7 Spirulina (Grove, 2012)

Spirulina's economic potential stems from its remarkable composition, which consists of up to 65% proteins, ten vitamins, high levels (one of the highest known in nature) of β-carotene and fatty acids such as γ-linoleic acid (Műhling *et al*. 2005 a & b) as well as vitamin A (Vit A) and B12 (Jassby, 1988). Advantages of consumption of *Spirulina* thus have a multitude of beneficial properties, ranging from the treatment of high blood cholesterol, hyperlipedemia and some cancers (Deshnium *et al*., 2000; Costa *et al*., 2004. *Spirulina* extracts have also shown some success against the HIV-1 by inhibiting the replication of the virus in human cells (Hirahashi *et al*., 2002) and may assist with the absorption of toxic minerals such as lead, and mercury form the liver. Certain extractible such as beta-carotene reach prices exceeding US$1000/kg (Li & Qi, 1997; Bowles, 2007; European Geothermal Energy Council, 2007; Grove, 2013).

The advantage of cultivating saline tolerant algae, such as *Spirulina spp.,* is that they are able to withstand extreme conditions which most other organisms cannot. This allows them to be grown as a monoculture that is predominantly free of parasitic contamination in large outdoor ponds (Weldy & Huesemann, 2007) (Fig 4.8).

Production costs arise from the cost of electricity to maintain a high temperate and the preparation of suitable growth media. Thermal spring waters are warmer than normal groundwater and thus alkaline thermal spring waters, containing high concentrations of minerals, can decrease production costs considerably. In addition, the heat from the thermal spring resource as well the burning of waste biomass could be used for drying the biomass – hence further reducing the costs. With a drop in production costs, the possibility of tapping into new, previously unexplored markets becomes very real.

An optimal growth temperature of between 35°C and 37°C is essential (Torzillo *et al*., 1991; Zitteli *et al.,* 1996). The production of *Spirulina* at plants in Musina, Limpopo, South Africa and in Imperial Valley, California, comes to a halt during the winter months because the water temperature falls below acceptable levels (California Energy Commission, 2005; Sebola, 2005). When geothermal water was used in Bulgaria, the surface temperature reached its optimum for algal growth even during winter months and increased production by 20%, and reduced the production cost by 40% (Torzillo *et al*., 1991; Bojadgieva *et al*., 2000; Fournadzhieva *et al*., 2003). Other factors that are important in *Spirulina* production are the content of dissolved solids (10-60 g/l), pH (8.5-10.5) and the presence of macro- and micro-nutrients (C, N, K, S, Mg, Na, Cl, Ca and Fe, Zn, Cu, Ni, Co, W) (Borowitzka, 1999; Sanchez *et al*., 2001; Shimamatsu, 2004). *Spirulina* is known to absorb and bio-accumulate heavy minerals such as As, Hg and Pb. The presence of any of these minerals in thermal spring waters – even at very low concentrations – renders such waters unfit for *Spirulina* production. Cu, Zn, Hg, Pb and As were thus used as essential factors in the evaluation of suitability of South African thermal springs for *Spirulina* production.

Copper, a well-known anti-algal agent does not significantly decrease the growth of *Spirulina.* Nevertheless, a cut-off point of 50 µg/l was used as criterion for selection of thermal springs for production. The same cut-off point was used for Zn. The concentration of the minerals (Na, K, Ca, Mg, Mo, B, Mn, Co and Fe) as in Schlosser's medium was used as additional criteria (non-essential) since this medium is assumed to be ideal for the growth of *Spirulina*. pH values ranging from 8 to 11 and temperatures of 18°C to 40°C were taken as being suitable. The results of the analysis are shown in Table 4.8.

Fig. 4.8 Spirulina production in Serres and Xanti, Greece (Popovski & Popovska Vasilevska, 2010)

TABLE 4.8: FITNESS FOR USE *SPIRULINA*

	pH	Cu	Hg	Pb	As	TOT	Na	HCO³	Temp	SO4	PO_4	TDS	CO3	HCO³	NO_3	Cl	Na	K	K/Na	Ca	Mg	Mo	B	Mn	Co	Zn	B	TSS
Elements in µg/l	>8<12	<50	0	0	0	[a1*a2…]	< 18000	<12200	18-40	>620	>270	26925	2282	12885	1824	632	7690	673	>5	14	20	430	110	70	10	20	B	
	a	a	a	a	a	A	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b		
LIMPOPO							Schlosser's medium																					
Tshipise	9	2	0	3	3	0	152	116	58	48	0	436	6	116	0	156	152	4	0	5	0	2	161	3	0	3	0	0
Sagole	9	1	1	2	3	0	66	83	46	17	0	207	17	83	0	43	66	1	0	2	0	1	49	3	0	15	0	0
Evangelina	7	11	1	3	22	0	355	225	35	210	0	1330	0	225	9	507	355	6	0	78	27	15	298	5	1	26	3	0
Moreson	8	2	2	3	5	0	84	55	44	46	0	334	14	55	12	87	84	3	0	5	0	1	57	6	0	3	0	0
Mphephu	8	0	1	3	2	0	42	114	44	9	0	187	4	114	1	35	42	1	0	11	8	1	33	4	0	1	0	0
Siloam	9	0	0	0	0	1	61	89	66	10	1	192	7	89	0	44	61	3	0	6	0	2	52	1	0	6	0	2
Warmbad	8						126	98	52	12		369	102	98	0	88	126	4	0	10	2	1	250	1			0	
Rhemardo	7	6	0	4	1	0	35	122	42	12	0	207	0	122	1	27	35	4	0	23	2	10	48	10	2	38	1	0
Soutini	7	9					486	34	44	170				34		680	486	15	0	86	5	18	388	21	17		2	
Die Oog	7	6	0	6	4	0	42	115	39	10	0	235	0	115	1	26	42	4	0	25	2	6	33	20	3	9	1	0
Vischgat	7	6	1	5	4	0	58	145	40	97	12	324	0	145	1	34	58	6	0	37	2	11	46	12	3	13	1	0
Loubad	7	5	0	7	4	0	8	142	30	2	0	164	0	142	0	3	8	3	0	29	6	11	47	4	2	20	2	0
Buffelsho	7						152	214	30	35		450	0	214	0	139	152	6	0	27	5	1					1	
Minvamad	7	0	0	0	0	1	11	81	33	2	0	113	0	81	8	19	11	1	0	9	13	0	39	0	0	4	1	2
Eiland	8	2	3	1	3	0	352	70	41	77	8	1029	2	70	1	546	352	15	0	34	2	10	126	3	14	581	2	0
Lekkerrus	7	6	2	6	7	0	22	105	49	8		162		105		7	22	5	0	19	9	12	44	14	2	15	1	0
Libertas	7	30	0	5	1	0	22	118	45	8	0	156	0	118	0	8	22	3	0	24	2	5	34	49	4	43	1	0
KNP																												
Tshalungw	7	0	3	6	3	0				26	1	734			1							2	73	4	0	42	0	0
Tshipala A	9	0	4	3	11	0	126		34	38						134	126	2	0	2		3	98	16	0	3	1	0
Maritum	8	30					35		29	24	0	455			0	65	35	32	1	8	9		60	150		110	1	
Magovan	7						25		26	9		211				44	25	5	0	16	15		40	230			2	
Malahl	8	0	4	2	0	0	191		38	74	0	722				270	191	6	0	19		3	89	9	0	11	2	0
Malahl B	6	4	1	4	0	0	231		38	159		921				328	231	9	0	33		15	110	104	4	8	2	0
Mafayini	8	1	3	3	0	0	562		39	355		2776				1166	562	14	0	312		5	217	5	1	3	1	0
Matiyavila	7	0	2	2	1	0	840		30	397	0	3985			0	1700	840	45	0	486		18	260	0	0	1	1	0
W CAPE																												
Brandvlei	7	1	1	0	1	0	10	19	63	2	0	48	0	19	1	14	10	2	0	4	2	0	13	1	0	6	0	0
Citrusdal	6	0	0	0	0	1	8	10	46	2	1	75	0	10	1	16	8	2	0	2	2	0	21	4	0	26	1	2
Caledon	7	0	0	0	1	0	18	38	49	5	0	116	0	38	0	33	18	5	0	8	3	0	26	2635	0	0	0	0
Toverwate	7	0	0	0	0	1	13	59	45	4	0	113	0	59	0	25	13	7	1	11	3	1	20	946	0	0	1	2
Goudini	7	3	0	0	1	0	9	21	43	2	1	63	0	21	0	10	9	2	0	9	3	0	19	4	0	13	0	0
Calitzdorp	7	0	0	0	0	1	16	47	51	6	0	133	0	47	0	32	16	9	1	10	4	1	32	574	0	0	0	1
Montagu	7	4			1	0	10		43	6		84			1	15	10	4	0	7	3	1		3			0	0

	pH	Cu	Hg	Pb	As	TOT	Na	HCO^3	Temp	SO4	PO_4	TDS	CO3	HCO^3	NO_3	Cl	Na	K	K/Na	Ca	Mg	Mo	B	Mn	Co	Zn	B	TSS
Elements in µg/l	>8<12	<50	0	0	0	[a1*a2...]	< 18000	<12200	18-40	>620	>270	26925	2282	12885	1824	632	7690	673	>5	14	20	430	110	70	10	20		
	a	a	a	a	a	A	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	B	
E CAPE																												
Aliwal	9	0	2	0	2	0	331	22	35	6	1	1255	3	22	0	608	331	2	0	84	0	1	510	1	0	5	1	0
Cradock	8	0	0	0	1	0	43	22	29	17	0	214	14	22	1	46	43	1	0	10	3	4	439	1	0	8	1	0
Fish Eagle	8	0	1	0	1	0	335	16	36	10	2	1293	1	16	1	853	335	3	0	76	0	0	580	3	0	2	1	0
F STATE																												
Badsfontei	7	0	1	0	1	0	316	17	30	4	0	1092	0	17	0	684	316	2	0	72	0	1	686	1	0	1	1	0
Florisbad	8	0	1	0	1	0	681	23	28	89	3	2108	1	23	3	1264	681	10	0	96	1	0	531	3	0	1	1	0
Baden B	8	2	2	1	2	0	728	39	21	4	0	2182	0	39	3	1375	728	7	0	37	1	0	584	24	0	2	1	0
N CAPE																												
Riemvasm	8	0	1	0	11	0	913	254	33	612	0	3254	0	254	6	1145	913	17	0	142	19	35	622	0	0	1	3	0
KZN																												
Natal Spa	8	0	1	0	1	0	67	84	43	18	0	229	11	84	0	42	67	4	0	6	1	7	10	0	0	0	0	0
Lilani	9	13	2	0	0	0	81	117	40	41	0	280	9	117	1	29	81	3	0	5	3	3	28	16	2	1	1	0
Thangami	9	0	6	0	1	0	112	143	39	28	0	398	4	143	0	42	112	4	0	6	2	3	34	0	0	1	1	0
Shu-Shu	9	12	2	0	0	0	145	118	50	52	0	724	15	118	0	93	145	6	0	8	5	4	24	0	0	1	0	0
Warmbath	10	0	2	0	1	0	64	110		10	0	195	23	110	0	16	64	4	0	9	5	5	4	0	0	0	0	0
Birlanyoni	8	1	0	0	1	0	69	66		24	3	217	0	66	3	47	69	6	0	6	5	5	5	26	0	2	0	0
MPU																												
Badplaas	9	62		2		0	111	44	51	16		384	18	44	0	131	111	4	0	6	1	6		11	2	640	0	0
Grovesbad									33																		1	
Machaddp	8	59					60	55	28	3		395		55		52	60	2	0	11	3	3	298	18	1		1	
Falcon G	8	73					64		42	0	3	232				12	64		0			5		25	2	441	0	
Amanzimt	8	29	5	0	4	0	140	58	33	69	0	699	6	58	3	298	140	5	0	28	1	6	205	56	0	0	1	0
Sulphur s	9	0	1	0	12	0	35	64		20	0	152	39	64	0	17	35	3	0	7	6	3	2	0	0	1	0	0
Swazi Spa	9	22					26		42	4		124				6	26	1	0	4	0	18		33	3		0	

No data	b values < Schlosser's	A = 0; cannot be used	b values >Schlossers	a conform/approximate

Given these norms, only five thermal springs (Siloam, Minwamadi, Citrusdal, Towerwater and Calitzdorp have a TSS value exceeding 0 and are suitable for *spirulina* production. Non-conformity of the other springs is mainly due to the presence of either Hg, Pb or As. Barring the latter three minerals, Riemvasmaak and Evangelina have the most suitable composition with respect to Schlossers medium (B value of 3). A large number of South African thermal springs were not tested for their content of trace elements. Further tests will have to be undertaken before decisions are made regarding their potential for S*pirulina* production.

Another alternative is to make use of the thermal properties of hot water springs to heat the ponds. The chemical composition of the springs is then irrelevant. Under these circumstances, springs with temperatures exceeding 35°C would be suitable for *Spirulina* production. The heat energy derived from thermal springs would be beneficial in two ways. Firstly it would offset the electricity costs necessary for heating the pools and for drying the biomass and secondly, it would enable production throughout the year.

The following springs (Table 4.9) could be used for the production of S*pirulina* on a year-round basis. This option seems to offer great potential as electricity costs are continuously increasing and comprise a major cost for *Spirulina* production.

TABLE 4.9: TEMPERATURES SPRINGS WITH THERMAL PROPERTIES SUITABLE FOR HEATING *SPIRULINA* PRODUCTION PONDS

SPRING	°C	SPRING	°C	SPRING	°C	SPRING	°C	SPRING	°C
Tshipise	58	Sagole	46	Eiland	41	Towerw	45	Thangami	39
Siloam	66	Evangelina	35	Lekkerrus	49	Goudini	43	Falcon Glen	42
Warmbad	52	Moreson	44	Libertas	45	Montagu	43	Rhermardo	42
Brandvlei	63	Mphephu	44	Malahlap.	38	Aliwal	35	Swazi spa	42
Calitzdorp	51	Soutini	44	Mafayini	39	Fish Eagle	36		
Shu Shu	50	Die Oog	39	Citrusdal	46	Natal spa	43		
Badplaas	51	Vischgat	40	Caledon	49	Lilani	40		

4.2.5 Biotechnology

Considerable attention has been focused on the use of micro-organisms as a human and animal food source and for the production of pharmaceuticals, nutraceuticals, bioenergy and extraction of bio-oil and sludge digestion (35-50°C). Thermophilic bacteria are of particular importance to researchers today because they live in environments similar to those required by industrial processes. Enzymes from extremophilic bacteria, such as amylases, pullulanases, cyclodextrin glycosyltransferases, cellulases, xylanases, chitinases, proteinases and other enzymes, such as esterases, glucose isomerases, alcohol dehydrogenases and DNA-modifying enzymes offer versatile tools for sustainable developments in a variety of industrial application as they show important environmental benefits due to their biodegradability, specific stability under extreme conditions, improved use of raw materials and decreased amount of waste products. Enzymes extracted from extremophiles are superior to those found in mesophiles. They are thus used to make high-quality products and make production processes more cost-effective and efficient and, therefore, more environmentally sound by minimising the use of water, energy and raw materials. Since they are biodegradable, enzymes are also a more environmentally sound substitute for synthetic chemicals (Novozymes.org (2005))

The link between these biological activities and many health benefits (e.g., anti-carcinogenic activity, prevention of chronic diseases, etc.) has raised the interest of several industrial sectors, especially in the cosmetics and pharmaceutical industries. For example, carotenoids – a natural pigment – exhibits many biological functions, such as antioxidant activities (i.e., promote oxidative stress resistance), membrane stabiliser and is precursors for vitamin A. *Deinococcus sp.* and *Flectobacillus and Flavobacteriap* contain carotenoids. These are found at Mphephu, Siloam and Sagole. The use of this water for, e.g. cosmetics, can be enhanced due to the microbes found in these springs.

Similarly, *Azovibrio, Azoarcus* and *Geobacter* occur in Siloam and Sagole waters. These bacteria are used in the degradation of aromatic hydrocarbons; *Azospira, Azospirillim, Azonexus, Desulfobacca* and *Desulfomonile and Syntrophobacter* are used for the degradation of hexane and are found naturally at Sagole, Siloam and Tshipise; *Stenotrophomonas sp* and *Alkanindiges* are used for remediation of chlorpyrifos remediation and an emulsifier, respectively, and are found at Mphepu and Eiland. Some bacteria from the genus *Pseudomonas, Bacillus, Deinococcus,* and *Geobacillus* found in Limpopo thermal springs, have been known to find applications in biomining and microbial mediated metal remediation (Slobodkin, 2005).

Of possible biotechnological interest is a peptidase (TTC1334) similar to carboxypeptidase G2 that occurs in *Pseudomonas sp*. This is a powerful pro-drug-converting enzyme applied in cancer therapy as well as a rescue agent during high-dose methotrexate therapy. *Pseudomonas spp.* are found in thermal spring waters at Sagole, Soutini and Tshipise.

It has thus been established that a number of bacteria that are currently used in industry, occur in South African thermal waters. Moreover, these spring waters contain 'newly identified and rare' bacteria. For example, the genus *Zavarzinella* (with only one species – *formosa)* has only been found in Siberian acid peat bogs (Kulichevskaya *et al.,* 2009). It is not known whether there are novel species of this genus or indeed, novel genera to be found in 'our' waters. If so, novel enzymes could be extracted for new uses or expand the range of uses mentioned above.

4.2.6 Water Mining

4.2.6.1 Minerals

Geothermal waters and brines are characterised by a wide variety of dissolved minerals ranging from alkali metals, alkali earth metals, halogens, metalloids and heavy and rare minerals. Thermal spring brines have for many years been recognised as a source of mineral reserves. Minerals such as I, Br, B, Li, As, Ge, W, Cs, B, Sr, Ta, Mg, Ca and W are commercially extracted from geothermal waters and in Japan and Russia. In the latter country, geothermal spring waters are a source of over 30% of the common stock of Li, 90% of the Br, and 85% of I (Svalova, 2010). The most common uses of minerals are listed in Table 4.10.

	TABLE 4.10: USES OF MINERALS FOUND IN THERMAL SPRINGS
ELEMENT	**USES**
Lithium	Ceramics, glass (for processing Si), batteries, electronics, thickens oils – lubricant, primary Al production, crystals for optics, coolant, bipolar, schizo-affected disorders & major depression. [pulmonary oedema]
Strontium	Durable creep-resistant magnesium alloy for BMW, neurotransmitter, toothpaste, gemstones (diamond imitation), glass, fireworks, pottery clays, screen for outdoor holographic 3D displays, power source for radio-isotope thermo-electric generation. Densifies bones when Ca lacking.
Selenium	Glass production, rubber industry, X-ray crystallography, with bismuth to replace Pb in brass, photocopying, photocells, light meters, solar cells, Zn-Se for LED lights, thyroid gland, inhibits Hashimoto's disease, cosmetics.
Nickel	Super-alloys, rechargeable batteries, alkaline fuel cells, [allergen], enzymatic activity (urease), coins, electroplating; stainless steel, jewellery.
Barium	Petroleum industry, paints (permanent white), varnishes, plastics, rubber, paper coating, X-rays, electrodes for fluorescent lamps, glass-making, fireworks (green colour) flame test = green; optics in infra-red application; muscle stimulant.
Caesium	Petroleum exploration; atomic clocks; electric power & electronics (converts heat to electricity); photo-electric cells; recognition devises; video camera tubes; detection of gamma & X-ray radiation; magnetometers; centrifugation fluid for isolation of virus particles; nuclear and isotope application: gamma emitter; cancer treatment; sterilisation on instruments; red pyrotechnic colourant in flares; epilepsy treatment.
Iodine	Food additive (thyroid hormones); co-catalyst for vinegar production; disinfectant; photographic film; cloud seeding.
Copper	Wires, cables, roofing, plumbing; electronics; architecture; anti-biofouling agent; antimicrobial action; ornaments; stained glass; ceramics; musical instruments.
Zinc	Galvanising; alloys with Cu, Al, Mg; anti-corrosion agent; wood preservative; fire retardant; propellant in model rockets; dietary supplement; topical ointment; treatment for prostate cancer
Chrome	Red colour of ruby; dyes; paints (yellow); chrome plating; tanning; wood preservative; catalyst; Chrome II oxide = green rouge; cleaning of lab glass wear for organic comp. Health supplement???
Bromine	Flame retardant; fumigate; drilling fluid; emulsifier in citrus-flavoured soft drinks; dyes; maintenance of spas and swimming pools; DNA staining; reduce HG pollution for coal-fired power plants.
Arsenic	Poison; insecticide; wood preservative; treatment for syphilis, cancer (leukaemia) psoriasis; animal feed (growth stimulant); alloys (As & Pb) car batteries; semi-conductors; LED lights; bronzing; pyrotechnics.
Mercury	Dental fillings; autism; Chinese medicine; ore = cinnabar; skin whitener; over-the-counter drugs – diaper rash, eye drops; nasal spray; neon signs; fluorescent lamps; optical spectroscopy; cosmetics – mascara).
Fluorine	Toothpaste, water fluoridation, pharmaceuticals, e.g. HIV, glass etching, organic synthesis for production of fine chemicals.

Sodium	Alloying metal, anti-scaling agent, street lights, heat transfer fluid in fast reactors, essential nutrient for blood vol. and press. & turgor press. in plants, food preservative. NaCl = salt.
Potassium	Medical supplementation, fertilizers, respiration systems in mines, submarines and spacecraft, used to saponify fats and oils in industrial cleaners, oxidant in gunpowder, used in inks, dyes, stains (bright yellowish-red colour); in explosives and fireworks; in the tanning of leather, in fly paper and safety matches, used industrially to dissolve copper and precious metals – in particular silver and gold, electroplating, solar cell fabrication; substitute for table salt, pharmaceuticals , to neutralize strong and weak acids, dry and air-free solvent in laboratory, magnetometers
Magnesium	Component of aluminium alloys, in die-casting, "mag wheels", engine components, flash photography, flares, pyrotechnics and fireworks sparklers, beverage cans; Grignard reagents, production of nodular graphite in cast iron, reducing agent for the production of uranium, photoengraving plates in the printing industry, dry-cell battery walls, roofing, solar cell fabrication, fertilizers (magnesium is a component of chlorophyll), and culture media.
Molybdenum	High-strength steel alloys and super-austenitic stainless steels, fertilizer for some plants, such as cauliflower, mammography and medical imaging, greases and anti-wear agent, biological staining, solar cell fabrication, molten salt reactors
Beryllium	X-ray tubes, energy-dispersive X-ray spectroscopy, aerospace industries in high-speed aircraft, guided missiles, space vehicles, and satellites, liquid-fuel rockets and rocket nozzles, bicycle frames, motor industry in pistons, mirrors, magnetic fuzes in mining industry, military radars, microwaves, beryllium tweeters in acoustics, printed circuit boards in surface-mount technology, electrical insulator and high-power transistors in radio frequency transmitters for telecommunications.
Boron	Glass & ceramics, composite metal for aerospace, golf clubs, fishing rods, borax = cleaning product, insecticide, semi-conductors, magnets, very hard abrasive, boron carbide = tank armour, bulletproof vests.
Titanium	Used in steel as an alloying element, pyrotechnics, white permanent pigment used in paints, paper, toothpaste, and plastics, optical opacifier in paper, strengthening agent in graphite composite fishing rods, tennis rackets and golf clubs, used in spectacle frames, used in aircraft, armour plating, naval ships, spacecraft, missiles, submarines – largely out of titanium, pulp and paper industry, ultrasonic welding, wave soldering, iridized glass, jewellery, surgical implements and implants, such as hip balls and sockets (joint replacement), surgical instruments used in image-guided surgery, "drip shield" for nuclear waste storage
Vanadium	Alloys, surgical instruments and tools, vanadium redox rechargeable batteries, used in making ceramics, superconducting magnets, against rust and corrosion by electrochemical conversion coating, production of glass coatings which blocks infrared
Manganese	Iron and steel production, brown pigment in black paints, dry cell battery, organic chem.: Oxygen production, oxidation of benzylic alcohols, cofactor in enz, found in mitochondria of bacteria, metalloprotein in brain, toxin, neurological disorders.
Cobalt	Cobalt blue pigment for glass, glaze, ceramics – jewellery. Produced with Cu, assoc. with As – toxic. Alloys, hip replacements, radiotherapy, batteries, polymer production, electroplating, constituent of Vit B12, essential mineral.
Thallium	Toxic, rat poison, insecticide, poison, manufacture of spectacles, photoresistors, infrared optical material, superconductor, nuclear cardiography, gold plating. Radioactive, remove using Prussian blue.
Bismuth	Chemically resembles As & Sb. White, iridescent, paints, glazes, cosmetics, pharmaceuticals, peptic ulcers, internal deodorant, can replace Pb in bullets, low melting point solders, pyrotechnics. No bioaccumulation, less toxic than any other heavy metal.

Tin	Prevents corrosion by water, solders, tin plating, specialised alloys, superconducting magnets, PVC stabiliser, Li-ion batteries. Organo-tin = v. toxic, wood preservative.

South African thermal springs have relative low concentrations of minerals when compared to some other countries. This is probably due the low temperatures of the resources. Although Svalova (2010) indicates that the concentration limits for the industrial extraction of minerals is I = 10 mg/l; Li = 10 mg/l; Cs = 0.5 mg/l, Br = 200 mg/l and Sr = 300 mg/l, it is not known whether mineral extraction from thermal springs in South Africa may be viable.

The value minerals in South African thermal springs was assessed using December 2012 mineral prices, assuming a 100% extraction rate, and a flow rate of 1 l/s where data are not available (Coolchem, 2012). At that stage the exchange rate was around R8 to the dollar.

Table 4.11 shows the possible monthly bruto earnings for each of the springs using Dec. 2012 mineral prices.

TABLE 4.11: MONTHLY VALUE (RAND) OF MINERALS IN THERMAL SPRINGS

MINERAL	flow rate l/s	F	Na	K	Mg	Mo	B	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	Br	Li	Sr	Cd	Sb	I	Ba	Hg	Tl	Se	Bi	As	Cs	Sn	TOTAL
Limpopo																														
Tshipise	10	2 125 544	7 870 909	835 661	75	170	371 597	43 652	6 839	525	45	6	198	35	28	2 883	3 620	45 514	2	7	1 278	1 201	47	14	761	18	2 239	4 115	0	11 316 982
Sagole	7	250 278	2 396 580	190 633	14	67	78 423	11 999	1 059	188	31	2	0	12	117	580	812	8 632	3	5	110	400	37	7	217	10	1 500	659	20	2 942 396
Evangelina	1	156 648	1 842 394	126 282	1 822	139	68 694	39 940	4 158	153	7	5	1	21	28	958	408	13 879	8	1	3 721	172	11	2	386	4	1 449	0	0	2 261 291
Moreson	1	127 126	434 868	66 355	15	12	13 066	3 749	626	49	9	0	0	4	3	153	224	1 346	8	1	998	300	19	1	127	0	323	0	0	649 383
Mphephu	6	640 224	1 354 428	157 248	3 538	69	48 060	16 587	4 196	230	30	3	0	5	4	325	240	6 188	11	7	2 360	2 646	87	10	301	6	838	1 029	3	2 238 678
Siloam	0	33 479	47 434	8 761	5	3	1 807	371	120	1	0	0	0	0	1	19	11	58	0	1	1	8	0	0	3	3	1	29	9	92 125
Warmbad	2	1 603 515	1 439 856	203 005	271	20	126 829	0	0	0	3	0	0	0	0	0	49	0	0	0	0	125	0	0	0	0	0	0	0	3 373 674
Rhemardo	7	1 557 155	1 272 145	545 411	1 016	611	76 209	217 055	1 169	130	90	63	97	84	286	285	3 085	22 430	118	7	189	748	0	53	332	212	621	0	0	3 699 602
Soutini	1	86 676	2 521 152	311 040	308	164	89 472	5 473	546	33	28	74	26	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3 015 011
Die Oog	38	8 585 581	8 230 608	2 986 357	5 156	2 169	288 258	925 592	6 369	1 382	1 024	573	1 044	422	358	405	1 743	85 808	335	0	0	18 182	0	13 9	792	1 099	10 566	0	0	21 153 966
Vischgat	1	235 602	298 676	124 105	149	101	10 539	25 328	158	21	16	15	19	12	14	2	146	3 710	9	0	31	219	9	6	0	30	264	0	0	699 182
Loubad	22	612 724	888 517	1 276 508	8 898	2 178	234 103	425 587	4 230	501	102	146	243	217	463	701	5 691	56 941	247	50	288	3 263	0	14 2	0	645	6 410	0	0	3 528 794
Buffelshoek	1	260 029	785 894	118 195	322	9	0	0	0	0	0	0	0	0	0	0	22	145	0	0	0	57	0	0	0	0	0	0	0	1 164 674
Minvamadi	3	12 476	137 246	51 322	2 280	0	22 725	347	262	20	1	0	0	0	12	102	30	1 491	0	0	21	53	0	0	17	0	12	37	0	228 457
Eiland	2	195 613	2 736 124	457 782	193	134	43 744	1 255	2 838	25	5	94	47	5	956	2 221	1 304	21 674	34	0	1 524	1 863	46	4	178	4	324	7 446	0	3 475 439
Lekkerrus	19	4 814 484	2 144 102	1 949 184	10 935	2 139	189 797	364 347	2 714	422	360	176	305	219	302	0	3 910	53 391	5	1	648	6 205	331	73	0	546	8 244	0	0	9 552 840
Libertas	10	2 029 018	1 122 854	661 478	1 702	442	79 280	92 180	2 231	197	656	164	101	602	470	389	0	10 228	0	0	383	3 375	32	98	391	291	874	0	0	4 007 437
KNP																														
Tshalungwa	1	35 459	0	0	0	17	16 730	394	318	12	5	0	0	0	46	225	126	5 535	0	0	26	911	25	2	10	11	197	2	72	60 123
Tshipala A	1	66 977	653 184	47 693	0	24	22 543	652	88	5	21	0	3 524	0	3	262	170	1 701	0	0	50	444	41	0	11	10	731	57	10 9	798 300
Maritumbe	1	0	181 440	663 552	616	0	13 836	0	0	0	202	0	0	61	121	0	0	1 449	0	0	0	1 025	0	0	0	0	0	0	0	862 301
Magovani	1	11 820	129 600	101 606	1 026	0	9 224	0	0	0	309	0	0	0	0	0	0	1 035	0	0	0	455	0	0	0	0	0	0	0	255 076

MINERAL	flow rate l/s	F	Na	K	Mg	Mo	B	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	Br	Li	Sr	Cd	Sb	I	Ba	Hg	Tl	Se	Bi	As	Cs	Sn	TOTAL
Malahlapanga	1	114 255	990 144	118 195	0	29	20 486	5 391	515	13	12	1	7 595	0	12	738	546	9 199	0	0	23	249	38	2	47	6	0	1 011	28	1 268 536
Malahlap B	1	122 135	1 197 504	180 403	0	133	25 458	24 041	664	72	139	19	115 287	9	9	898	742	12 662	1	0	37	357	14	5	62	6	0	2 377	31	1 683 065
Mafayini	1	47 278	2 913 408	282 010	0	45	49 948	613	469	3	7	4	49 650	2	3	2 855	1 646	120 785	0	0	184	474	25	1	193	4	25	4 190	15	3 473 835
Matiyavila	1	0	4 354 560	933 120	0	166	59 932	744	482	7	0	2	0	0	1	4 397	2 253	164 089	0	0	425	694	16	2	305	4	64	6 307	12	5 527 582
Klopperfon-tein	1	74 857	0	0	0	24	31 108	615	1 195	52	0	0	0	1	0	430	11	24 467	0	0	189	1 619	7	0	36	3	96	0	7	134 718
W CAPE																														
Brandvlei	127	998 946	6 327 208	6 282 847	17 957	346	386 767	74 190	8 533	1 036	85	33	328	300	794	4 445	6 726	28 919	140	0	419	13 139	724	60	2 802	5	4 649	25 505	0	14 186 908
Citrusdal	22	160 351	950 020	1 009 705	2 604	0	106 790	7 405	1 172	162	129	0	18	0	629	983	454	2 773	0	0	34	1 217	0	0	572	0	379	952	0	2 246 350
Caledon	9	96 904	904 064	1 060 259	1 968	8	56 631	6 077	366	34	33 535	12	0	0	0	852	1 059	6 693	0	3	109	9 098	0	31	177	0	530	5 837	36	2 184 284
Towerwater	9	92 783	640 204	1 426 583	2 136	114	42 999	2 762	168	23	11 992	6	0	0	1	695	3 969	26 168	0	0	334	16 419	0	26	41	0	301	4 544	0	2 272 269
Goudini	3	28 363	151 063	155 444	670	0	13 865	1 340	124	22	19	0	0	18	44	125	163	1 045	0	0	12	136	0	0	29	0	146	362	0	352 991
Calitzdorp	1	12 214	83 903	184 654	292	5	7 409	437	40	1	772	0	0	0	0	0	212	1 405	0	0	23	983	0	2	12	0	9	481	0	292 853
Montagu	6	0	297 665	511 142	1 014	53	0	0	264	115	23	0	9	47	0	0	519	8 644	0	0	0	726	0	0	0	0	384	0	0	820 607
E CAPE																														
Aliwal	43	7 019 101	74 481 033	1 973 124	1 173	225	5 099 352	8 756	24 883	126	80	7	0	19	217	46 440	169 713	796 279	6	12	17 094	8 566	779	9	6 138	7	5 456	4 378	0	89 662 972
Cradock	1	193 370	209 417	20 184	217	34	94 125	355	169	13	1	0	0	0	8	225	578	1 830	0	0	165	90	0	1	31	0	73	90	1	520 978
Fish Eagle Spa	1	156 412	1 738 817	53 084	30	4	133 747	0	645	3	4	0	0	1	2	863	3 371	23 888	0	0	816	232	7	0	79	2	88	509	0	2 112 605
FREE STATE																														
Badsfontein	3	440 683	4 354 360	119 692	39	13	420 817	510	1 324	6	5	0	0	0	3	2 683	9 376	32 952	0	1	1 481	489	28	0	149	0	176	33 306	0	5 418 093
Florisbad	1	208 615	3 529 371	198 962	42	4	122 517	59	1 011	7	4	1	0	1	1	2 478	3 413	54 689	0	0	4 943	1 462	9	0	98	0	84	1 824	0	4 129 592
Baden Baden	1	271 455	3 772 656	139 968	50	4	134 692	24	1 101	7	33	0	0	5	3	2 783	5 975	46 596	0	0	5 494	3 026	23	1	159	7	163	3 472	20	4 387 717
N CAPE																														
Riemvasmaak	1	88 505	2 459 916	180 449	662	167	74 549	317	369	4	0	0	0	0	1	2 442	2 177	5 592	0	0	204	20	7	6	178	0	378	7 753	0	2 823 695

MINERAL final templ	flow l/s	F	Na	K	Mg	Mo	B	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	Br	Li	Sr	Cd	Sb	I	Ba	Hg	Tl	Se	Bi	As	Cs	Sn	TOTAL
KZN																														
Natal Spa	3	980 744	1 190 517	252 434	278	202	7 643	3 518	101	22	0	2	1	0	0	409	1 613	10 440	0	0	178	0	38	0	180	0	147	4 573	0	2 453 041
Lilani	3	1 168 084	1 424 765	214 680	740	89	21 726	3 340	190	2 202	73	22	1 129	86	4	213	513	7 682	1	0	231	0	81	0	97	0	38	5 241	0	2 851 227
Thangami	1	393 590	582 422	72 783	121	31	7 921	409	80	16	0	0	0	0	1	240	747	3 127	0	0	229	0	55	0	48	0	64	1 769	0	1 063 654
Shu-Shu	1	313 414	752 691	114 463	341	34	5 539	1 044	55	11	0	0	0	23	1	58	143	1 954	0	0	81	0	17	0	22	0	3	1 371	0	1 191 265
Warmbaths	`	315 975	330 947	92 068	344	45	980	1 013	11	7	0	0	0	0	0	56	131	479	0	0	32	0	18	0	9	0	44	232	1	742 392
Birlanyoni	1	771 815	360 236	134 369	313	49	1 105	2 073	40	16	35	1	1	2	2	71	140	3 734	0	0	9	0	4	0	29	0	42	462	0	1 274 549
MPU																														
Badplaas	10	2 611 457	5 582 618	800 534	438	486	0	0	0	5 654	137	84	1 979	1 215	6 811	0	7 996	50 331	92	0	0	0	0	0	245	0	0	0	0	9 070 079
Machadorp	2	231 663	652 476	103 203	451	57	144 308	0	0	0	51	9	452	250	0	0	395	12 259	20	0	0	2 271	0	0	0	0	0	0	0	1 147 866
Falcon G	6	385 159	2 032 853	0	0	278	0	0	0	5 302	206	53	1 617	901	2 956	0	4 713	45 026	116	0	0	0	0	0	0	0	0	0	0	2 479 179
Amanzimt	1	292 336	724 499	99 464	42	52	47 312	362	296	305	75	0	0	59	0	532	6 637	22 677	5	2	382	789	49	1	38	0	297	4 012	0	1 200 221
Sulphur s	1	516 513	179 107	55 158	429	29	540	660	6	9	0	0	0	0	1	31	99	228	0	0	11	0	12	0	25	0	800	255	0	753 913
SWAZILAND																														
Swazi S	14	3 064 565	1 877 910	348 508	238	2 277	0	0	2 530	17 205	617	181	7 727	617	0	0	3 649	18 689	0	0	0	0	0	0	1 228	0	0	0	0	5 345 941
SUM		44 682 887	162 169 358	27 999 668	70 931	13 487	8 940 034	2 320 974	85 042	36 362	50 984	1 762	191 398	5 272	14 763	85 451	261 271	1 886 457	1 164	100	44 768	103 711	2 638	699	16 556	2 935	49 032	134 190	364	249 172 259
Price$/100g		190	25	100	0.33	44	1114	661	220	32	6.5	21	7.7	9.76	5.3	5	27	100	46	4.5	8.3	55	48	48	61	39	320	1100	24	
	5 Dec 2012 Chemicool																													

>R1 mil		R500 000-R1 mil		R100 000-R500 000		R50 000-R100 000		R20 000-R50 000		<R20 000	No data	All values / month

Contrary to expectations, extracting all the minerals for all the above-mentioned from thermal springs could be enormously economically beneficial. The most viable springs where extraction could generate a bruto amount of R10 mil/month are Aliwal (R90 mil), die Oog (R21 mil), Brandvlei (R14 mil) and Tshipise (R11 mil). Those with potential exceeding R5 mil per month are Lekkerrus and Badplaas (R9.5 mil). Even undeveloped springs such as Sagole and Riemvasmaak could earn R2.9 mil and R2.5 mil per month.

It is would obviously not be economically viable to attempt to extract all minerals from a thermal spring. Except for fluoride, sodium and potassium (that may be very difficult to extract in a pure form), the three most lucrative minerals are boron, titanium and strontium. If only these three could be extracted, many thermal springs could earn an addition R50 000+ per month. The following thermal spring waters have concentrations of B that could earn more than R100 000 per month: Aliwal (R5 mil), Badsfontein, Brandvlei, Tshipise, Warmbad, Die Oog, Loubad, Lekkerrus, Citrusdal, Cradock, Fish Eagle Spa, Florisbad, Baden Baden and Machadodorp. Potentially lucrative (R50 000+ per month) mining for Sr could be undertaken at Die Oog, Lekkerrus, Aliwal, Badplaas and Loubad. (It appears that water mining of Sr extraction at Mavanyini and Matyavilla could also earn considerable revenue for the Kruger National Park.) Die Oog, Loubad, Lekkerrus, Rhemardo and Brandvlei could earn more than R50 000 from the extraction of Ti. Springs that have already been developed into resorts, mineral extraction could be a source of addition capital. Die Oog alone could increase revue from current activities by R925 000 per month if all the titanium could be extracted. Other resorts that could benefit from this income stream are, *inter alia,* Badplaas, Tshipise, Amanzimtaba, Rhemardo, Evangelina and Vischgat. Currently undeveloped springs such as Riemvasmaak, Sagole, Towerwater could earn a handsome revenue for the local community if these three minerals were extracted in a small scale mining venture. These values are based on the assumption that all minerals could be extracted. This is obviously not possible.

The cost of mineral extraction has not been factored into the values given in Table 4.12 either. Many methods and techniques are documented in literature to remove cations and anions from water such as ion exchange, multiple ion-exchange resins and electro-coagulation. One of the biggest companies in the field of resin research and development (Anhui Sanxing Resin Technology in China) recommend that their resin D72 will remove Titanium, Boron and Strontium each separately from geothermal spring water. This strong acid macro porous cation exchange resin can be used for extracting these metals separately.

Other methods include a series of adsorption and desorption cycles. Several research papers have been published about the use of a variety of natural sorbents to remove metals from synthetic or industrial effluents (Ag, Al, As, Au, Ba, Bi, Ca, Cd, Co, Cr, Cu, Fe, Hg, Ir, Mg, Mn, Mo, Na, Ni, Os, Pb, Pd, Pt, Ra, Sb, St, Ti, Tl, V, Zn, Zr), lanthanides (Ce, Eu, La, Yb) and actinides (Th, U). Biosorbents, especially those derived from seaweed (macroscopic algae) and alginate derivatives, exhibit high affinity for many metal ions. Because biosorbents are widely abundant (usually biodegradable) and less expensive than industrial synthetic adsorbents, they hold great potential for the removal of metals. Electrolysis allows metal recycling and removal from water while reverse osmosis and membrane processes can also be utilised. Some of the latest developments include the use of algae to remove cations together or separately from each other (Water & Oil Technologies, Inc).

The Crystallisation and Precipitation Research unit, Dept. Chemical Engineering and Built Environment, at the University of Cape Town is conducting research on optimising the crystallisation of Pt, Rh, Ni, Co, Fe, Mg and Ca (Water Wheel, 2013). It is possible that they will in the near future, perfect cost effective ways of precipitating the other minerals from solution.

It should be also be borne in mind that geothermal water mining does not hold all the environmental disadvantages of traditional underground or surface mining and that the water flows naturally from the underground reservoir, thus no pumping is required. Also, the water flow is continuous – 24 hours per day; year-in year out, and – depending upon the extraction method – the 'outflow' water would still be uncontaminated and suitable for other uses. Moreover, a conservative estimate of a flow rate of 1 l/s was used in the calculations in Table 4.11. More accurate flow rates of springs with high contents of lucrative minerals should be undertaken. It should be pointed out that this study does not suggest that big mining operations should be carried out at the thermal springs, but that a relatively simple, labour intensive operation be set up and a niche market identified for specific minerals. It might also be possible to start-up small ventures by local communities so as to beneficiate raw materials on site.

4.2.6.2 Kieselguhr

Kieselguhr, also called diatomaceous earth (DE) or diatomite, is a deposit formed by the fossilisation of unicellular microorganisms (algae) known as diatoms in sedimentary rock. The fossilised skeletal remains (frustules) vary in size with the outer shells of these diatoms are made of silica.

BOX 4.4

Kieselguhr was first discovered in 1836 around Lüneburg in the vicinity of Hamburg, Germany. It has many uses. In 1876, Alfred Nobel used the properties of this diatomaceous earth mineral to produce dynamite while Wilhelm Berkefeld, recognised kieselguhr's ability as filter material and developed tubular filters that were successfully used during the cholera epidemic in Hamburg in 1892 (Wikipedia).

The uses of this material are primarily due to its abrasive, absorptive and thermal (insulation) properties. Uses range from mild abrasive in toothpaste and scrubs in the cosmetic industry, to the control of insects (due to its water absorptive properties), to its use as a fine filter in the beverage and pharmaceutical industries. Some recent studies by Aytaş *et al.,* (1999) indicate the possibility of the removal of uranium from aqueous solutions by diatomite earth. Kieselguhr is used on Thin Layer Chromatography (TLC and HPTLC) and can also been used for reclaimed used lubricating oil (Katiyar & Satar, 2012; Merck Millipore, 2013).

Until World War I most of the world demand for kieselguhr was met by the mines in Hannover in Germany (Nagendrappa, 2013). Currently, diatomite is mined all over the world in countries such as Kenya, China, India, Mauritius Congo, North America, Canada and England (Kent, 1948). South Africa does not produce kieselguhr on a large scale (Department Minerals and Energy, 2005). Only a few companies in South Africa such as SA Diatomite Ltd (Kathu and Olifantshoek area, Northern Cape) are suppliers of diatomite. At the latter, the small scale mining project but currently employ more than 18 locals from the isolated little town where jobs are few and far between. At Temba Organics, the workers have shares in the company and own 25% of SA Diatomite. The factory is not able to produce enough processed diatoms to satisfy soaring demand in South Africa (Delmar, 2010). Diatomite imports for the year 2004 were more than 5000 ton, valued at R10 670 018.

Thermal springs in Namibia have been shown to be rich in diatoms (Kent & Rodgers, 1948). Diatomite (kieselguhr) has also been found under 0.3 to 0.9 m of peaty material at Soutini thermal spring (Gevers, 1942). The diatomite ranges from 0.1 to 0.3 m in thickness (Gevers, 1942). Calculations done by Kent (1948) on the possible economic viability of diatomite indicated deposits of nearly 200 ton diatomite at thermal springs at Riftfontein and 2500 ton at Soutini.

Ideal conditions for the formation of Kieselguhr are alkaline waters, a silica content of 1-4 ppm, some K and Mg (necessary for diatomic growth) and waters low in phosphate and nitrate (Kent 1948; Haddon, 2010). Unfortunately, the Si content was only measured at a few thermal springs. Eiland and Soutini thermal springs have temperatures >40°C, high alkalinity and a pH> 7.6 and both have high silica concentrations of 39.8 mg/l and 57 mg/l, respectively. Kieselguhr imported from England and used by a South African rubber manufacturing company at Howick, mainly consists of the diatoms *Synedra, Melospira*, *Cymbella*, *Cocconeis* and *Fragilaria.* Kieselguhr needed for the manufacturing of explosives comprises of small diatoms (0.03-0.08 mm) from genus *Hyalodiscus*, *Epithemia*, *Melospira*, *Cyclotella* and *Synedra*. These diatoms where also found at Riffontein and Soutini by Kent (1948) and by Jonker *et al.* (2013) at at least six thermal springs in Limpopo Province.

The guideline for small-scale mining by the Department of Water Affairs has recognised Kieselguhr extraction as suited for small, medium and micro enterprise development in South Africa (DWAF, 2006). This may be viable at a variety of thermal springs, excluding those in the Western Cape where the alkalinity is very low. This aspect needs much more attention and thorough surveys should be carried out to identify possible Kielseguhr deposits at South African thermal springs.

4.2.6.3 Salt

Historically, salt has been the cause of wars, uprisings and revolutions. It has been taxed all over the world, used as money and has been a powerful force in the economic rise and fall of civilisations.

BOX 4.5

Salt shed and solar evaporation method – 1908 (Wikipedia)

In Africa, salt was traded along well known routes over the Sahara in exchange for gold at Timbuktu (Briggs, 2007).

The term salt usually refers to NaCl. It has widespread uses as a food preservative and a seasoning. It has gained status during the large few years as a gourmet seasoning. Salt tasting festivals are held in South Africa, and highly priced boxes of a selection of salts including Himalayan pink salt, Marray River peach flakes, Persian blue, Dead Sea salt, etc. are available at select food outlets. It also makes an ideal base for essential oils to be used in the cosmetic industry. Salt is either mined (as halite) or recovered from the evaporites of sea water and natural brines for large-scale production. South Africa has large salt production works near the coast and at a few pans. Salt has been produced for hundreds of years at Soutini (Baleni) and the nearby Eiland thermal springs.

When using a sodium concentration of >300 mg/l and a chlorine concentration of >500 mg/l (based on those of Soutini and Eiland) against the dataset in Addendum B, it was found that salt production might be viable at Evangelina, Mafayini, Matiyavila, Riemvasmaak, Aliwal, Fish Eagle spa, Badsfontein, Baden Baden, and Florisbad. This is borne out by the fact that Florisbad is located on the bank of the large Soutpan – from which salt is mined as an evaporite. It might thus be possible for additional income to be earned from small scale salt production at the springs mentioned above – where niche salts could be produced for the gourmet food and the cosmetic markets.

4.2.7 Application of thermal water for geothermal energy

Geothermal heat in hot spring areas has been exploited for many years to generate electric power. The benefits are that geothermal power plants involve no combustion, unlike fossil fuels plants, so they emit very low levels of greenhouse gases. Binary and flash/binary plants produce nearly zero air emissions. Electricity generation from geothermal resources also eliminates the mining, processing, and transporting required for electricity generation from fossil fuel resources. Using geothermal energy helps to offset the overall release of carbon dioxide into the atmosphere, as well as its effects. Geothermal energy also takes up very little surface land (see Box 4.6) – it has among the smallest footprint per kilowatt (kW) of any power generation technology, including coal, nuclear, and other renewables.

BOX 4.6

Dr BisErnest Tshibalo on field trip to East African Rift Valley at a geothermal well testing site – WELL MW-01 and MW-04, in Menenga (Kenya)

Depending on parameters of the geothermal reservoir such as temperature, flow rate and quantity of dissolved gases and salts, different types of geothermal power plants are used worldwide. Dry and flash steam power plants are used in areas with high temperature resources (>200°C) (Yibas *et al.*, 2011; Deliverable.16)

Many thermal springs do not meet the thermal criteria for large-scale steam generated power plants and recent research has focused on increasing the efficiency of binary systems. A binary-cycle (the Organic Rankine Cycle) plant is defined as "a geothermal electricity generating plant employing a closed-loop heat exchange system in which the heat of geothermal fluid (the primary fluid) is transferred to a lower-boiling-point fluid (the secondary or working fluid), which is thereby vaporized and used to drive a turbine/generator set". This is illustrated in Fig. 4.6.

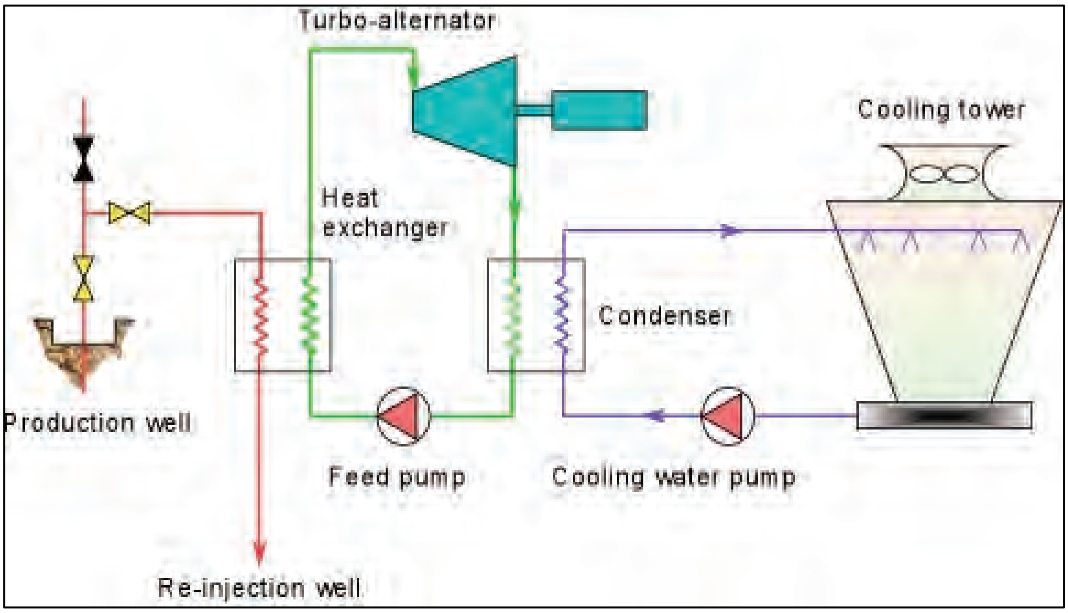


Fig. 4.9 Schematic representation of a binary-cycle geothermal power plant. (Source: Dickson & Fanelli 2004, In: Tshibalo 2012)

Binary-cycle plants are often used where geothermal temperatures are typically less than 220°C, but greater than 100°C. The European Commission (1999) recommended a temperature range of 85°C and 170°C. However, in Alaska, the Chena Geothermal Power Plant is currently operating at 74°C. Typical fluids used as the 'working medium' are isobutene and propane. A recent modification to the Rankine cycle, is the Kalina cycle, in which ammonia and water mixture is used as a working fluid instead of propane or isobutane. Only a few plants in the world are based on the Kalina cycle – two power plants in Japan and one each in Iceland, the USA and Germany. A new 'Ecogen unit' is based on the miniaturisation of the Kalina cycle. It has been designed for the Japanese hot spring market and other low enthalpy geothermal markets (http://en.wikipedia.org/wiki/kalina_cycle). The first 50 kw Ecogen-Kalina-unit was installed at the Matsunoyama onsen hot spring at Tokamachi, Niigata in Japan during 2011. It is possible that binary systems will soon be able to generate power from thermal springs with temperatures as low as 25-70°C (Rodriqueza, 2012).

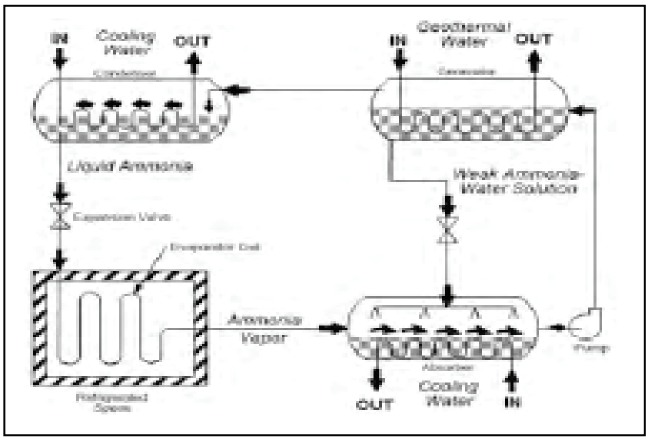
Advantages of binary cycle plants include the fact that they do not emit air pollutants, environmental effects of the geothermal fluid can be controlled, and energy produced by this system is relatively cheap. Disadvantages are the possible hazardous effect of secondary working fluids and initial high capital input costs.

Two criteria are required for direct hydrogeothermal electricity production: high temperature and high flow rate. The differential between ambient temperature and that of the thermal spring water should be as high as possible. Unfortunately, South African thermal springs have relatively low temperatures, and appear not to be suitable for use for the generation of electricity.

Brandvlei, which has a temperature of 64°C and a flow rate of 0.127 m^3/s (126 *l*/s) is the most suitable for the generation of electricity. Hartnady & Jones (2007), estimate a power generation capacity of least 27 megawatts. The source of the spring is currently within the Brandvlei prison, in the vicinity of Worchester (W Cape). This would constitute an ideal setting for a geothermal energy plant since the ambient temperature at Worchester falls to below freezing point during winter nights. Moreover, the plant could provide energy to a relatively small and isolated community – even if just to remove the prison from the ESKOM gridline during periods of peak demand.

Other thermal springs with geothermal potential are those with temperatures above 50°C, i.e. Badplaas, Warmbad, Calitzdorp and Shu Shu. The low flow rate at Siloam would hamper this application. However, if boreholes could be drilled to produce higher flow rates, this site would also be suitable for small energy production initiatives. The surrounding community and hospital could benefit from this energy source, especially during peak electricity usage periods and during winter.

Geothermal refrigeration



BOX 4.7

Geothermal absorption refrigeration cycle

Cooling can also be accomplished from geothermal energy using lithium bromide and ammonia absorption refrigeration systems. The lithium bromide system is the most common because it uses water as the refrigerant. However, it is then limited to cooling above the freezing point of water.

The major application of lithium bromide units is for the supply of chilled water for space and process cooling. They may be either one- or two-stage units. The two stage units require higher temperatures (about 160°C); but they have higher efficiencies. The single-stage units can be driven with hot water at temperatures as low as 77°C.

The lower the temperature of the geo-thermal water, the higher the flow rate required and the lower the efficiency. Generally, a condensing (cooling) tower is required, which will add to the cost and space requirements. For geothermally-driven refrigeration the freezing point of water, the ammonia absorption system must be considered. However, these systems are normally applied in very large capacities and have seen limited use. For the lower temperature refrigeration, the driving temperature must be at or above about 12°C for a reasonable performance (Popovski & Vasilevska, 2010).

Different minerals and gases within the geothermal waters are claimed to have specific curative powers. Murken (2006) stated that treatment with natural thermal water was not exclusively intended for external ailments of the musculoskeletal system and skin but also diseases of the heart, stomach, intestines, bladder and kidneys.

4.2 8 Health and wellness

TABLE 4.12: MINERALS FOR HEALTH	
Chemical/Trace Elements	**Potential Curative power/Essential in human health**
Calcium and Magnesium	Essential in human diet
Fluoride	Promotes dental health
Carbolic water	Have significant medical importance circulatory and heart disorders
Sulphated water	May heal hepatic insufficiency (inability of the liver to function properly) and problems with the accumulation of organic waste
Bicarbonate water	May relieve gastrointestinal illness, hepatic insufficiency and gout
Sodium Chlorinated water	May cure chronic infection of mucous membrane (ledo, 1996)
Mineral water	Recommended for diseases such as gout, urinary and kidney stone complaints (Murken, 2006)
Trace elements	
Selenium	Essential for AIDS, arthritis, asthma, cancer, cardio vascular diseases, reproduction, thyroid and viral infections
Strontium	Reduction in bone pain from patients suffering from osteoporosis Improvement to patients with postmenopausal osteoporosis
Iodine	It builds thyroid hormones, the nervous system and metabolism
Lithium	Lithium salts treat manic-depressive illness, (bi-polar disorders) or used as antidepressant.
Manganese	Important in human diet
Molybdenum	Can be used as food supplement mineral
Nickel	Dietary requirement for many organisms
Platinum bonds	Applied as medicine to cure cancer. Compounds are used in tumor therapy
Information : Tshibalo (Deliverable 18)	

The therapeutic properties of the warm water are thought to be due to the relaxing effect of the heat and the buoyancy of the water – thus relieving muscular pain. Murken (2006) also indicated that warm water stimulates the body to release of endogenous biochemicals such as endorphins, the steroid hormone cortisone and other hormones which have anti-allergenic properties or help to reduce inflammation and pain. Waters high in mineral salts are believed to have different beneficial chemical effects on diseases through the absorption of the dissolved minerals via the skin.

The use of carbolic water is thought to have significant medical importance for circulatory and heart disorders. Sulphated water may heal hepatic insufficiency and problems with the accumulation of organic waste. Bicarbonated water may relieve gastro-intestinal illness, hepatic insufficiency and gout. Sodium chlorinated water may cure chronic infection of the mucous membrane (Ledo, 1996; Lund, 2000; Skapare, 2001; Skapare *et al*., 2003). Drinking mineral water is claimed to alleviate ailments such as gout, urinary and kidney stone complaints, which are accompanied by severe attacks of pain (Murken, 2006).

Although the art and science of balneology is not currently well known in South Africa, many thermal springs were used in the past for their purported curative properties – ranging from rheumatism to the healing of wounds. Around twenty South African thermal springs were historically used for therapeutic purposes. These include the baths at Caledon, Aliwal, Montegu, Warmbad, Florisbad, Black Umfolozi (Thangami) and Towerwater.

4.2.9 Specialised Tourism

According to Hall *et al*. (2005), tourism is one of the most labour intensive industries that has considerable potential to contribute to job creation and economic development in rural areas, and tourism is seen as a linchpin in many rural development strategies: "It has proved to be a powerful engine for economic growth – transferring capital, income and employment from industrial, urban and developed areas to non-industrial regions" (Organisation for Economic Co-operation and Development (OECD), 1994:5-7).

Globally, tourism contributes 10.7% to Gross Domestic Product (GDP) and 10,7% to employment. In 2002, for example, unemployment dropped from 25% to 7% in Argentina within a period of four years due to development in the tourism industry (Pesce, 2002; Ghosh *et al*., 2003). Estimated figures for the Middle East-Africa region reveal that tourism generated 9,8% of the GDP in 1996 (Creemers & Wood, 1997; Edgell, 2006). International travel for tourism involved about 665 million people at the turn of the twenty-first century. It triggers important processes of capital formation and the distribution of economic wealth (Williams, 2004).

Niche tourism is becoming increasingly popular as the tourist want to 'experience something different'. Ecotourism is perhaps the most popular type of tourism in South Africa. However, cultural tourism, adventure tourism and 'political' tourism is gaining popularity and a trip to Robben Island is becoming a must for tourists visiting Cape Town. Interesting tours visiting ship wrecks and light houses along the coast are being offered.

Geothermal power plants can be a tourist draw when students, scientists, or interested individuals visit the site of a power plant, thereby bringing business to the local community. Iceland's most popular tourist destination is the Blue Lagoon, a geothermal spa connected to the Svartsengi power plant in the island's southwest.

Thermal springs have considerable potential for the revival of health and wellness tourism – especially if this can be combined with other tourism resources such as the Ivory route and the proximity to the Kruger National Park in for the thermal springs in the Soutpansberg. Reference was previously made to thermal spring resorts specialising in safari tourism and those that cater for people want to relax and revive.

New thermal spring uses could also act as a trigger for niche tourism. For example, salt extraction could act as a pivot for a salt trail, including not only salt tasting and food (and wine) events, but highlighting the ancient civilisations at Baleni and Florisbad. Indigenous Knowledge of the mysteries and myths surrounding thermal springs would enchant tourists and could be harnessed to the benefit of holders of this knowledge. Thermal spring-centred tourism could open new vistas in the tourism industry.

CHAPTER 5: POTENTIAL USES OF THERMAL SPRING RESOURCES: CASE STUDIES

Jonker CZ & Olivier J

In the previous chapter, the suitabilities of South African thermal springs were assessed for a number of different uses. A summary of potential alternative uses for the South African thermal springs is given in Table 5.1.

TABLE 5.1: SUITABILITY OF SOUTH AFRICAN THERMAL SPRINGS

USE	Bottle	Cosmetics	AGRICULTURE			AQUACULTURE						MINING			Geothermal	Balneology	Tourism	Swimming	SCORE
			GH & Mushrooms	Irrigation	Crop drying	Fish	Fish	*Spirulina*		Oysters		Minerals	Salt	Keiselguhr					
SPRING	W	W	H	W	H	W	H	W	H	W	H	W	W	W	W	W	W	W	
LIMPOPO																			
Tshipise			2	2			1		1	1	1	2			1		1		12
Sagole			2				1		1	1	1	1				1	1		9
Evangelina			2				1		1		1	1	1				1		8
Moreson			2				1		1	1	1	1					1		8
Mphephu		2	2				1		1	1	1	1		2			1		12
Siloam			2		2		1	1	1	2	1			1	1		1		13
Warmbad			2				1		1		1	1			1	1	1		9
Rhemardo		2	2				1		1	1	1	1					1		10
Soutini			2				1		1		1	1	2	2			1		11
Die Oog			2				1		1	1	1	2					1		9
Vischgat			2				1		1	2	1	1					1		9
Loubad			2				1		1	2	1	1					1	1	10
Buffelshoek			2				1		1		1	1		1			1		8
Minvamadi		2	2	1			1	1	1	2	1	1					1		13
Eiland source			2				1		1	2	1	1	2	1			1		12
Lekkerrus			2				1		1	2	1	2					1		10
Libertas		2	2				1		1	2	1	1					1		11
KNP																			
Tshalungwa		1	2	1			1		1	1	1						1		9
Tshipala A			2				1		1	1	1	1					1		8
Maritumbe			2				1		1		1	1					1		7
Magovani Hoof			2				1		1		1	1					1		7
Malahlapanga			2				1		1	1	1	1					1		8
Malahlapanga B		2	2				1		1	1	1	1					1		10
Mafayini		1	2				1		1	2	1	1	1				1		11
Matiyavila act		1	2				1		1	1	1	1	1				1		10
SPRING	W	W	H	W	H	W	H	W	H	W	H	W	W	W	W	W	W	W	
W CAPE																			
Brandvlei		2	2	1	1		1		1	2	1	2			1		1	1	16

Citrusdal		2	2				1	1	1	1	1	1				1	1	1	13
Caledon		2	2				1		1	2	1	1				1	1	1	13
Toverwater		2	2				1		1	1	1	1				1	1	1	12
Goudini		2	2	1			1	1	1	1	1	1					1	1	13
Calitzdorp		2	2				1	1	1	1	1	1			1	1	1	1	14
Montagu		1	2				1		1	1	1	1				1	1	1	11
E CAPE																			
Aliwal		1	2				1		1	2	1	2	1			1	1		13
Cradock			2				1		1	2	1	1				1	1		10
Fish Eagle Spa		1	2				1		1	2	1	1	1				1		11
FREE STATE																			
Badsfontein		1	2			1	1		1	1	1	1	1			1	1		12
Florisbad		1	2			1	1		1	1	1	1	1			1	1		12
Baden Baden		1	2			1	1		1	1	1	1	1			1	1		12
N CAPE																			
Riemvasmaak		2	2			1	1		1	1	1	1					1		11
KZN																			
Natal Spa		1	2				1		1	1	1	1					1		9
Lilani		1	2				1		1	1	1	1					1		9
Thangami			2				1		1	1	1	1				1	1		9
Shu-Shu		1	2				1		1	1	1	1			1		1		10
Warmbaths		1	2				1		1	1	1	1					1		9
Birlanyoni		1	2				1		1	2	1	1					1		10
MPU																			
Badplaas			2				1		1		1	1			1	1	1		9
Grovesbad			2				1		1		1	1					1		7
Machadodorp			2				1		1	1	1	1					1		8
Falcon Glen			2	1			1		1	1	1	1					1		9
Amanzimtaba			2			1	1		1	2	1	1				1	1		11
Sulphur spring			2				1		1		1	1					1		7
Swazi Spa			2				1		1	1	1	1					1		8
H=HEAT W=WATER																			
Red colour= not suitable; 1 suitable; 2 = very suitable. Oyster production: (1) if 1-3 criteria similar to sea water; (2) if 4 or more similar to sea waters. Minerals: 0 if total potential < R100 000/month; 1 if R100 000 to R5 mil; 2 if > R5 mil.																			

It is not surprising that all springs are suitable for at least one alternative use. What is unexpected is the large number of uses for which an individual spring is fit. Aliwal, for example, can be used for 10 alternative uses in addition to its current use for recreation, health and wellness tourism. Ideally, such as versatile resources should not be restricted to a single use. Some way should be found to cascade the resource (heat and/or water) through a number of tiers of developed so as to derive benefits at each step of the cascade. Numerous examples exist of such multi-faceted developments in other parts of the world. Prawn Park at Taupo, South Island, New Zealand is one such development.

Fig. 5.1   Illustration Prawn Park at Taupo (www.prawnpark.com)

Here, the geyser is used for power production. The hot water from the power station's outlet is used to warm the water of the Kaikato River to around 20°C for the cultivation of fresh-water prawns.

A number of prawn ponds, each equipped with water features and fountains are surrounded by large lawns where people can relax in the sun (Fig 5.2 and 5.3). A large water-based play park forms part of the development. Visitors pay and entrance fee and can purchase a prawn fishing licence if so desired. A restaurant specialising in prawn dishes is on hand to prepare the ‘catch’. The Park is very popular with children as well as adults and drawn large numbers of tourists. In this development, geothermal resource plays a pivotal role in power generation, the leisure and recreational tourism industries and in the restaurant and food industries.

Fig. 5.2 Water features and lawns

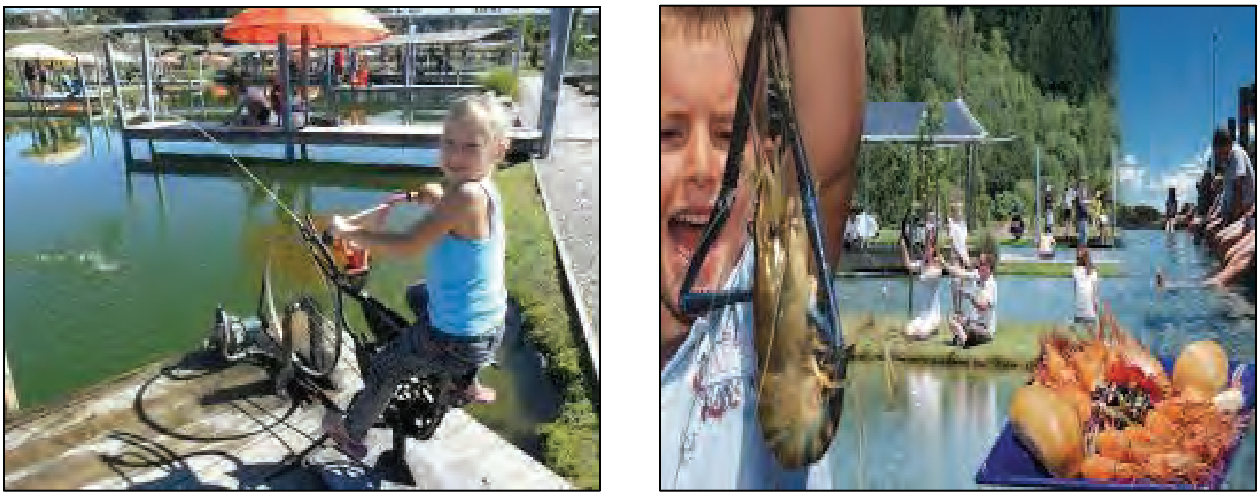


Fig. 5.3 Water-based Play Park

Popovski and Vasilevska (2003) illustrate a multi-tiered integrated thermal cascade using a low enthalpy geothermal resource in Macedonia (Fig. 5.4).

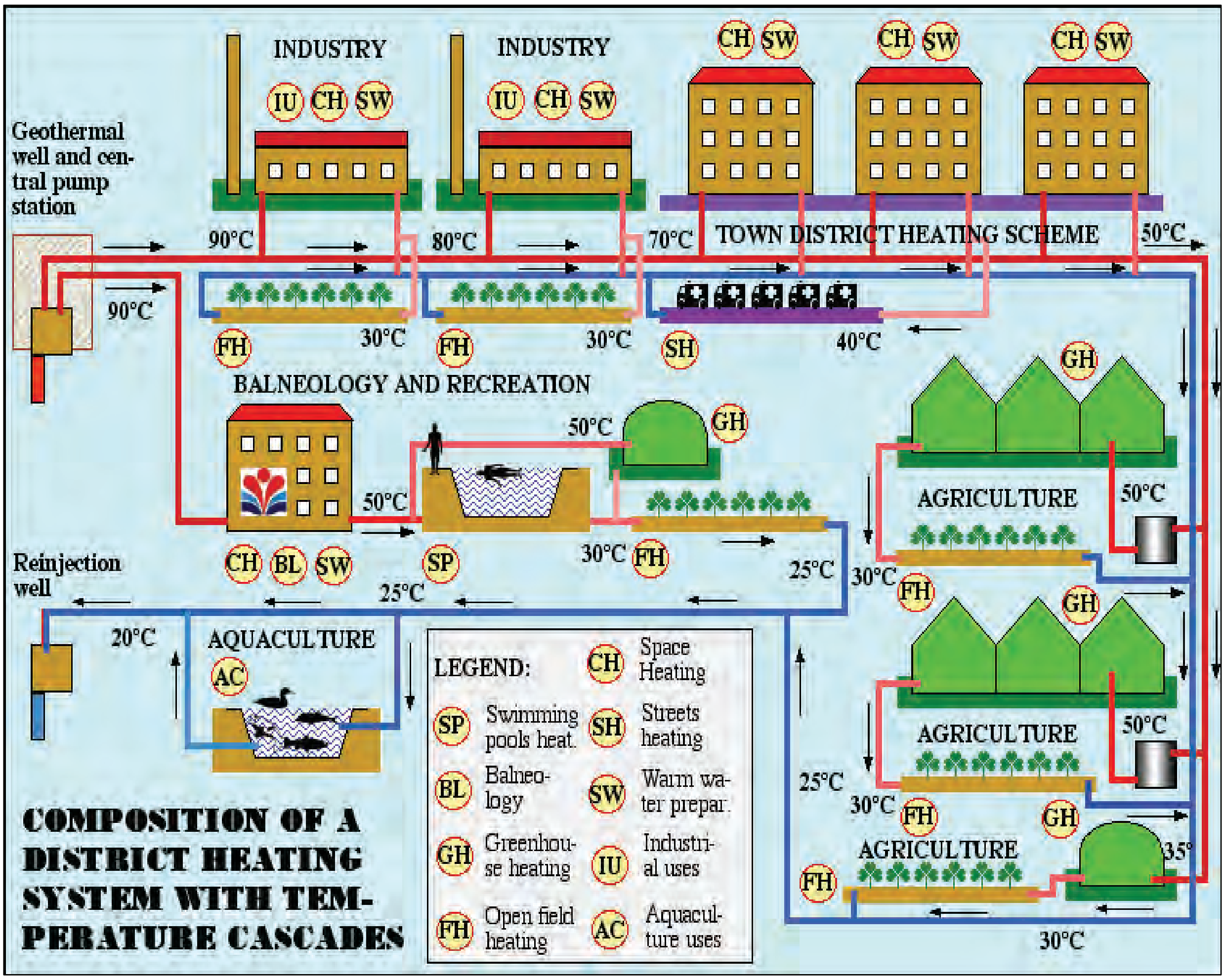


Fig. 5.4 Geothermal temperature cascade in Macedonia (Popovski & Vasilevska, 2003)

For some of these uses, thermal energy is used, and for others, the hot water is required. In the latter case, some uses (e.g. bottling and the manufacture of cosmetics) will remove water from the system and thus decrease the availability for other uses. Others such as swimming and balneology where chlorine or essential oils are added to the water, will affect its quality and may prohibit it for further stages in the cascade. Mining and the isolation of micro-organisms for biotechnical applications will remove components of the water, but will have no negative impact on the integrity of the resource. This is also the case if the thermal energy (heat) properties alone are employed. Such uses include space heating and heating for agriculture (greenhouses for flowers and vegetables and mushroom cultivation), the heating of aquaculture ponds, drying of crops; distillation, and pasteurisation

In this chapter, two case studies have been used to illustrate a possible cascade of uses of thermal spring resources in South Africa. Both are in rural areas and endeavour to build on existing potential.

CASE STUDY 1: GEOTHERMAL RESOURCE DEVELOPMENT AT SAGOLE

Sagole is located in the north-eastern part of Limpopo Province in a hilly region with Bushveld vegetation interspersed with Boabab trees (see Box 5.1). The climate is warm to hot throughout the year and rainfall is low. The thermal spring has a temperature of 46°C with a flow rate of 6-7 l/s (Kent, 1949).

BOX 5.1

The village and thermal spring with the same name are located within the Tshikundamalela Tribal Authority area of the Vhembe district of the Limpopo Province and fall under the authority of the Mutale Municipal Council. Other nearby towns are Musina to the north-west and Thohoyandou to the south-east. There are two villages in the immediate vicinity of Sagole, namely Zwigodini and Tshipise. A newly constructed tar road links Thohoyandou and Sagole. The Sagole community is small, mainly unemployed.

Photo (below): Tshibalo, 2011

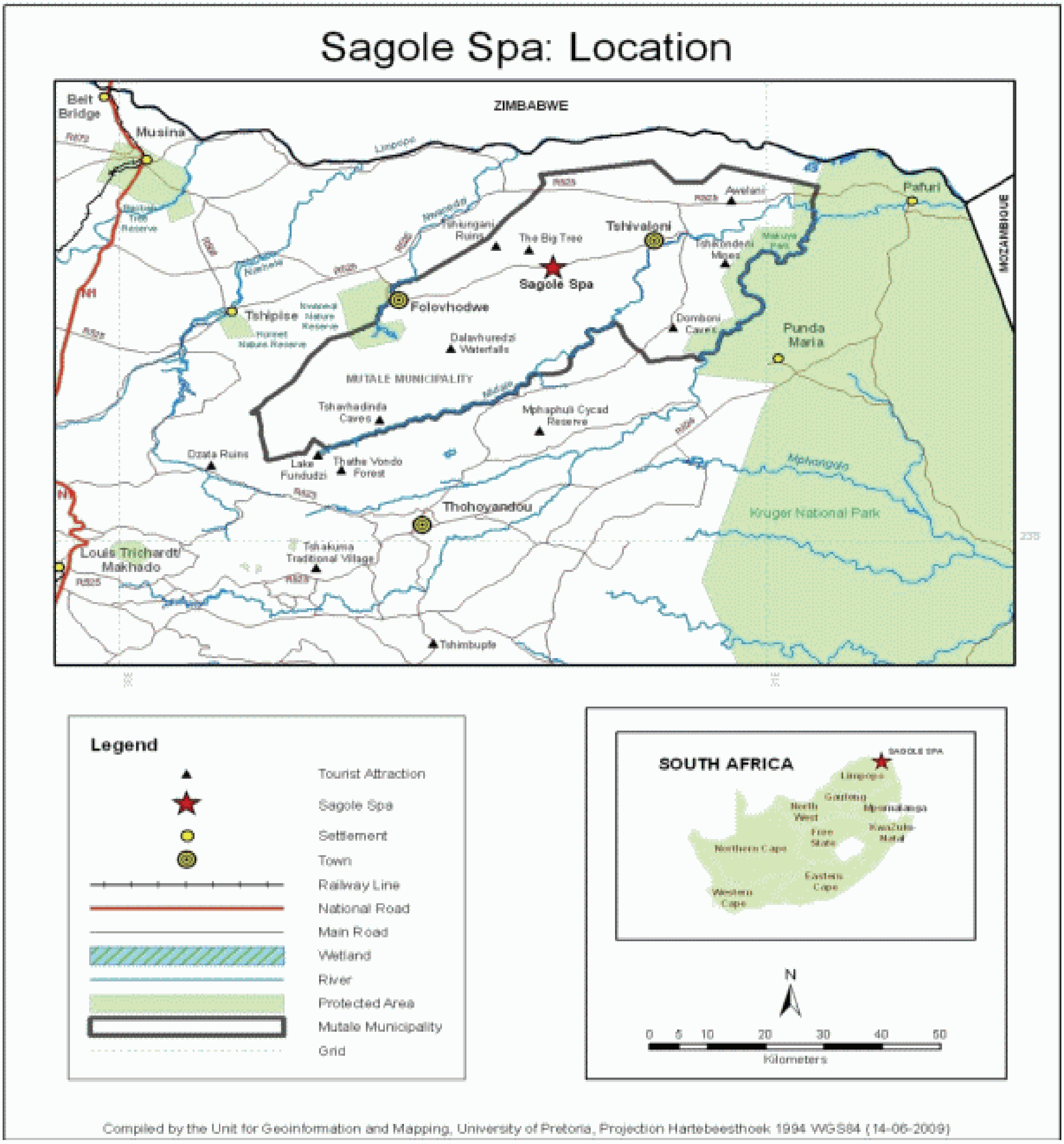


Fig. 5.5 Location of Sagole Spa

The spa at Sagole was previously known as Klein Tshipise (due to its proximity to Tshipise) and was a small but prosperous thermal spring resort. Facilities included a large swimming pool and several chalets – each boasting its own small outside thermal spa-pool. The entire 'resort' is currently dilapidated and in a state of total disrepair (Fig. 5.5).

Sagole has considerable tourism potential as shown by the attractions listed in Table 5.2. The village already forms part of the Ivory Tourism Route and lies on the main road linking Musina to the Pafuri gate of the (only 53 km) Kruger National Park. The tourism market is thus available – it just needs to be developed.

TABLE 5.2: TOURISM ATTRACTIONS IN MUTALE LOCAL MUNICIPALITY		
Tourist Attraction	**Location (Distance from Sagole Spa)**	**Exclusiveness**
Baobab Tree	Zwigodini Village 2 km	Biggest Boabab in Africa
Domboni Caves		
Nwanedi Nature Reserve		
Makuya Park	Adjacent to Kruger National Park 30 km	Animal viewing & camping facilities
Tshavhadinda Cave	Ha-Rambuda 40 km	Hiding place during Tribal wars
Awelani	Tshikuyu 35 km	Caves
Dzhinzhikoni Potholes	Dzamba 30 km	Potholes
Dalavhuredzi Water falls	Mufulwi 35 km	Ancient finger prints
Domboni Village 3 km	Hiding place during tribal wars	Traditional houses arts & culture
Folovhodwe 15 km	Animal viewing & accommodation	Hiding place during tribal wars
Mutavhatsindi Nature reserve	Thengwe 30 km	Miracle tree
Tshiungani Ruins	Tshiungani 4 km	Traditional Chief Kraal
Dambale Caves	Dambale 2 km	Bushmen (Khoisan) paintings
Kruger National Park	40 km from Sagole	Wildlife viewing and camping
Tshikondeni Mine	Tshikondeni 40 km	Coal mining
Kaolin Clay Mine	Tshipise 500 m	Kaolin clay mining
(Mutale Municipality IDP 2008/2009) (source Tuwani, 2012; Tshibalo, 2011)		

There is considerable indigenous knowledge about the health benefits of this spring. A famous traditional healer (Tshikovha) lives near the spring and is known for his ability to 'cure' mental illnesses. It is noticeable that the spring contains some in lithium – a mineral known to alleviate depression.

Ideally these attributes should be employed for a geothermal development at Sagole without attempting to compete with Tshipise resort. The good water quality, indigenous knowledge together with its accessible location and warm climate, make Sagole thermal spring a prime site for the establishment of an African Health and Wellness retreat. Although it is close to Tshipise resort – a flourishing family recreation centre – it could be marketed locally and internationally for its curative treatments and health benefits. Development for this purpose could target visitors to the KNP especially those seeking a Health and Wellness experience with a unique African ambience.

The African Health and Wellness Centre at Sagole would require accommodation and a restaurant, a treatment centre and swimming pool. Some infrastructure already exists such as a few chalets with their own spa pools, and a large swimming pool. The current dormitory can be converted into a restaurant. Day visitors could make use of the restaurant, while the accommodation could be reserved for visitors who come specifically to relax and experience health and wellness 'treatments' in an exclusive – but truly African – environment. Visitors to such a centre would require not only appropriate facilities and trained personnel in a variety of health and wellness field, but expect that the cuisine should be well prepared and the produce used should be fresh, locally and organically produced. The alternative uses for the thermal spring resource (as identified in Table 5.1) could be used to fulfil these needs. The proposed cascade for Sagole thermal spring resource is depicted in Figure 5.6, below.

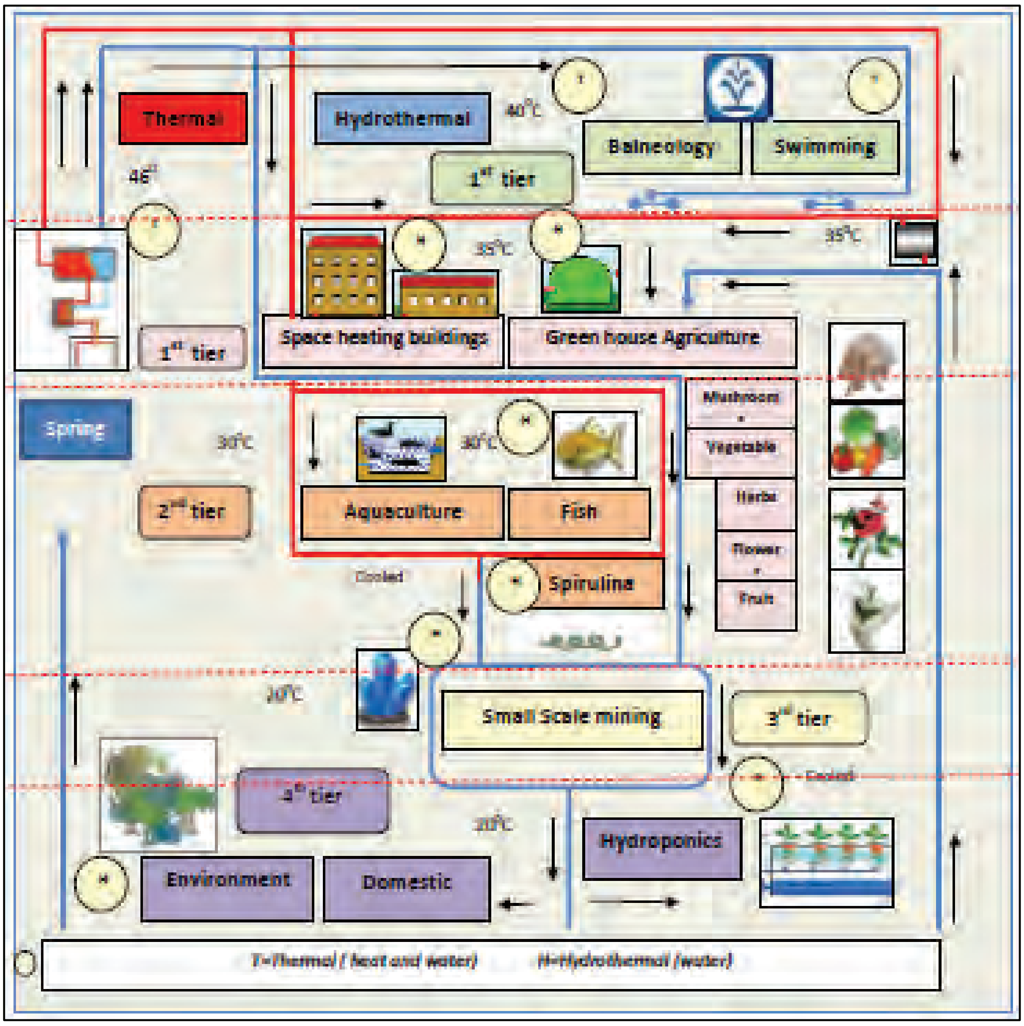


Fig. 5.6 Proposed geothermal cascade at Sagole

In the *first tier of uses* the thermal (heat alone) and the hydrothermal (water and heat) could be used separately. The relatively high pH prohibits its use for drinking purposes (DWAF, 1996), but its mineral content and temperature make it eminently suitable for warm water therapy. The water could thus be used in the treatment centre and to fill the hot spa pools and possibly also the swimming pool. The thermal component could be harnessed for space heating of buildings (in winter) and for small-scale agriculture such as the production of fresh fruit (e.g. strawberries), vegetables, herbs, mushrooms and flowers in greenhouses. The water that has been used for heating greenhouses could now be cascaded to *second tier* of uses for heating aquaculture ponds for the production of *spirulina* and fish.

By the time that the water has been used to heat greenhouses and aquaculture ponds, it will probably have cooled considerably. This water can now be used for small-scale mineral extraction (*3rd tier*). Theoretically, the Sagole spa can "earn" almost R100 000 per month if only B, Sr and Ti were extracted after cascading though the other uses. If acidic resins are used for mineral extraction, the pH of the outflow would probably be close to neutral and would be suitable for the *final tier* of uses. This could include a variety of domestic uses (bathing, sanitation, cleaning and washing up), for the swimming pool and possibly for hydroponics in the greenhouses. Unfortunately, the high SAR values will prohibit open field irrigation. A portion of the water recovered from mineral extraction should be returned to the environment to ensure flow of the stream and survival of the wetland. Since the community does not make use of the thermal spring, this cascade of uses will not affect them in any way, except to create income and generate jobs.

The agricultural and aquaculture products harvested from the greenhouses and ponds could be utilised at the resort. The fresh fish, organically produced fruit (strawberries), vegetables, herbs and mushrooms could be used in the restaurant while (exotic) flowers could be used in the wellness centre and accommodation facilities. *Spirulina* can be dried and used in the wellness centre. The water can be bottled by hand, specifically for use by the Centre to combat ailments such as gout or excess acidity. This together with the IKS of the local inhabitants and Traditional Healer can be used to make this a unique African experience.

Excess produce could be sold at stores in the area or at local markets. Conversely, the resort could serve as a market for local produce. Utilisation of the geothermal resources at Sagole could thus bring about a ripple effect of economic benefits that extend far beyond the resort itself.

CASE STUDY 2: GEOTHERMAL RESOURCE DEVELOPMENT AT SILOAM AND MPHEPHU

Mphephu and Siloam are located within the Nzhelele valley in Limpopo Province (Fig. 5.7). The springs are approximately a kilometre apart on either side of the R521 route linking Wyllies Poort (north of Makhado (Louis Trichard)) to Thohoyandou. The road to Siloam turns off at the Siloam hospital and that to Mphephu, at the local shopping complex.

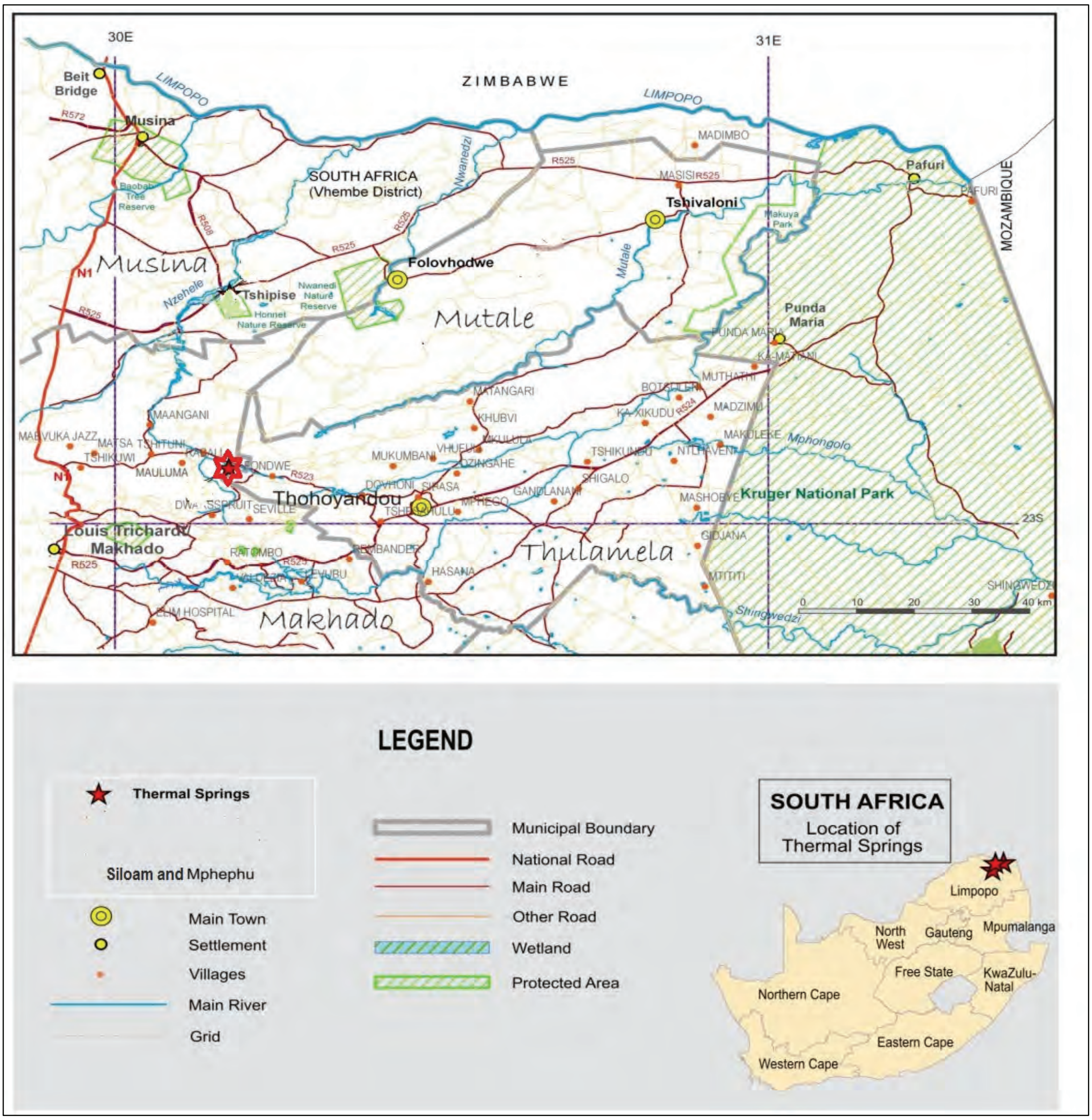


Fig. 5.7 Map showing location of Siloam and Mphephu

The **Siloam hot spring** is situated at the foot of the south western flank of the Tonondwe Mountain (in the Soutpansberg Range) on the property of one of the locals in the Siloam community. The spring emerges near the bank of a small stream running through the settlement. According to local residents, the spring was cold until 1969 when it became hot overnight. It is currently (2012) around

71°C with a flow rate of only 1 l/s (note: the flow rate has varied from 0.15 l/s in 2004 to 1 l/s in 2012). Mineral encrustations of $CaCO_3$ were observed in pipes leading from the spring. The spring water is currently used by the local community who collect water in buckets and use it for cleaning their homes. Local women also congregate around the spring where they use the hot water for plucking chickens. This resource could have considerable economic due to its geothermal properties. However, for any development, additional volumes of hot water would be required. Drilling would thus be required. Fortunately, Nyabeze and Sekiba (2012) have identified suitable sites for this using various geophysical techniques. At these sites, the aquifer should yield large volumes of hot water on a sustainable basis.

The **Mphephu thermal spring** is situated at the foot of the northern flank of the Tswime Mountain at an elevation of around 851 m. It has two eyes approximately 1.5 km apart. The Mphephu hot spring was known as 'Tshipise tsha Tshavhalovhedzi' and was used by the indigenous people for rituals and domestic purposes for generations. The westernmost eye has been sealed off and the water used to fill the pools at the Mphephu holiday resort. The temperature of this resort spring eye is 44°C and the flow rate, 6 l/s. The second eye is undeveloped and has been used by the Dopeni community for bathing ever since the Mphephu Resort was developed for commercial purposes. Men and women are allocated specific times to bath in this thermal pond.

There are abundant tourist attractions in the vicinity of these two thermal springs including: the Dzata ruins (cultural site of an ancient Venda king); Lake Fundudzi (South Africa's only natural lake and is held sacred by the Vhavenda); the Sacred Forest (holy ground for the Nethathe community); Tswime Breathing Rock where hot air blows out of a vent; the Kokwane footprint (footprint of ancient inhabitants embedded in rocks); the Nzhelele dam and the Phiphidi waterfall – rich in cultural heritage and traditional beliefs.

Despite these tourism attractions, the Siloam thermal spring is totally undeveloped while Mphephu is currently used as a venue by locals to drink their 'sundowners' and watch soccer games on the large TV screen on the veranda. Schools sometimes arrange day visits for groups of learners. The considerable tourism potential is not utilised by the resort, nor are the geothermal resources used optimally.

It is proposed that Siloam and Mphephu thermal springs be developed as a unit – but with each having its own characteristics and functions. In view of Siloam's geothermal capability, it would be suitable for developed as a Green Industrial Hub (albeit very small) whereas Mphephu would be most suited as a resort using a modified Prawn Park model from New Zealand.

Proposed development at Siloam

Assuming that drilling takes place and the flow rate is not limiting, all alternative uses identified in Table 5.1 could be used for development. Figure 5.8 shows the envisaged cascade of water and heat at Siloam.

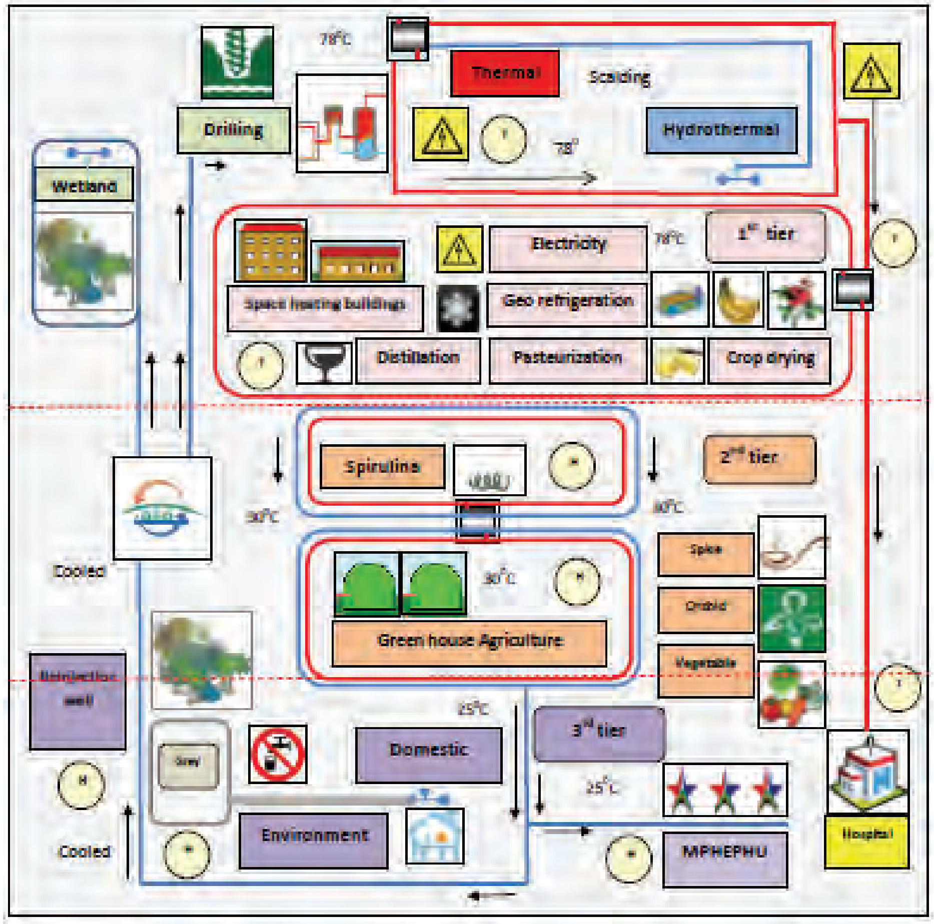


Fig.5.8 Cascade of uses at Siloam

Due to the relatively high temperatures, the *first tier* of uses could include the production of electricity as well as distillation, pasteurisation and crop drying. For these four uses, only heat will be extracted, leaving the quality of water and the volume untouched.

Generation of electricity: A Kalinka type of binary system would be the best alternative for the generation of electricity. Although the local residents already have access to ESCOM power any addition power could be fed into the existing grid. It should also be kept in mind that the geothermal water could be used for cooling purposes using heat exchange. Geo-refrigeration could be used for product and food storage as well as for use by the Siloam hospital.

Another first tier activity is *pasteurisation.* It is estimated that there are around 400 000 goats In Limpopo with around 5% in the Vhembe district (Archaeopong-Boateng & Menne *et al.* n.a.) Goat's milk cheese is particularly sought-after and is sold for high prices in supermarket chains. Large quantities of goat's milk cheese could be manufactured at Siloam using geothermal heat for pasteurisation (for home pasteurization, a temperature of 63°C is required for 30 minutes). Other products that are commonly pasteurized are canned food, juices, alcoholic beverages, syrups, vinegar and wines.

Distillation: As far as is known, geothermal heat for distilling alcohol is only being used in Iceland to produce an unique vodka. The production of distilled liquor at Siloam would only be feasible provided that the thermal water temperature exceeds 78.37°C (b.p. ethyl alcohol). Since grapes, potatoes and barley are not produced on a large scale in Venda, the production of alcoholic beverages such as Vodka and whiskey will not be feasible. However, the potential for development of beverages from indigenous fruits from the Venda region was investigated by Rampedi (2010). He identified four indigenous fruits that could be used to produce liqueurs, namely, the African mangosteen (*Garcinia livingstonei*), Kei apple (*Doyvalis caffra*), sand paper raisin (*Grewia flavescens*) and stem fruit (*Englerophytum magalismontanum*). During the course of his study, liqueurs from these fruits were prepared (on a small scale) and a market survey conducted in Gauteng. All four were extremely popular and were deemed to have market potential (Rampedi, 2010). Siloam would be an ideal location/site to produce these unique African beverages. In addition, liqueurs could be distilled from fruit produced in the area (Rampedi & Olivier, 2012). They can be further flavoured by using locally produced nuts, spices, cream, herbs and other fruits (Chapman, 2006). Currently the only liqueurs made from indigenous South African plants are from Amarula and Illala Palm.

Crop drying: The area around Siloam is exceptionally rich in tropical and subtropical fruit. The geothermal resources could be used to dry, e.g. bananas, mangoes, tomatoes, mushrooms, seeds and flowers.

After the multitude of first first-order tiers, the water should still be warm but not scaldingly hot. This makes it ideal for the *second tier of uses* for *spirulina* production (utilising water and heat) and for heating greenhouses for both exotic tropical crops (e.g. orchids and spices such vanilla and Ylang Ylang) as well as mushrooms and organically grown vegetables. These produce could be used locally or transported to major outlets (markets) such as Polokwane and Gauteng or exclusive guesthouses and game lodges.

This water is not fit for irrigation and the low mineral content of water does not make it viable for aqua-mining. Thus, part of the water originating from the second tier of uses can be injected back into re-injection wells while some could be used for domestic purposes (other than drinking). Since the Langelier index $\approx$ 0.12 12 (Lenntech, 2013 Addendum D), it should not cause corrosion or scaling and excess could be piped to Mphephu. This comprises the *third tier of uses.*

In theory, the current thermal spring will not be affected by the drilling and the community – if they so wish – can continue to use it. The wetland is not solely dependent on the thermal spring and should not be affected in any way.

Proposed development at Mphephu

The combination of water resources at Mphephu together with the extra water piped from Siloam, could trigger a host of new types of development at the Mphephu resort. It is proposed that the development at Mphephu should be based on a modified the model used at the Prawn Park, New Zealand. In the Venda region of Limpopo, inhabitants are not familiar with prawns but fresh fish such as tilapia are very popular and in short supply but there is a large market for fresh-water prawns at the KNP, lodges and nearby cities. The creation of an 'aquaculture park' at Mphephu could boost regional, national and international tourism without impacting on the current use since the Park would still cater for day-visitors.

Based on Prawn Park in New Zealand, several prawn and fish ponds could be constructed interspersed with lawns and other recreational facilities. Visitors (tourists) could purchase fishing licenses to catch or net the fish – to be prepared at the restaurant or to be braaied over the coals. These braai facilities already exist at Mphephu. The restaurant could specialise in the preparation of fish (and prawn) dishes using fresh and dried vegetables, herbs and spices from Siloam. The kitchen and food preparation will have to be improved to cater for the new market. This would address one of the major factors impeding tourism development at the resort (Tuwani 2012, Deliverable 8).

It is proposed that water from *Siloam* be used to supplement Mphephu spring water. At **the *first tier*** of the cascade, ***Siloam thermal spring waters*** could be used for filling the warm swimming pools and for heating the aquaculture (fish) ponds. In addition, warm water from Siloam could be used for domestic purposes for bathing and in the kitchens (e.g. for washing up) and be channelled for space heating of buildings during winter. The SAR values of water from Siloam could be returned not be suitable for irrigation and those from the pools will be contaminated with chlorine. This water could be used for sanitation and discharged into the Nzhelele River to boost flow (Fig. 5.9).

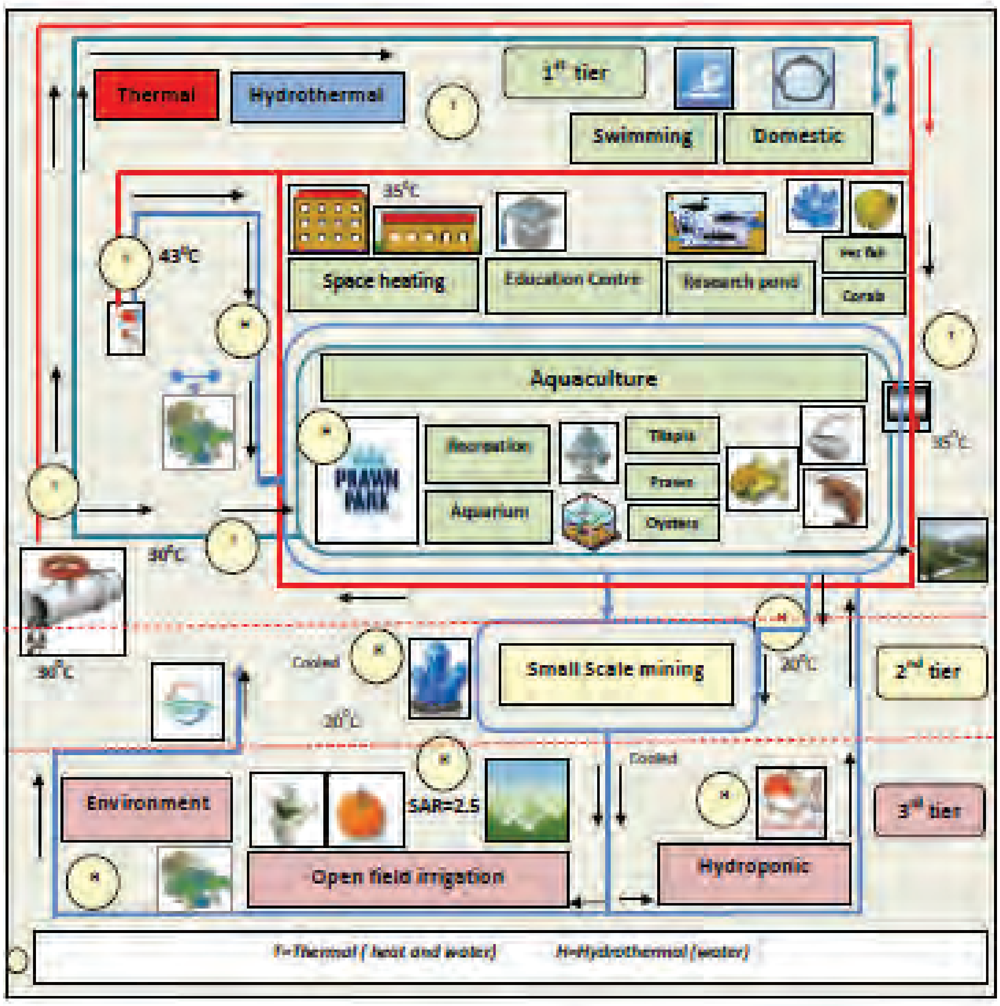


Fig. 5.9 Cascade of uses at Mphephu

The ***water from the Mphephu* spring** could to be used as at present, i.e. for filling the small thermal swimming pool. In addition, the water as well as heat could be harness for tilapia production. All water from this first tier uses, could be used for the extraction of minerals. Assuming that all the B, Ti and Sr could be extracted from these waters, Mphephu could earn almost R70 000 per month from this ***second tier of activities***. After this, this water as well as that originating from the fish ponds, could be used for the ***third tier*** of uses – comprising irrigation.

The waters from Mphephu have a SAR value of 2.5 and – although not recommended for irrigation – should not damage the soil in the short-term. Open field agricultural production could be used for growing, e.g. pumpkins and herbs for the restaurant.

BOX 5.2

Pumpkin flowers are a delicacy in Venda cooking. There is a huge market for pumpkin flowers in Gauteng where it is not currently available. Pumpkin seeds can be harvested from mature plants and dried at Siloam. Pumpkin seeds have many benefits, *inter alia,* contain minerals including phosphorus, magnesium, manganese, iron and copper and are a good source of vitamin K, B and E as well as Zn, serotonin, niacin and tryptophan. These substances are thought to reduce levels of LDL cholesterol, depression, sleeplessness, osteoporosis, arthritis, and an enlarged prostate gland. In third world countries they are used as a natural treatment for tapeworms and other parasites..

An unexplored market with considerable potential is the use of herbs for flower arrangements and fresh and dried bouquets (Fig 5.10). All produce could also be sold at the tourist shop at Mphephu.

Fig. 5.10 Herbal, mushroom or pumpkin baskets and wreaths

The above activities should not affect the natural wetland at Mphephu (since it is related to the thermal spring but arises from a breach in the bank of the Nzhelele River) nor will it affect the community's use of the thermal spring eye at Dopeni.

The proposed developments and existing facilities at Mphephu would make it eminently suitable for the development of a resourced based educational centre. Barring the poor quality of the cuisine, Tuwani (2012) identified lack of skills of the management and staff as the second major limiting development at Mphephu (Tuwani, 2012; Deliverable 8). Not only could it cater for the in-house training of workers at Mphephu but also for those working at Siloam. In fact, Mphephu would be an ideal setting for an indigenous/African culinary training centre. This school could twin with existing culinary schools to produce truly rounded chef with knowledge of Western, Asian and African cuisine.

In addition, Mphephu could be developed as the first resource-based educational centre in South Africa. In Iceland and Kenya, geothermal resources (hot springs) are utilised to teach science – but only at tertiary level. A geothermal education centre in rural parts of South Africa could be used to provide hands-on classes and workshops for learners and teachers at primary and secondary school levels. Programmes would not only cover a wide range of subjects currently forming part of the curriculum (e.g. Biology, Geography, Physical Science, Chemistry) but could introduce others such as Microbiology, Hydrology, Geology, Biodiversity and ecosystem studies and many more. In addition, literature, poetry, history, cultural studies, anthropology and many more could be integrated by using this natural resource as focus. Indigenous knowledge – employing knowledge from the local community – would form an integral part of such an educational centre whereby knowledge of the uses (also medicinal), myths and legends of the past would be conserved. At tertiary level, specialised courses could be offered on thermal-spring based horticulture and aquaculture, geothermal energy production and exploitation, thermophilic ecosysystems, industrial development (notably for the pharmaceutical and neutraceutical industry). In addition, research on the production of unusual aquatic species such as oysters and even corals (Fig 5.11) would make Mphephu a truly unique aquacultural park. The industrial park at Siloam could be used for practical work for the students at Mphephu.

BOX 5.3
See Geothermal Aquaculture Research Foundation Inc. http://www.garf.org

Fig.5.11 Corals

A closing note

The two case studies above are based solely on the suitability of the springs for uses in terms of their physical and chemical properties. The three thermal springs used to illustrate a cascade of uses reflect the versatility of South African thermal springs. They do not have the widest variety of potential uses (as shown on Table 5.1). Indeed, they are only middling in comparison with others. A similar number of potential uses are available to developers at Tshipise, Eiland, Minvamadi, Rhemardo, Soutini, Die Oog, Vischgat, Loubad, Lekkerrus, Libertas, Tshalungwa, Malahlapanga, Mafayini, Matiyavila, Citrusdal, Caledon, Towerwater, Goudini, Montagu, Cradock, Fish Eagle sap, Aliwal, Badsfontein, Florisbad, Baden Baden, Riemvasmaak, all those in KZN as well as Badplaas, Falcon Glen and Amanzimtaba. Only eleven of the thermal springs have lower total scores but this is mostly dueto dearth of information on the mineral composition of their waters. Even these still have at least seven alternative uses. Brandvlei and Calitzdorp appear to be the most versatile.

It is thus clear that South African thermal springs – although being of only low enthalpy – have considerable development potential, which can be optimised by cascading the watesr through multiple tiers of uses.

The success of the actual developments depends on a host of economic, social, legal and regulatory factors. If the considerable potential of geothermal resources in South Africa is to be realized, governments and industry should play an active role in creating an environment where private and outside investments can be justified and reasonable rate of returns are realized.

CHAPTER 6: CONCLUSION

Olivier J & Jonker CZ

6.1 SUMMARY

The aim of the project was to identify the optimal uses of thermal springs in South Africa. The objectives were three-fold, including the determination of the geological, biological, physical and chemical characteristics of the thermal springs in South Africa; their fitness for current use; and their suitability for alternative uses.

Field trips were undertaken to most of the thermal spring that were mapped by Kent in 1950. Whereas a number of these had dried up during the intervening 60 years a few (previously unrecorded) thermal springs were found during the course of this project – including seven in the Kruger National Park. A map showing the location of all documented thermal springs was compiled and is presented as Figure. 3.1. Physical parameters such as temperature, pH and EC were measured at source and water samples collected for analysis for major and trace elements. These data, together with that sourced from literature were used to compile a comprehensive database of the physical and chemical properties. The final dataset that was drawn up after elimination of outliers (Addendum B) was used as a basis for further analyses.

Seven thermal springs, namely Siloam, Tshipise, Warmbad, Badplaas, Shu Shu, Brandvlei and Calitzdorp can be classified as scaldingly hot, i.e. with temperatures exceeding 50°C while the rest have temperatures of more than 25°C. The majority of the springs have pH values that fall in the neutral to slightly alkaline range. Those in the Western Cape are slightly acid (pH ≈ 6) and only four in Limpopo and KZN have pH values exceeding 9. Flow rates vary from 126 l/s at Brandvlei to 0.15 l/s at Siloam. As expected, the chemistry of the thermal springs was found to reflect the geology at depth.

Since most previous work on South African thermal springs focused on those in the Cape Fold belt, more attention was given to the Limpopo thermal springs in this project. Geophysical and isotope studies were conducted at most Limpopo springs and selected hot springs in the Eastern Cape. These confirmed the previously assumed origin of the waters as being meteoric. Results of magnetic, electrical and electromagnetic surveys indicated that all Limpopo thermal springs are associated with faults and impenetrable dykes or sills and showed high terrain conductivity values. The latter can be attributed to high moisture content and deposits of dissolved salts from the hot water. The most important hydrogeochemical process controlling the chemical composition of thermal groundwater was found to be water-rock interaction and to a lesser extent, crystallization. The geochemical processes affecting the carbon isotopes are natural decay and isotope exchange between soil CO_2 and aquifer matrix – thus placing the age of the waters in the Holocene.

This project provided the first opportunity to investigate the biological diversity of South African thermal springs. Previous studies had identified diatoms present in a few thermal springs, but this was the first to focus on thermophilic bacteria and algae. The method of 454 genome sequencing was used to determine the diversity of bacteria of six Limpopo thermal springs. The majority were known genera often found under mesophilic conditions but few rare genera were identified that had hitherto only been found in isolated environments overseas. This suggests that novel species may be present in South African thermal springs. If this is the case, they might contain enzymes that could be used in industry. This research is thus a first step in identifying bacteria with industrial potential. Another interesting finding was that thermophilic algae could possibly be used an indicator species for specific minerals and the underlying geology.

Many South African thermal springs have a rich cultural heritage, with some being of significant archaeological and anthropological importance. The development of thermal springs into resorts was based on purported therapeutic properties. This emphasis on health effects has been diluted over time and the vast majority of resorts now cater for family recreation and leisure tourism. Most of these have hot to scalding temperatures and a moderate to high flow rate. Undeveloped thermal resources are mostly confined to those that were located in previous homeland areas.

The dataset presented as Addendum B was used to identify a spring's suitability for current use and for alternative uses based on developments in other parts of the world. The physical and chemical properties of spring waters were compared to recognised standards or guidelines for a particular use. A simple rating scale was devised to measure the degree of conformity.

Using this scale it was found that the water quality of thermal springs in the Western Cape conform to DWAF (1996) Domestic Water Use standards whereas the majority of the springs in the rest of the country have unacceptably high levels of the halogens, especially fluorine. If thermal spring water is not consumed, the amount fluorine ingested during swimming should thus not pose a severe health risk – at most causing some skin and eye irritation. At a few resorts the water contains more dangerous minerals such as arsenic and mercury. Although these toxins might originate from equipment or piping, the resort management should take cognisance of the risk and take remedial action. Gases such as H_2S and CH_4 may also lead to discomfort and adequate ventilation should be ensured in enclosed areas such as spas.

The high halogen concentration in thermal spring waters may also pose a hazard to domestic animals and wildlife if consumed over a long period of time. High fluorine and bromine levels are of particular concern. Some of the thermal springs in the Kruger National Park and those at Evangelina and Riemvasmaak have high concentrations of fluorine, bromine, sodium and mercury. This is a potential problem not recognised by most game and livestock farmers.

Countries around the world have recognised alternative uses for waters and heat generated from thermal springs. Currently, the South African thermal springs are under-utilized. This project has explored the suitability of South African thermal springs for a variety of alternative uses as applied elsewhere in the world. Alternative uses included geothermal power generation, the bottling of thermal waters, use for agricultural such as greenhouse heating, the production of fish and *spirulina* and the extraction of minerals. It has also sought to assess the suitability of thermal springs for more unusual uses such as for cosmetic purposes and to identify springs that could possibly associated with Kieselguhr deposits.

The suitability assessments in Chapter 4, reveals that the thermal springs are versatile and can be used for a number of different purposes. At some springs there at least 10 different alternative or supplementary uses could be implemented. The most viable for the low enthalpy springs in South Africa include agriculture, aquaculture and water mining. The former make use of the thermal properties of the springs whereas the latter extracts minerals from the water. Some springs are suitable for niche markets, such as bottled spring water, balneology and for the cosmetic industry, while a few can be used to generate electricity. In the majority of the cases it is the thermal energy that is useful rather than the water itself.

Although most thermal spring waters fall within the limits for domestic water standards, they do not conform to the South African National Bottled Water Standards. Nor are thermal spring waters suitable for the production of aquatic crops such as tilapia fish or *spirulina*. Nevertheless, utilizing the heat from the geothermal resource could ensure crop production throughout the year. This makes the hottest springs suitable for a greater variety of agricultural and aquaculture activities.

This also applies to the generation of geothermal electricity – again on a small scale during winter when the differential between thermal spring water and ambient temperatures reach a maximum. Only two thermal springs, namely Brandvlei and Tshipise, could be suitable for power generation at present. While the flow rate at Siloam is too low for this use, drilling could be a viable option.

However, the very presence of minerals in the water that prohibits its use for drinking and bathing purposes enhances its suitability for mineral extraction. Modern technological advances in the field of water purification enable specific minerals to be extracted without contaminating the water source. Although the concentrations of minerals in South African spring waters are low in comparison to the very hot geothermal resources in countries with volcanic springs, small scale mineral extraction appears to be feasible, provided that industry is prepared to invest in rural development. The most viable minerals for extraction are boron, titanium and strontium.

Numerous international studies have shown that the hot water can be channelled through multi-tiered cascade of uses with benefits accruing at each stage. Two case studies illustrating such a diversification of thermal spring use were presented in chapter 5. In both cases, the suggested developments used existing infrastructure and/or potential. It should be kept in mind that these reflect but one of many permutations and combinations of alternative uses, above and beyond those currently employed at the resource.

6.2 SIGNIFICANCE OF THE RESEARCH w.r t. the WATER RESEARCH COMMISSION

The significance of the research and outcomes can be measured in terms of the degree of compliance to WRC requirements and is based on the Knowledge tree (Fig 6.1)

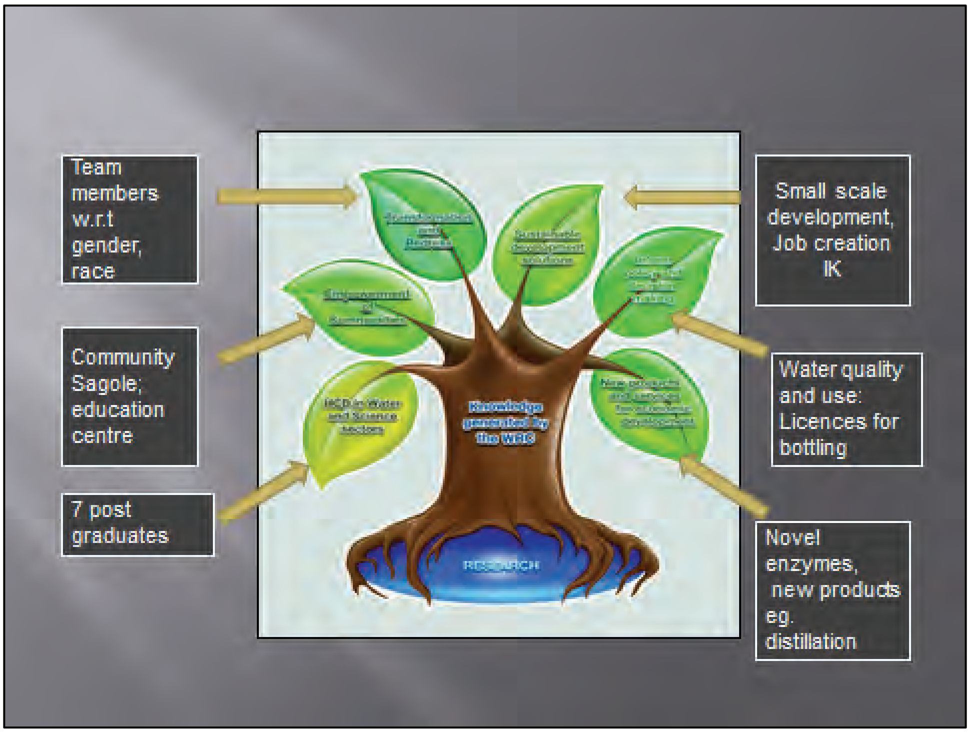


Fig. 6.1 The WRC knowledge tree

Knowledge generated can be measured by the outputs such as the deliverables completed, the articles published and the papers presented at conferences.

The project plan included 28 deliverables of which this report comprises no. 29. These are listed in Addendum E. All barring the annual reports can be found on the CD (inserted). A total of 18 papers were presented at national and international conferences and with 10 of these published in their Proceedings. A further nine articles and one technical report was published with another three in the review stage. These are presented in Addendum F. Other outputs include two databases; one containing information on the physical and chemical properties of South African thermal springs and the other showing the full bacterial composition as obtained from 454 genome sequencing. The map included in chapter 3 shows the location of thermal springs.

6.2.1 Human capital development in the Water and Science sectors

Seven post-graduate students were directly involved in this project of whom one has completed his BSc hons, three their Masters degrees and one completed his doctorate. Two doctorates are pending, one of which should be complete by the end of 2013. The other candidate is just starting her studies. Table 6.1 provides information on the degrees, topics, gender and race of the students.

TABLE 6.1: LIST OF STUDENTS INVOLVED IN PROJECT K5/1959/1			
NAME	**RACE/ GENDER**	**DEGREE**	**TITLE**
Tshibalo, Azwindini Ernest	M/B	PhD completed	Strategy for the sustainable development of thermal springs: a case study for Sagole in Limpopo Province
Tuwani, Patrick	M/B	MA completed	Success factors for the development of natural resource-based resorts: a comparative analysis of Mphephu, Sagole and Tshipise thermal springs, Limpopo, South Africa.
Sheppard, Linda	F/W	MSc completed	Environmental risk assessment of geothermal springs: a case study of "Eiland" in the Limpopo Province
Nyabeze, Peter	M/B	PhD pending	Characterisation of thermal aquifers in the Limpopo Province of South Africa: Evidence from geophysical and geological investigations.
Motlakeng, Tshepo	M/B	BSc hons completed	To characterise hot springs using environmental, geophysical, geology and geochemical methods with special reference to the Brandvlei spring in Western Cape.
Grove, Francois	M/W	MSc completed	The beneficiation of carbonate rich coal seam water through the cultivation of *Arthrospira maxima (Spirulina)*
Jonker Nelia	F/WF	PhD commenced	Balneological classification of thermal springs in South Africa
B = black; W = white; M = male; F = female			

6.2.2 Empowerment of communities

The whole project is geared to empowering communities – either those living near thermal springs in remote rural areas or at resorts, where the resource is used for but a single purpose. Most of the South African thermal geothermal spring resources are located in rural areas, which may suffer from economic depression and high unemployment. Geothermal developments are labour intensive and provide a stable source of employment for a wide variety of skills, often in regions with high unemployment rates. Additional economic advantages such as tax payments to local economies may benefit minority communities (The Geothermal Energy Association (GEA), 2012). The use of the geothermal resources could thus generate development while on the other hand while additional funding could be generated at established resorts. Dr Tshibalo, who obtained his doctorate in the course of this project, is in close contact with the communities, traditional and local leaders at Sagole and Mphephu to inform them of his research and to obtain their input on future development of the spring. Unfortunately due to infighting between these role players, little progress has been made to implement any of the findings to date.

One of the strengths of this project was the interdisciplinary nature of the research. Although basic research was included (geological and microbiological components), most emphasis was placed on applying the results to optimise water resource use. If thermal spring developments could be implemented, the outcome could contribute – albeit in a small way – to problem of rural unemployment. Thermal springs could also be used to promote education and training. Benefits of establishing a resource-based educational centre in a rural area would be advantageous at all levels of education – from primary school through secondary and eventually tertiary levels. Skills development would form an integral part of the functions of the centre as would the incorporation of traditional knowledge into learning material.

6.2.3 Transformation and redress

Of the students mentioned above, Nelia Jonker, Peter Nyabeze, Tshepo Motlakeng and Dr Ernest Tshibalo were also team members. The latter three are black males. The rest of the research team (not necessarily for the entire duration for the project) included Jaco Venter (W/M), Matome Sekiba (B/M); Dr Bisrat Yibas (B/M); Dr Isaac Rampedi (B/M); Prof Memory Tekere (B/F); Esther Joubert (Indian/F); Elna van Niekerk (W/F); Nelia Jonker (W/F) and Prof Jana Olivier (self) (W/F). This constitutes a mix of seven black, one Indian and four white team members, of whom seven were males and five, females.

6.2.4 Inform policy and decision making

- It is vital that geothermal spring resources be recognized and included in the government's renewable energy portfolio as well as climate change laws and regulations.
- In view of their environment benefits and potential for job creation and rural development, it is recommended that tax incentives should be offered to drive geothermal developments.
- Incentives in the form of funding should be allocated to geothermal-centered research and technology.
- A water analysis (for all minerals mentioned in the DWAF Guidelines for Domestic Use) should be a prerequisite for granting of a water user's license for recreational use or for bottling.

6.2.5 New products and services for economic development

This project was innovative in many respects. Amongst others, the project was the first to investigate the microbiological diversity of thermal springs. Although no novel organisms were identified, the results indicated a high probability of such organisms existing in our springs. If present, novel enzymes would probably have application in industry.

The project included detailed geophysical and isotope studies with the focus on thermal springs in Limpopo Province. The emphasis on these springs was due to the following: There are more springs in this Province than in any other; previous studies focused on thermal springs in the Cape Fold Belt – and not in the highly faulted Limpopo mobile and greenstone belts; as well as practical concerns such as proximity and accessibility.

6.2.6 Sustainable Development Solutions & Empowerment of communities

The main focus of the project was on sustainable development solutions and empowerment of communities. It aimed at identifying alternative uses of thermal spring resources so as to promote development and create jobs. Since most of the thermal springs are located in rural areas, the outcome of the project would have a positive impact rural development while the use of geothermal resources for agriculture and aquaculture, would necessarily bring about food security. Not only would such developments benefit the surrounding communities, but the use of heat to manufacture products such as cheese and beverages from local produce would be advantageous to the region in general.

Water mining of minerals and salt could also be extremely lucrative with the added advantage of being environmentally friendly. This would be in sharp contrast to current mining activities that are one of the most destructive to the environment. The use of geothermal energy helps to offset the overall release of carbon dioxide into the atmosphere, as well as its effects. Green mining and geothermal energy generation – albeit on a small-scale – could be used to source funding from carbon offset. The success of such a venture would also require the involvement of both industry and government. Most ventures should not be exorbitantly expensive and could be of direct benefit to a participating company – especially in view of mounting consumer awareness of environmental and social issues. Nevertheless, a thorough SWOT and cost benefit analysis would be required to before investing in any development.

It is thus important to note is that the envisaged outcomes of this project will be used for **small-scale development,** taking social, environmental and economic factors into consideration. Care should be taken to preserve the quality of the resource and to maintain the integrity of wetlands. The importance of the preservation of springs with cultural or customary significance should not be overlooked. With this aim in mind a project proposal entitled: *Indigenous knowledge on the discovery, custodianship, history, legend, belief, customs and uses of thermal springs in South Africa: Using the past as a basis for sustainable future development* was submitted to the National Heritage Council through the Kara Institute.

Despite the number of 'successes' as indicated above, the research had short-comings. These included:

- Microbial analyses were conducted on only a limited number of springs. The high cost of the microbiological analyses was not envisaged at the outset of the research. It was also not anticipated that the 454-genome sequencer would only identify bacteria to the genus, and not species, level.

- Quality of water chemistry data: There were considerable differences in the results of chemical analyses conducted at the CGS and the ARC laboratories. These differed for some elements by a factor of ten and at other times, by a factor of 100. Moreover, no analyses were done for halogens other than fluorine. The distances involved in reaching in remote thermal spring such as Riemvasmaak, prohibited further research trips to obtaining new water samples. Information as obtained from literature – where available – was used to verify data. Unfortunately relatively little could be found for the majority of trace elements.

- Data on water flow rates: Since many spring have been capped, it was not possible to determine flow rates. Data as given in literature were included in the data set.

It is thus recommended that:

- More research – especially on thermal spring ecosystems – is required. This project has just touched upon the microbial diversity of the surface of algae. The potential importance of thermophilic bacteria has been mentioned. Research on algae is also vital since these organisms are increasingly being used for food, fodder, biomass production, extraction of bio-oils, and in the pharmaceutical and cosmo-ceutical industries.

- More research should be conducted on the composition of gases in and radioactivity of thermal waters. These may hold advantages (e.g. methane is a source of energy while carbon dioxide could be used to enhance growth of plants in greenhouses).

- All analyses should be conducted at accredited laboratories.

- The results of the research should be disseminated to owners/managers of resorts and authorities.

- Research should be conducted prior to any development so as to ensure that it will not impact on current and future land use. This is particularly important if drilling for hot water is to be undertaken since this could affect the local and regional water table.

- Care must be taken to maintain the integrity of wetlands and to ensure that current users are not disadvantaged by the development.

- Additional studies should be conducted on the indigenous knowledge pertaining to thermal springs.

- The database must be kept up to date with new data.

- `South Africa needs to become part of the global trend in use of geothermal resources

6.3 THE SIGNIFICANCE OF THE PROJECT w.r.t THE NATIONAL DEVELOPMENT PLAN (NDP) FOR 2030

This project and its possible outcomes address the goals of the NDP which aims to eliminate poverty and reduce inequality by 2030. Meeting these objectives of the Plan requires the nine elements for a decent standard of living as shown in Figure 6.2.

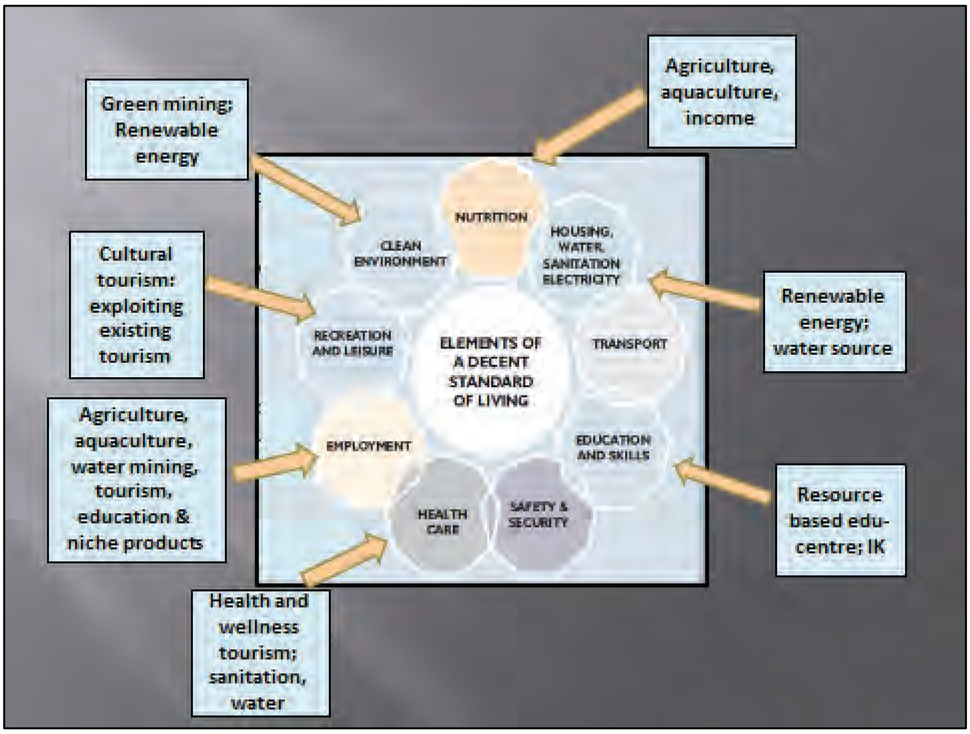


Fig. 6.2 Elements of the NDP for 2030

The most important aspects of the NDP are to promote economic growth and to decrease unemployment. Raising employment levels will have benefits beyond the empowering experience of having a job. It will help people invest in their children's education, upgrade their homes and manage life's risks. This project impinges directly on seven of the nine elements.

The Commission believes that the country can create 11 million jobs by 2030. To do this, South Africa has to exploit its strengths and comparative advantages which include its mineral and natural resource endowments. Geothermal resources represent a hitherto untapped natural resource that could address a number of the elements of the NDP since they are a source of both energy and water.

According the NDP, "South Africa's rural communities should have greater opportunities to participate fully in the economic, social and political life of the country, supported by good-quality education, health care, transport and other basic services. Successful land reform, job creation and rising agricultural production will contribute to the development of an inclusive rural economy. South Africa's hinterland is marked by high levels of poverty and joblessness. To change this, the NDP proposes a multi-faceted approach through creating more jobs through agriculture development based on the growth of irrigated agriculture".

Since most of the thermal spring resources are located in rural areas, any development should theoretically contribute to the economy and create jobs. One of the goals of the NDP is to create an additional 643 000 direct jobs and 326 000 indirect jobs in the agriculture and agro-processing industry. Developing industries such as agro-processing, tourism and small enterprises where potential exists. As indicated in Chapters 4 and 5 of the report, thermal spring waters – especially the energy component – can be used for agricultural purposes such as greenhouse heating and crop drying. The former would enable crop production throughout the year. This would result in sustained supply to markets and ensure premium prices during off-seasons. The use of such heated greenhouses could stimulate the production of exotics that could boost small-scale export to neighbouring African countries. Geothermal energy resources could also be used for agro-processing of locally produced produce. This would not only bring about sustained food security and enhance the resilience of people and the economy to climate change, but could boost the local and regional economy by, for example, the creation of home-based cottage industries for niche products such as local cheeses, beverages, vegetables and herbs. Similar benefits could also accrue from aquaculture. The production of fish in inland rural areas would provide a rich source of protein to people and impact directly on the health status of communities. Fish wastes make an excellent organic fertiliser for local use and for sale elsewhere, while all agricultural and agro-processing waste could be used for the generation of fuel in the form of biogas. *Spirulina*/algae production, using geothermal energy resources alone, could be developed into small enterprises supplying the local pharmaceutical industry. *Spirulina* is also a rich source of nutrition for humans and animals. All algal waste can be fashioned into building materials with high insulation properties – contributing to the energy efficiency and comfortable homes. Beneficiation could occur on-site or raw products could be supplied to other outlets. Thermal spring waters could also be used for small-scale irrigation projects without harming the environment.

The NDP highlights the negative environmental impact of the most important SA economic sector, namely, mining. Changes are needed to protect the natural environment while allowing the country to benefit from its mineral deposits. Geothermal water mining might be viable at many of the country's thermal springs. This has a low to negligible environmental impact since it does not impinge on the landscape and does require underground or open-cast mining operations. Furthermore, no additional energy is required since natural earth energy produces a constant and continuous flow of mineral-rich waters. Although the number of jobs created in such small-scale mining operations would be much less than in the conventional mining industry, some revenue could be generated for communities – provided that local markets would support this small niche industry.

Another one of the goals of the NDP is to provide access to the electricity grid to 90% of the people by 2030, with non-grid options available to the rest. The latter include only the use of natural gas; solar, hydro and wind energy; and biogas as alternative sources of energy. Geothermal energy resources are not mentioned. Geothermal energy production is used extensively internationally and modern technology has eliminated the need for high temperature resources. It has been found to have the least environmental impact, since no combustion is required. It eliminates the production of Greenhouse gases and does not impact negatively on existing water sources. Since only the heat energy is used for energy production, the water quality is not affected. All water can be returned to the aquifers via re-injection wells. Such developments would necessarily qualify for the proposed incentives for the use of greener technologies.

A large part of the NDP focuses on the need for education. The creation of resource-based educational centres using geothermal resources as focus – discussed in Chapters 4 and 5 – would impact on all levels of education, from primary through to tertiary level as well as for skills acquisition in agriculture, aquaculture, geothermal energy production and tourism. If implemented, such centres could lead to the development of specialised programmes in universities so as to expand science, technology and innovation outputs.

Furthermore, South Africa is rich in cultural legacy and creativity of its people means that “South Africa can offer unique stories, voices and products to the world” (NDP 2013). This, together with our natural eco-resources, forms one of the cornerstones of the tourism industry. Many thermal springs are located on existing tourism routes, but have not been exploited optimally for this purpose. Thermal springs have a rich heritage of legends, beliefs and customs. Moreover, salt from thermal springs, is one of the most ancient industries in the country and formed the basis for extensive African. This knowledge should not be lost and should be incorporated into future tourism development plans. The role of an African Health and Wellness tourism at thermal spring resources, is self-evident.

It is thus clear from the above that the sustainable development of thermal spring resources could impact significantly on the health and wellbeing of communities. In addition to the production of food and fuel throughout the year, thermal springs could provide a renewable and clean source water that could be used to fulfil basic sanitation needs (see Chapter 5). In addition, job creation in rural areas. These can be generated from expansion of tourism projects, small-scale water mining, niche product developments, agricultural and aquaculture ventures as well as from the establishment of educational centres. A major advantage of developing thermal spring resources is that, after the energy has been extracted from the warm water in a cascade of uses, the same resource could be exploited for a multitude of uses without depleting or contaminating the resource.

A comprehensive management strategy for water resource development as suggested in the NDP for 2030. This will include a set of indicators for natural resources accompanied by annual report on the health of identified resources to inform policy. It is essential that thermal spring resources be included in this programme.

Not only will geothermal resource development provide work and education, but will enable citizens to improve their own lives. It is hoped that this project will encourage scientists, scholars and entrepreneurs to recognise the potential development options of the country’s geothermal resources and so help develop these to their full potential.

Why not one for South Africa?

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