AN INVESTIGATION INTO LEVELS OF CADMIUM IN THE UMTATA RIVER AND ASSOCIATED HEALTH IMPACT

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Water Research Commission

AN INVESTIGATION INTO LEVELS OF CADMIUM IN THE UMTATA RIVER AND ASSOCIATED HEALTH IMPACT

Report to the

Water Research Commission

by

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EXECUTIVE SUMMARY

1. Introduction of the project

The Umtata River provides water and a conduit for effluent disposal in a densely populated area of Eastern Cape. The catchment supports a rapidly growing population in which Umtata is the main town. Other towns in the study area are Mqanduli, Ngqeleni, Libode and Elliotdale. Other large informal settlements located in the catchments are Tabase, Tipini, Polla Park and Kanbi, all situated along the riverbanks. Population numbers and rate of change in the catchment are at present in a state of uncertainty (DWAF, 1998).

(i) Water quality situation in the Umtata River has always been giving cause for concern (DWAF, 1998). The results of a pollution study on Umtata River done between May 1999 and March 2002 (WRC, 2003) indicated high levels of cadmium in the river, which ranged from 0.01 mg/l to 0.08 mg/l for representative data.

The high levels of cadmium in the river has given rise to worries that water supplied from the river will be unfit for domestic use and may also impact on the "health" of the community that live on the river banks that depend on it primarily for their domestic water supply.

Recommendations were then made aimed at preventing or reducing cadmium pollution in the Umtata River one of which was an intervention programme to manage the pollution of the river and a workshop was conducted for all stakeholders in the catchment (DWAF staff, DEAT staff, staff of the local industries in the catchment, municipal staff, councilors and local communities) on actions to take to reduce pollution of the river. The workshop was well attended and the need to implement the recommendations in that report (WRC 2003) was impressed on them.

2 Aims

The major aim of the project was to re-investigate the levels of cadmium in the river catchment. A subsidiary aim of the project was to carry out a risk assessment study of the possible health effect of cadmium in the river on the community who are primary users of water from the river for their domestic supply.

3. Methods

Calibration standards were prepared for cadmium and zinc (zinc has a synergistic interaction with cadmium). Blank determinations were done for cadmium and zinc using double distilled water, which gave clean backgrounds. The detection limits for cadmium and zinc were determined using the lowest concentrations of each of the elements that gave the least detectable signal by the flame AAS (DWAF, 1992).

Six replicates each of the concentrations were prepared and analyzed and detection limit was determined from 3δ (δ = standard deviation) of the replicate determinations for each element (Miller and Miller, 1998).

Quality assurance studies were performed with distilled water samples fortified at levels of 0.005 mg/l for Cd and 10 mg/l for Zn using comparative open beaker digestion technique (DWAF, 1992) and extractive concentration method with amino pyrolidine dithiocarbamate (APDC) as complexing agent and methyl isobutyl ketone (MIBK) as the extracting solvent, respectively (van Loon, 1982). Determination was done by flame AAS. Samples for chemical analyses were collected according to standard procedures described in the sampling guide (DWAF, 1992, 1999) and analysed by the open beaker digestion method (DWAF, 1992) as it gave better recoveries and better repeatability than the extractive concentration method (van Loon, 1982). Temperature (determined on site) and pH (with un-acidified water samples) were determined using the Merck (Pty Ltd) 330 pH meter. Risk assessment study was done using the standard USEPA (USEPA, 1989) method to access the potential health risks to community making use of the river water as their primary domestic water source.

4. Objectives Reached

The following objectives have been reached:

- The levels of cadmium in the river were determined;
- The potential health risk of cadmium to communities that use the river for their primary domestic source was assessed.

5. Results

5.1 Detection limits of cadmium and zinc and their percentage recoveries

The detection limits for the heavy metals by flame AAS were 0.001 mg/l for Cd and 0.006 mg/l for Zn. The mean (SD) % recovery of Cd from spiked water samples was 90.67 (6.80) % and for Zn, 90.47 (0.29) % by open beaker digestion method (DWAF, 1992) and 83.33 (5.73) % for Cd and 88.17 (3.09) % for Zn by extractive concentration method (van Loon, 1982). Thus the open digestion method gave better recoveries and was therefore tested on environmental water samples for Cd and Zn.

5.2. Water quality situation in the Umtata River regarding cadmium

The mean (SD) values of Cd in the river water samples ranged from 0.002 (0.001) mg/l to 0.007 (0.002) mg/l. The levels of Zn varied between trace and 0.196 (0.10) mg/l. The levels of cadmium detected in the Umtata River in this study were much lower than the levels detected in previous study between May 1999 and April 2000 (WRC, 2003) and the levels generally fell within the SA guideline of 0.005 mg/l (WRC, 1998). The results for Zn levels in the river also fell within the SA guideline for Zn in water for domestic supply, which is 3 mg/l (WRC, 1998).

5.3 Hazard quotients of cadmium through use of Umtata River

The hazard quotients calculated from the data from present this study varied between 0.35 and 1.22 for adult exposure and between 0.2 and 0.8 for child exposure. The hazard quotients using representative data calculated from the previous study (WRC, 2003) ranged from 1.8 to 14. 0 for adult exposure and from 1.2 to 9.3 for child exposure (hazard quotients that exceed 1.0 indicate the possibility of non-cancer toxic risks from exposure).

6. Discussion

Cadmium concentrations in the Umtata River has substantially reduced compared to the results of the previous study and the levels now fell within the normal safe range expected in river water for domestic uses (WRC, 1998). At these levels of cadmium and zinc in the river the effect of the any synergistic interaction of zinc with cadmium would be negligible.

While for samples taken during May 1999 to March 2000 (WRC, 2003) the risk assessment study showed exceptionally high hazard quotients which indicate that if people were using the water for domestic purposes, adverse health effects would occur, the results of the new study with samples taken between October 2002 and December 2003, indicates that generally the hazard quotients are acceptable. The greater part of the anticipated adverse health effects arise as a result of ingestion of fish or shellfish (approximately 60% of the calculated dose is a result of assuming exposure via ingestion of fish/shell fish). However, if one were to assume that no fish or shellfish were consumed, the anticipated health risks would be significantly reduced. This effect would be most significant for the exposure calculations during the 2nd sampling run between October 2002 and December 2003.

7. Conclusions

The remedial actions taken following the 1999 to 2000 sampling appear to have been successful in reducing the cadmium levels in the Umtata River water and have therefore resulted in reducing the potential health effects.

8. Technology Transfer

O. R. Awofolu (2003). Methods for selective determination of persistent organochlorine pesticide (OCP) residues and toxic heavy metals (Hg, Cd) and Zn in water systems. Ph. D. Thesis, University of Fort Hare, Alice.

The following publications emanated from the project:

1. **O. S. Fatoki** and O. R. Awofolu (2003). Levels of Cd, Hg and Zn in some surface waters and sediments from Eastern Cape Province, South Africa. Water SA 29(4), 375 – 379.
2. **O. S. Fatoki**, O. R. Awofolu and B. Genthe (2004). Cadmium in the Umtata River and the Associated Health Impact on Rural Communities Who are Primary Users of Water from the River. Water SA (In press).

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Mrs. APM Moolman	Water Research Commission (Chair)
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1. INTRODUCTION

1.1 Background

The Umtata River provides water and a conduit for effluent disposal in a densely populated area of Eastern Cape. Water from Umtata River is used for various purposes such as domestic, agricultural, industrial, recreational and aquatic environmental (WRC, 2003) by a large population of Transkei, most of which is rural and it is one of the new designated catchment management areas, (in-stream ecosystem) (Hammer, 1975). One of its major uses is domestic purposes (WRC, 2003).

The results of the first study on cadmium in Umtata River (WRC, 2003) done between May 1999 and March 2002 indicated high levels of cadmium in the river, which ranged from 0.01 mg/l to 0.08 mg/l for representative data. Probable sources of cadmium in the catchment identified include:

(i) from waste discharge from a wood processing factory situated near the source of the river which use cadmium-based chemical for wood treatment (however the head of industry denied ever discharging waste directly into the river);
(ii) from urban runoff and from disused nickel-cadmium based batteries from the rural communities that had been disposed of in the waste disposal sites;
(iii) from runoff from agricultural soils in the catchment that used phosphate fertilizers cadmium is a common impurity in phosphate fertilizers;
(iv) from effluent discharge from Umtata Sewage Treatment Plant; and from natural source due to the geology of the catchment.

The high levels of cadmium in all reaches of the river has given rise to worries that water supplied from the river will be unfit for domestic use and may also impact on the health of the ecosystem. Of particular concern is the health of the communities along the banks of the river that depend on it primarily for their domestic water supply.

The following recommendations were made aimed at preventing pollution in the Umtata River:
(i) monitoring and removal of wastes close to the river banks;
(ii) management of agricultural practices in such a way as to control the use of pesticides and fertilizers;
(iii) a valid permit to be obtained by the Umtata Sewage Treatment Plant to comply with DWAF effluent regulations according to the National Water Act, 1998;
(iv) development and implementation of routine education programmes to the rural community on the need to prevent pollution of the river.

Also, as an intervention programme to manage the pollution of the river, a workshop was conducted for all stakeholders in the catchment (DWAF staff, DEAT staff, staff of the local industries in the catchment, municipal staff, councilors and local communities) on actions to take to reduce pollution of the river. The workshop was well attended and need
to implement the recommendations in the report was impressed on them.

This study was embarked upon to re-investigate the levels of cadmium in the river and its associated health effect on communities that depend on it primarily for their domestic source. The study would also help to assess the success of the intervention programme embarked upon at the end of the first study.

1.2 Uses and Users of Water in the Catchment

Water supplies in the catchment are mainly derived from the four dams, but the main supply to Umtata is met by the Umtata River. The major primary user of water from the Umtata River is the Umtata Municipality. The municipality supplies all other secondary users in the catchment with treated water abstracted from the river. There are other primary users, among the local people at informal settlements situated along the riverbanks - Tabase, Kanbi, Pollar Park and Mhlanhlane locations and at Norwood in central Umtata (WRC, 2003). They use raw water directly from Umtata River for domestic and recreational purposes.

The main uses of water from the river are for domestic (cooking, drinking and washing), agricultural (livestock watering, irrigation is rarely done in the catchment), and recreational purposes (swimming). Other uses such as aquaculture (fishery) and industrial (cooling of engines in the wood industry) are less significant (WRC, 2003).

1.3 Cadmium Pollution in River Water Systems

The accumulation of metals in an aquatic environment has direct consequences to man and the ecosystem. Cd is a common environmental pollutant, which is widely distributed, in the aquatic environment. Its sources are mainly from weathering of minerals and soils (Merian 1991); atmospheric deposition from non-ferrous metal mines, smelters and refineries; coal combustion, refuse incineration and iron and steel industries (Merian, 1991); industrial effluents (Asami, 1974; Prater, 1975); domestic effluents (Preuss and Kollman, 1974); urban storm water runoff (Startor, et al. 1974; Field and Lager, 1975) and spoil heaps (Heitfield and Schottler, 1973). The concentration of cadmium in unpolluted water is usually less than 0.001 mg/l. The South African guideline for cadmium is 0.005 mg/l (DWAF, 1996; WRC, 1998).

Because of the synergistic effect of Zn (an essentially non-toxic element but could enhance the effects of cadmium if the two are present together)) on cadmium, the cadmium levels will be investigated together with zinc. The pH of a water body determines the chemical species of many metals and thereby alters their availability and toxicity in aquatic environment (DWAF, 1996).

Metals like cadmium and zinc are most likely to have increased detrimental environmental effects as a result of lowered pH (DWAF, 1996). Temperatures at which a sample is collected and at which physico-chemical measurements are made are important for data correlation and interpretation purposes. For domestic use high temperature may increase the toxicity of heavy metals in waters (van Loon, 1982, Dojlido and Best, 1993). Thus pH and temperature need to be measured in addition.

1.4 Health Risk Assessment

Risk assessment and risk communication leads into the risk management process, which allows for good environmental health decision-making. The health risk assessment approach briefly involves the following:

Hazard identification, where potential contaminants of concern and their effects on human health are identified.

Dose-response assessment, which collects data on the relationship between the amount of
hazardous substance taken into the body and the onset of adverse health effects. Dose response data provides a quantitative basis for assessing health risks.

Exposure assessment, where the routes are established whereby contaminants may be released, the intensity, frequency and duration of human contact with a particular contaminant.

Risk characterisation, which provides an indication of the likelihood of adverse health effects from a given exposure to a contaminant of concern. Quantitative methods of risk characterisation derive numerical estimates of risk, while qualitative techniques are used to rank health risks where data are insufficient for quantitative calculations.

1.4.1 Health effects of cadmium on humans

Cadmium can affect human health either via acute or chronic exposure.

1.4.1.1 Acute exposure:

Acute exposure to cadmium can cause flu-like symptoms including chills, aching, headaches and fever. Exposure to high concentrations of cadmium may cause nausea, salivation, vomiting abdominal cramps and diarrhea (ATSDR, 1999). Exposure to higher concentrations can cause a build up of fluid in the lungs (ATSDR, 1999).

1.4.1.2 Chronic exposure

Effect of chronic cadmium exposure includes kidney damage (Friberg, et al., 1986a; Herber et al., 1988) and pains in bones (Itai-itai disease) (Tsuchiya, 1978; Kjellstroem, 1986).

Cadmium is also suspected to have mutagenic, carcinogenic and teratogenic effects (Fischer, 1987; Friberg, et al., 1986b, Kazantzis, 1987) and recently it is been classified as an endocrine disruptor. Studies have also shown that babies of animals exposed to cadmium during pregnancy experienced behavioural changes and learning disabilities (NJDHSS, 1999; ATSDR, 1999).

1.4.1.3 At what level does cadmium cause adverse health effects? (Dose-response assessment)

To assess a dose response to a chemical one must know the concentration where no adverse health effects are observed or expected. The dose at which it is thought that no adverse effect occurs is based on the assumption that a threshold exists for toxic effects. A dose is expressed as units of mg/kg/day (Hampshire Research Institute, 1995).

In general, the 'safe' Reference Dose (RfD) is an estimate of a daily exposure to a human population that is likely to be without deleterious effects over a lifetime. The population includes sensitive subgroups, with a possible order of magnitude uncertainty (Hampshire Research Institute, 1995).

A few numeric benchmark values are used to describe dose-response relationships in the literature. Commonly used benchmarks are:

- *Reference dose (RfD):* the pollutant level that can be ingested over a specified time period without toxic health effects occurring;

- *No-Observed-Adverse-Effect Level (NOAEL):* The highest exposure level at which there are no statistically or biologically significant increases in the frequency or severity of adverse effects between the exposed population and an appropriate control population;

- *Lowest-Observed-Adverse-Effect Level (LOAEL):* The lowest exposure level at which there are statistically or biologically significant increases in frequency or severity of adverse effects between the exposed population and its appropriate control group;

- *Minimal Risk Level (MRL):* An estimate of daily human exposure to a substance that is likely to be without an appreciable risk of adverse toxic effects over a specified duration of exposure. MRLs can be derived for acute, intermediate, and chronic duration exposures by the inhalation and oral routes.

According to the US-EPA, the Reference Dose (RfD) for cadmium in drinking water is 0.0005 mg/kg/day (IRIS, 2003). In other words, a 70 kg person can safely consume 0.035 mg (or 35 μg) cadmium per day without any adverse effects expected, whereas the estimated lethal oral dose for humans is 350–3500 mg of cadmium dose (WHO, 1996), i.e., 10 000 times the reference dose.

Even though cadmium is classified as a "probable carcinogen", there is no quantitative value for the carcinogenic potential of cadmium, as insufficient evidence is available to calculate the potency factor (IRIS, 2003).

1.4.1.4 How much cadmium are people potentially being exposed to via the water? (Exposure assessment)

Exposure assessment is a key phase in health risk assessment, because without exposure, even the most toxic or carcinogenic compound is not hazardous. Exposure assessment involves the identification of potential receptors, exposure pathways, exposure media and receptor behaviour, which affects exposure duration (USEPA, 1989).

For human health risk assessment, the receptors are generally members of the public who may be exposed to hazardous substances. In this instance it would focus on resident communities in the area making use of river water as a source for domestic purposes. When an exposure assessment is used as part of a quantitative risk assessment, a numerical estimate of exposure must be calculated. The value employed for this estimate varies, according to the route of exposure and is called the Average Daily Dose (ADD) or exposure concentration (Hampshire Research Institute, 1995).

In the evaluation of the chronic non-cancer health effects from oral or dermal exposures, the Average Daily Dose (ADD) received during the period of exposure is compared to the reference dose.

1.5 Aims of the Project

The major aim of the project was to re-investigate the levels of cadmium in the river in order to determine the levels of implementation of the recommendations that came out of the previous study. A subsidiary aim of the project is to carry out a risk assessment study of the possible effect of cadmium in the river on humans who are primary and secondary users of water from the river and on biota in the catchment.

2. METHODS

2.1 Calibration Curves and Blank Determinations for Metal Analysis in Water Samples

Cd: Normal concentration of Cd in freshwater is 0.005 mg/l (DWAF, 1996). However concentration as high as up to 0.1 mg/l could be found where there is contamination. Calibration standards in the range of 0 to 0.1 mg/l Cd were therefore prepared using 1000
mg/l Cd standard solution with $Cd(NO_3)_2.4H_2O$), supplied by BDH laboratory, England and diluted to the required concentrations with doubly distilled water. Blank determination was done using the doubled distilled water, which gave a clean background.

Zn: Normal concentration of Zn in freshwater sources is 3 mg/l (DWAF, 1996) but concentration up to 10 mg/l is not uncommon. Therefore calibration standards in the range 0 to 10 mg/l Zn was prepared from 1000 mg/l Zn stock standard solution using standard $ZnCl_2$ with doubled distilled water. This initial concentration was suitably diluted with the distilled water. Blank determination was also performed with the doubled distilled water, which gave a clean background.

2.2 Detection Limits and the Determination of Percentage Recoveries of the Elements from Spiked Water Samples for Quality Assurance.

The detection limits for each of the elements were determined using the lowest concentration of each of the elements that gave the least detectable signal by the flame AAS for Cd and Zn (DAWF, 1992). Six replicates each of these concentrations were prepared and analyzed. The detection limits were determined from 3δ (δ = standard deviation) of the replicate determinations for each element (Miller and Miller, 1998).

The quality assurance studies were performed with distilled water samples by spiking method at fortification levels of 0.005 mg/l for Cd and 10 mg/l for Zn. The open beaker digestion method (DWAF, 1992) was initially employed for Cd and Zn before employing comparatively extractive concentration method with amino pyrolidine dithiocarbamate (APDC) as complexing agent and methyl isobutyl ketone (MIBK) as the extracting solvent (van Loon, 1982) for the metals (Cd and Zn). Determination was by flame AAS. Recoveries were calculated from the ratio of the amount of the element (s) recovered after spiking to the amount added. Three replicate analyses were done for each element for water samples collected.

2.3 Sampling Sites

The sampling sites along the rivers and the dams are shown in Figure 1.

Figure 1: Map of the sampling sites

The sites were chosen due to their easy accessibility and they also reflect different activities in the catchments, which may affect the quality situation in the river. Samples were taken between October 2002 and March 2003.

Before sampling for chemical analysis, sample bottles were cleaned by soaking in detergent for 24h., followed by rinsing several times with tap water until free of detergent, rinsed with 5% nitric acid and then thoroughly with distilled-deionized water (DWAF, 1992; WRC, 1999).

Water samples were collected in clean plastic bottles from the river according to the standard procedures described in the sampling guide (DWAF, 1992; WRC, 1999). Samples for metal analyses were preserved with 5 ml conc. HNO_3. The samples after
collection were kept at about 4°C until analyzed.

2.4 Analyses of Water Samples for Metals (Cadmium and Zinc), pH and Temperature

Total metal contents (Cd and Zn) of water samples were analyzed by the open beaker digestion method (DWAF, 1992) as it gave better recoveries and better repeatability than the extractive concentration method (van Loon, 1982). Three replicate analyses were done for each element for each of water and sediment samples collected. Temperature (determined on site) and pH (with un-acidified water samples) were determined using the Merck (Pty Ltd) 330 pH meter while and electrical conductivity was determined by the Merck (Pty Ltd) LF 330 conductivity meter.

2.5 Health Risk Assessment

The health risk assessment methodology that used is the one recommended by the US Environmental Protection Agency (USEPA, 1989). This protocol was originally intended to accommodate carcinogen assessments. However, current trends favour the application of similar procedures to chemical toxicants. This methodology consists of four distinguishable but interactive phases referred to as hazard identification; exposure assessment; dose-response assessment and risk characterisation. The interrelation of these phases is depicted in the Figure 2.

In the evaluation of the chronic non-cancer health effects from oral or dermal exposures, the Average Daily Dose (ADD) received during the period of exposure is compared to the reference dose.

The cadmium concentrations that were used to calculate the exposure doses were those measured at 3 sampling sites along the Umtata River (Figure 1), namely S_1, S_2 and S_3 and presented in Table 2.

Figure 2: The Health Risk Assessment Process

The Health Risk Assessment programme Risk*Assistant™ (Hampshire Research Institute, 1995) was employed to calculate the potential exposure concentrations (doses).

As this is a preliminary screening health risk assessment the exposure assessment presented simply examines the potential health effects of a representative adult and a representative child living in the vicinity of the Umtata River using the river water as their sole source for domestic purposes. Exposures that were considered in the assessment include;

- ingestion via drinking, including accidental ingestion during recreational activity and bathing;
- dermal absorption due to washing/bathing activities;
- consumption of fish and shellfish caught in the river.

In a quantitative human health risk assessment, numerical estimates of human exposures are expressed in terms of:

- Average daily dose (ADD) for toxic effects. This is the amount of substance taken into the body on a daily basis during the exposure period and is calculated from the expression:

$$ADD = \frac{(C_{medium} \times IR \times ED \times F_c)}{BW \times AT} \quad \textit{(mg/kg/day)}$$

where C_{medium} is the concentration in the contaminated medium (e.g., water), IR is the daily intake rate, ED is the exposure duration, F_c the fraction contaminated, BW, the body weight and AT, the lifetime averaging time. A number of exposure parameters needed to be assigned for the exposure concentration calculation and are presented in the following two subsections.

2.5.1 Exposure parameters used to calculate exposure estimates

The dose (or exposure concentration) values presented in this assessment reflect not only the concentrations of contaminant in various environmental media and the exposure pathways selected for analysis, but also the specific numerical parameters applied to each exposure scenario. Different exposure pathways can lead to differing degrees of severity in health effects for the same chemical substance. Table 3 summarizes the exposure parameters used in this assessment.

2.5.2 Trans-media concentrations: Calculations

For some exposure scenarios a contaminant concentration specified in one environmental medium must be converted to a concentration in another medium, to which a person is exposed. For instance, crops grown in soil polluted with cadmium or irrigated with cadmium polluted water may contain increased concentrations, as may meat from animals grazing on contaminated pastures (WHO, 1996). Animal kidneys and livers concentrate cadmium.

The following equation was used in this assessment to predict such cross-media contaminant transfers (Thistle Publishing, 1995):

Consumption of recreationally caught fish & shellfish – Conversion of Water concentration to Edible Tissue concentration

C(f) = BCF*(Fat /3)*C(w); (2)log(BCF) = (0.79*log(Kow)) - 0.40

C(t)	Concentration in edible tissue - Calculated
C(w)	Concentration in water
Fat	= Fat Content of Edible Portion of Fish - 3.00%
BCF	= Bioconcentration Factor for Tissue Fat
Kow	= Octanol-water partition coefficient

2.5.3 What is the potential health risks associated with the domestic use of the river water? (Risk characterisation)

Risks were calculated for exposure to cadmium assuming that people were making use of the river water as their sole source for domestic purposes.
For toxic chemicals, a Hazard Quotient (H.Q.) is calculated, which compares the expected exposure to the agent to an exposure that is assumed not to be associated with toxic effects. For oral or dermal exposures, the Average Daily Dose (ADD) is compared to a Reference Dose (RfD):

H.Q. = Average Daily Dose / Reference Dose.

The hazard quotients calculated using exposure parameters to cadmium through use of Umtata River for a lifetime exposure, representing 26 different possible exposures as described in the text are shown in Table 5.

3. RESULTS

The results of the detection limits and the percentage recoveries of cadmium and zinc from fortified river water samples are shown in Table 1. The results of the metals levels in water samples from Umtata River are shown in Table 2. Results of the hazard quotients calculated using exposure parameters to cadmium through use of Umtata River for a lifetime exposure, representing 26 different possible exposures are shown in Table 5.

3.1 Detection Limits and Percentage Recoveries of Cadmium and Zinc

The detection limits for the heavy metals by flame AAS were 0.001 mg/l for Cd and 0.006 mg/l for Zn. The mean (SD) % recovery of Cd from spiked water samples was 90.67 (6.80) % and for Zn, 90.47 (0.29) % by open beaker digestion method (DWAF, 1992) and 83.33 (5.73) % for Cd and 88.17 (3.09) % for Zn by extractive concentration method (van Loon, 1982). Thus the open digestion method gave better recoveries and was therefore tested on environmental water samples for Cd and Zn.

Table 1: Detection limits (mg/l) and mean (SD) percentage recoveries for cadmium and zinc from water samples (n=3)

Element	Detection Limits (mg/l)	[a]% Recoveries ± SD	[b]% Recoveries ± SD
Cd	0.001	90.67 (6.80)	83.33 (5.73)
Zn	0.006	90.47 (0.29)	88.17 (3.09)

a – Open beaker digestion method (DWAF, 1992)
b – Extractive concentration method (van Loon, 1982)
SD – Standard deviation

3.2 Levels of Cadmium, Zinc, pH and Temperature in the River

The concentration of Cd in the river water samples ranged from trace to 0.007 mg/l in Umtata River. The levels of zinc also varied between trace and 0.0.019 mg/l (Table 2). The pH values varied between 5.9 and 7.2 while the temperature ranged from 19.4 °C to 24.6 °C.

Table 2: Mean (SD) % cadmium and zinc levels in the Umtata River (mg/l) for water samples taken between October 2002 and December 2003 (n+3 for each sampling site).

Sampling sites*	Sampling dates	Cd	Zn	pH	Temp. °C
S_1	29/10/2002	0.002 (0.001)	0.110 (0.06)	6.7	23.2
S_2	29/10/2002	0.003 (0.001)	0.161 (0.06)	7.1	23.5
S_3	29/10/2002	0.003 (0.001)	0.053 (0.01)	6.5	20.4
S_1	23/11/2002	0.006 (0.001)	0.019 (0.01)	7.2	22.2
S_2	23/11/2002	0.007 (0.003)	0.019 (0.01)	5.9	21.5
S_3	23/11/2002	0.007 (0.002)	0.090 (0.07)	6.0	21.8
S_1	15/02/2003	Trace	0.035 (0.05)	6.8	23.7
S_2	15/02/2003	Trace	0.085 (0.12)	6.9	22.5
S_3	15/02/2003	0.004 (0.005)	0.073 (0.05)	6.3	23.2
S_1	04/11/2003	0.002 (0.002)	0.04 (0.002)	6.7	23.5
S_2	04/11/2003	0.005 (0.002)	0.03 (0.010)	6.8	24.6
S_3	04/11/2003	0.002 (0.002)	0.04 (0.003)	6.1	24.1
S1	24/11/2003	0.002 (0.002)	0.02 (0.001)	6.2	24.2
S_2	24/11/2003	0.004 (0.002)	0.05 (0.010)	6.4	23.6
S_3	24/11/2003	0.005 (0.002)	0.06 (0.030)	6.5	22.8
S_1	08/12/2003	0.002 (0.001)	Trace	7.1	25.8
S_2	08/12/2003	0.002 (0.001)	0.02 (0.002)	6.6	22.6
S_3	08/12/2003	0.004 (0.001)	0.02 (0.001)	6.3	19.4

- S_1 = near the source,
- S_2 = Midstream at Umtata Dam and
- S_3 = downstream
  (after the Umtata Sewage Treatment Plant effluent discharge point).

3.3 Hazard Quotients through Use of Umtata River Water

The hazard quotients (Table 5) calculated from results of October 2002 to December 2003 (Table 2) varied between 0.2 to 0.8 for child exposure and between 0.35 and 1.22 for adult exposure. The hazard quotients calculated from representative data from the study of May 1999 – 2000 (Table 3) ranged from 1.2 to 9.3 for child exposure and from 1.8 to 14.0 for adult exposure.

Table 3: Representative Data (mg/l) from the results of the first study for Umtata River (May 1999 – March 2000)

Sampling sites	18/5/99	18/6/99	12/8/99	23/9/99	29/10/99	8/12/99	20/01/00	10/2/00	01/3/00
S_1	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.01	0.04
S_2	0.04	0.05	0.04	0.06	0.02	0.03	0.02	0.03	0.01
S_3	0.05	0.03	0.12	0.05	0.03	0.07	0.03	0.08	0.07

- S_1 = near the source,
- S_2 = Midstream at Umtata Dam and
- S_3 = downstream
  (after the Umtata Sewage Treatment Plant effluent discharge point).

4. DISCUSSION

4.1 Water Quality Situation Regarding Cadmium

The levels of cadmium detected in water samples from Umtata River fell within the SA guideline of 0.005mg/l (DWAF, 1996) in water for domestic use (with one exception, i.e., river water containing 0.007 mg/l cadmium. The levels of zinc were also below the SA guideline of 3 mg/l for water for domestic use (DWAF, 1996). At these levels of cadmium and zinc in the river the effect of the any synergistic interaction of zinc with cadmium would be negligible. The pH and temperature values also seemed to fall within the normal levels (DWAF, 1996).

Elevated cadmium levels were detected in the Umtata River during the execution of a previous WRC project (WRC, 2003) – with concentrations ranging from 0.01 to 0.08 mg/l from representative data from previous sampling locations (Table3). Many probable sources of the cadmium were identified, and an intervention programme was carried out to reduce cadmium pollution. The results of this new study have shown the cadmium levels to be reduced by an order of magnitude, with concentrations now falling within acceptable range.

4.2 Potential Health Effects of Cadmium

The hazard quotients calculated and presented in the Table 5 indicate that the concentrations of cadmium found in the Umtata River during May 1999 to March 2000 result in exceptionally high hazard quotients which indicate that if people were using the water for domestic purposes, adverse health effects would occur. The next sampling run, which took place in October 2002 to December 2003, indicates acceptable hazard quotients (with one exception, i.e., river water containing 0.007 mg/l cadmium) and therefore of cadmium.

The greater part of the anticipated adverse health effects arise as a result of the assumption of ingestion of fish or shellfish (approximately 60% of the calculated dose is as a result of assuming exposure via ingestion of fish/shellfish – data not shown).

If one were to assume that no fish or shellfish were consumed, the anticipated health risks

would be significantly reduced. This effect would be most significant for the exposure calculations during the 2nd sampling run between October 2002 and December 2003. The cadmium concentrations detected in the first sampling run (May 1999 to March 2000) even though reduced, would remain unacceptably high, with high hazard quotients in almost all cadmium concentrations measured during that time, even if the consumption of fish/shellfish were to be excluded from the dose calculations.

Table 4: Exposure parameters used to generate exposure dose estimates

Parameters used in exposure assessment for calculation of cadmium dose		
Specific parameters	**Adult**	**Child**
Body Weight	70 kg	24 kg
Lifetime:	70 years	70 years
Exposure Period	30 years	6 years
Drinking Water	350 events per year 2 litres per event 100% fraction contaminated	350 events per year 1.4 litres per event 100% fraction contaminated
Showering	350 events per year 0.2 hours per event	350 events per year 0.2 hours per event
Fish and Shellfish	350 events per year 0.054 kg per event 100 % fraction contaminated	350 events per year 0.054 kg per event 100 % fraction contaminated
Swimming	7 events per year 2.7 hours per event 50mL accidental ingestion, 100% fraction contaminated	150 events per year 2.4 hours per event 50mL accidental ingestion 100% fraction contaminated

Table 5: Hazard quotients[****] calculated using exposure parameters to cadmium through use of Umtata River for a lifetime exposure, representing 26 different possible exposures – as described in the text

Results from May 1999- March 2000			Results from October 2002 – December 2003		
ug/l cadmium in river water	Hazard Quotient		ug/L cadmium in river water	Hazard Quotient	
	Adult exposure	Child Exposure		Adult exposure	Child Exposure
10	1.8	1.2	2	0.35	0.2
20	3.5	2.3	3	0.52	0.4
40	7.0	4.6	4	0.70	0.5
50	8.7	5.8	5	0.87	0.6
60	10.5	7.0	6	1.05	0.7
70	12.2	8.1	7	1.22	0.8
80	14.0	9.3			

**** - Hazard Quotients that exceed 1.0 indicate the possibility of non-cancer toxic risks from the exposure.

The remedial actions taken following the 1999 to 2000 sampling appear to have been successful in reducing the cadmium levels in the Umtata River water and have therefore resulted in reducing the potential health effects. It is only when cadmium levels exceed 0.006 mg/L that possible adverse health effects could be anticipated for humans using the river water as their sole source for domestic purposes. The bulk of the source of the anticipated health risk is derived from the ingestion source (drinking water and ingestion of fish from the river), with a small proportion of the estimated risk being as a result of dermal exposure.

There is no quantitative value for the carcinogenic potential of cadmium, as insufficient evidence exists to calculate the potency factor, therefore no quantitative risk results can be presented. It is generally assumed however, that carcinogenic risks are zero only when exposure is zero.

4.3 Uncertainty Analysis

All risk estimates involve some degree of uncertainty. Uncertainty in the health risk assessment process exists at numerous levels. Uncertainty regarding exposure has two primary sources: uncertainty about contamination including concentrations of chemicals to which the potential population may be exposed over the duration of the exposure period, and uncertainty about the exposed population. In this study both of these were significant. The exposed population was not studied and the health risk assessment is based solely on hypothetical exposure scenarios. Therefore uncertainty in the results will be substantial.

This health risk assessment can only be seen as a rapid, cursory investigation. The results of this health risk assessment only reflect the potential risks associated to the exposure conditions described. This exposure represents a typical "higher" end of the exposure scenario as it represents the individuals who would need to use the river water as their sole source for domestic purposes.

Uncertainty exists in a quantitative health risk assessment at every stage of the risk assessment process:

- Firstly, there is uncertainty in the hazard identification process, with uncertainty regarding whether cadmium is carcinogenic. Cadmium has been classified as a probable human carcinogen, but without adequate supporting data, which will indicate the potency factor of the chemical, no quantitative risk assessment can be carried out;
- Secondly there is uncertainty regarding the dose response data for toxic effects associated with cadmium. An uncertainty factor of 10 was used to set the 'safe' Reference Dose (RfD) based on the 'No observed adverse effect level' – or NOAEL data available;
- Thirdly there is uncertainty in the dose calculation in assessing how much cadmium people may be exposed to. The potential exposure or dose presented in this report are based on assumptions and 'default' values based on previous exposure assessments.

A true dose calculation would involve intensive and expensive studies looking at assessing how much river water people use for different domestic activities – such as ingestion through drinking or food preparation, washing, bathing, laundry activities, recreational activities in the river, as well as consumption of fish or shellfish;

- Most of the hazard quotients presented are likely to be overestimated for the realistic situation, with true exposures lower than estimated. This conservative approach has been taken because it is protective of human health i.e. any error in the estimate is on the side of human safety.

5. CONCLUSION

The levels of cadmium in the Umtata River now seemed to fall within acceptable level and the intervention programme embarked upon after the first study appeared to have worked. If people were to use the water now for domestic purposes, adverse effects are most likely not to occur.

6. RECOMMENDATION

It is recommended that the research team give feedback to the workshop participants and that the Departments of Health and Water Affairs & Forestry should follow up the monitoring of water quality in the Umtata River.

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The aims of the project included:

- The determination of the quality of water at the point of provision at selected sites;
- The examination of usage patterns, for all domestic purposes as well as farming. The quantity of water used as well as the identification of water treatment by the end-user prior to use;
- The development of surveillance techniques as well as the testing and evaluation of such techniques, incorporating sanitary inspection and water quality monitoring; and
- The prioritisation of remedial action strategies to protect the user from the risk of water-borne diseases.

The following interim conclusions have been reached:

- Intersectoral co-operation plays a key role in planning and operating a water quality surveillance programme.
- There is an urgent need for training material or guidelines for the implementation of surveillance programmes.
- Water quality problems that were noted include:
  - Faecal coliform pollution of surface water is widespread in the district under surveillance. Two clinics in the district had experienced major outbreaks of water-borne disease (*Shigella*, gastro-enteritis, diarrhoea)
  - Human users share water sources with domestic animals such as pigs and cattle.
  - The majority of water end-users do not make use of water purification methods
  - Elevated concentrations of iron and manganese and salt were identified in a significant number of dams and boreholes.
  - The effects such as staining of clothing or unpleasant taste caused users to switch to unsafe surface water.
- Consumer involvement and effective transfer of information is all-important

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