Human health aspects of certain metals in tissue of the African sharptooth catfish, *Clarias gariepinus*, kept in treated sewage effluent and the Krugersdrift Dam: Iron and manganese

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Abstract

Health risks associated with the utilisation of waste water for fish production were studied by investigating the possible bioaccumulation of iron and manganese in the muscle tissue, kidneys and liver of the African sharptooth catfish, *Clarias gariepinus*, kept in treated sewage effluent and in the Krugersdrift Dam, Bloemfontein, South Africa. Metal concentrations were also determined in the water and sediment of the mentioned localities. The water of natural water sources, such as the Krugersdrift Dam, was found to be more subject to changes in chemo-physical factors, e.g. pH and hardness, compared to that of treated sewage effluent. This finding correlates with the higher concentrations of Fe measured in the former-mentioned habitat during certain months of the year. The average wet mass concentrations of Fe and Mn in the muscle tissue for fish in treated sewage effluent (0.804 and 0.024 $mg{\cdot}g^{-1}$ respectively) and for fish in natural dam water (0.880 and 0.017 $mg{\cdot}g^{-1}$ respectively) were well below the recommended values set by health authorities for domestic water supplies. In contrast, the concentrations of these metals were noticeably higher in the liver and kidneys of catfish. As the latter concentrations approached the maximum permissible levels in the liver and kidneys of catfish, especially in the Krugersdrift Dam, these organs are not recommended for human consumption.

Introduction

Periodic water shortages in South Africa, which lies in a semi-arid region in which rainfall and water bodies are unevenly distributed, have made an investigation into the use of treated sewage water for the purpose of aquaculture, imperative. This water, which is unsuitable for domestic use, has an abundant supply of nutrients (Duffer, 1982) and is usually discharged into rivers without further ado. In general the effluent of most well-planned maturation ponds of sewage purification plants in South Africa is of such a good quality that many species of fish could survive in it.

According to the Council for Population Development (1990), the SA population at present increases at a rate of 2.3% per year which, if maintained, will result in an alarming 138 m. people by the year 2025. However, it is estimated that only a maximum of 80 m. people could be supplied with adequate water due to the country's limited natural water sources. Fourie (1989) also warns that more food will have to be produced per unit area in South Africa in order to satisfy future domestic needs. Bearing these facts in mind it is clear that the development and utilisation of alternative water sources in the RSA for domestic purposes as well as for food production is of the utmost importance.

Published records pertaining to the use of domestic effluent for the production of fish in South Africa, date back to the beginning of the second half of the 20th century. In the 1950s Hey (1955) had already reported on the use of sewage for the production of fish. However, various authors (Guelin, 1962; Janssen, 1970; Reichenback-Klinke, 1973; Feachem et al., 1978; Lawton and Morse, 1980) are of the opinion that, although treated sewage effluent is a good source of nutrients, it may be a potential health hazard to handlers and consumers of fish inhabiting it. According to Simpson and Stone (1988) effluent from cities during rainy conditions could cause dangerous and toxic substances to accumulate in rivers and dams. However, stringent control may ensure that the same does not happen in maturation ponds of biological filter purification plants.

The idea of fish production in maturation ponds still has several drawbacks such as public disapproval of sewage-related products and conditions resulting in stress to the fish (Wrigley et al., 1988). According to Sandbank and Nupen (1984), the biggest disadvantage regarding aquaculture in effluent, is the accumulation of heavy metals, pathogens and pesticides in the tissues of fish and, as a result, the possible transmission of diseases to man. However, Hejkal et al. (1983) stated that the health risk related to the consumption of fish kept under the controlled conditions of maturation ponds cannot be greater than in the case of fish kept under uncontrolled conditions and that the latter may be contaminated by pollutants at any time. The various discrepancies regarding health hazards related to human consumption of fish living in treated sewage therefore still have to be clarified. As a result, such waters have not yet been approved for the purpose of aquaculture by health authorities in South Africa.

To investigate the health risks regarding the concentrations of heavy metals in fish kept in treated sewage effluent produced by a biological filter purification plant, it was decided to compare the occurrence of selected heavy metals and related trace elements in the water, sediment and tissue of fish kept in the first maturation pond of the Bloemspruit Sewage Purification Plant with that of the water, sediment and tissue of fish kept in the Krugersdrift Dam. Due to their possible synergistic relationship in the same habitat (WHO, 1984), Fe and Mn were selected for one of a series of papers covering this topic. The previous paper (Van den Heever and Frey, 1994) dealt with the occurrence of Zn and Cu in the respective habitats as well as in the tissues of catfish inhabiting these habitats.

The Bloemspruit Purification Plant (Fig. 1) is situated just

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Received 10 March 1995; accepted in revised form 18 August 1995.

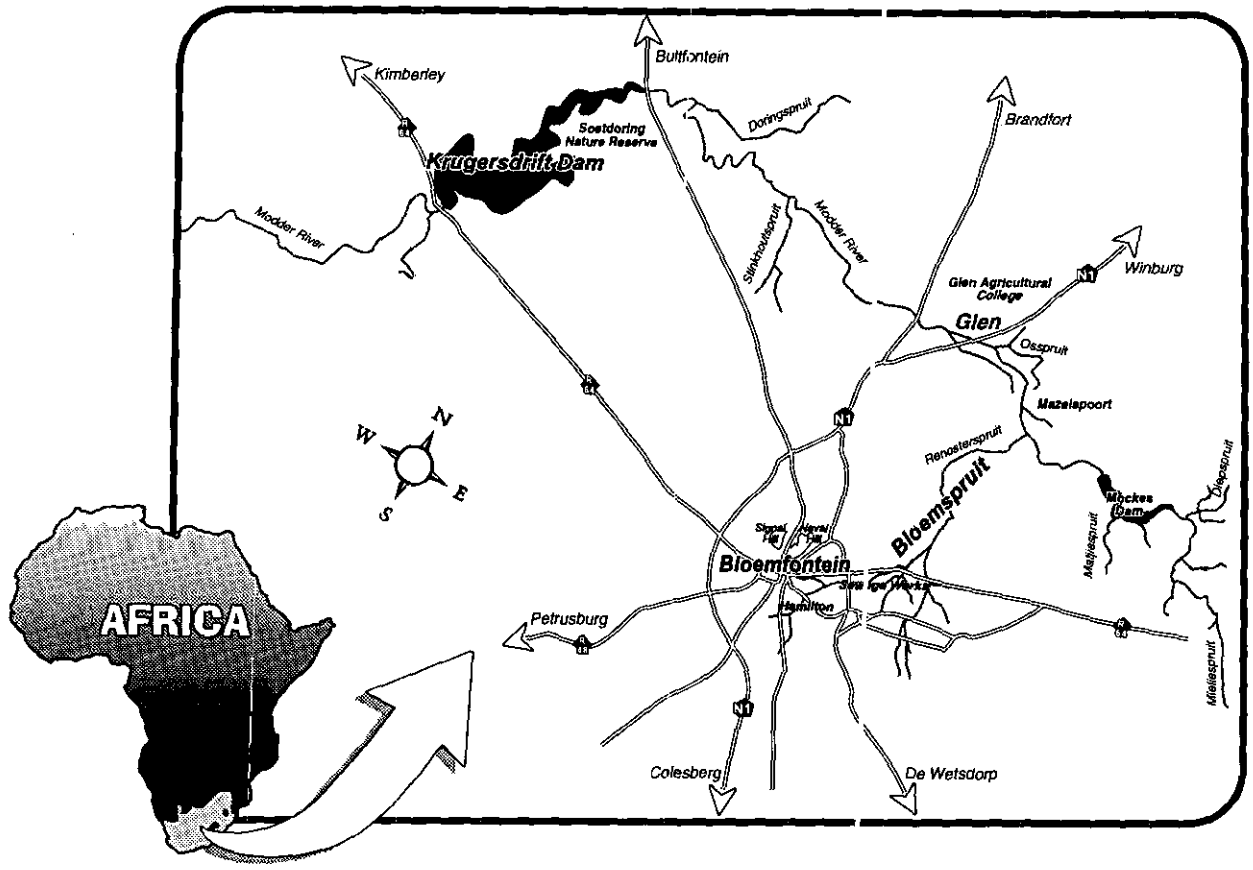


Figure 1
Map of the Modder River catchment area showing the geographical location of the sampling localities (Bloemspruit Sewage Works and Krugersdrift Dam)

outside Bloemfontein, capital of the Free State province and mainly treats domestic waste with a minimum of industrial effluent. The Krugersdrift Dam, which is a typical rural water source, is situated approximately 30 km outside Bloemfontein away from extensive industrial activities. It is fed by the Modder River which is bordered upstream by several informal settlements.

The African sharptooth catfish (*Clarias gariepinus*) was chosen as an experimental fish species for the study. This fish, generally known for its hardiness, is an obligatory air-breather and thrives in water with a high organic content (Prinsloo et al., 1989). These characteristics of *C. gariepinus* make it an ideal choice for extensive studies of this nature.

Materials and methods

Collecting and keeping of fish

Healthy adult catfish were collected in the Brandfort district near Bloemfontein, South Africa in December 1990 and kept in a 2 150 *ℓ* polyethylene pond for two weeks to rid the tissue of any foreign substances which could possibly be present. The pond system had a domestic tap-water throughflow of approximately $20 \ell \cdot h^{-1}$. During this phase of the study the fish were fed commercial breakfast food (Weet-Bix) every second day.

After the freshening process, two groups of 30 fishes each were respectively transported to the first maturation pond of the Bloemspruit Sewage Purification Plant and the inlet of the Krugersdrift Dam (Fig. 1). Here the fish were placed in two cube-shaped 10 x 50 mm galvanised cages, each with a capacity of 8 m^3. The cages were firmly positioned on the bottom in such a way that the water could flow through freely. Approximately 20 cm of each cage protruded above the water allowing the fish to surface for air if necessary.

Tissue sampling and preparation

In June 1991, after 6 months in captivity, 9 fishes were removed at random from each of the two cages with the aid of a scoop net and transported to the laboratory in 200 *ℓ* polyethylene drums filled with water from the two localities respectively. Both groups of nine fishes were then subdivided into 3 groups of 3 each. The same procedure was followed in December 1991 with the remaining groups of fishes kept in the cages at the two localities. All fish were slaughtered within h after removal from the cages.

Liver, kidney and muscle tissue were collected from each fish and prepared for chemical analysis according to the method described by Nupen (1983) and adopted by Van den Heever and Frey (1994).

Water and sediment sampling and preparation

Water and sediment samples were collected monthly from January to December 1991 from each locality according to the method of Watling (1981). Sediment samples were exposed to a temperature of -20°C for 24 h and thereafter passed through a 1 mm nylon sieve before drying (Brouwer et al., 1985). Dissolution of sediment samples was carried out according to the method of Watling (1981).

TABLE 1
CONCENTRATIONS OF Fe AND Mn IN SEDIMENT SAMPLES COLLECTED MONTHLY OVER A 12 MONTH PERIOD DURING 1991 FROM THE FIRST MATURATION POND OF THE BLOEMSPRUIT SEWAGE WORKS AND THE KRUGERSDRIFT DAM. CONCENTRATIONS ARE EXPRESSED IN $mg \cdot g^{-1}$ DRY MASS

Element	Maturation Pond Range	Maturation Pond $\bar{x}$	Maturation Pond SD	Krugersdrift Dam Range	Krugersdrift Dam $\bar{x}$	Krugersdrift Dam SD
Fe	784-1 265	1 096	300	995-1 522	1 385	211
Mn	12.3-24.9	18.5	7.22	24.8-33.5	29.6	4.59

$\bar{x}$: Mean concentration
SD: Standard deviation from the mean value

Tissue, water and sediment analyses

Fe and Mn concentrations of tissue, water and sediment samples were determined by means of an ARL inductively coupled plasma (ICP) emission spectrometer (Model 3410) according to the method of Kempster (1986). Various physical properties of the water of the two habitats such as pH, total hardness, conductivity, redox potential and temperature variations were also determined regularly in order to give possible explanations for unexpectedly high or low concentrations of metals in solution.

Results

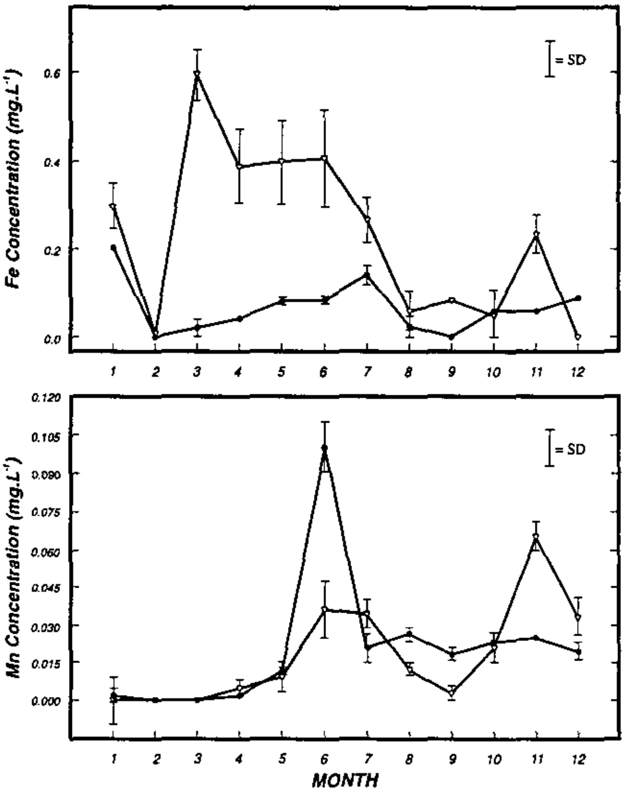
Mn and Fe concentrations in water and sediment

The mean concentrations of Fe and Mn with the standard deviations from the mean of treated water from the Bloemspruit Sewage Works and water from the intake of the Krugersdrift Dam measured from January 1991 to December 1991, are shown in Fig. 2. Means and standard deviations were calculated for 9 samples collected at each locality respectively during each month.

Concentrations of Fe in treated sewage effluent varied irregularly from insignificant quantities to 0.206 $mg \cdot \ell^{-1}$ throughout the year of study (Fig. 2). A similar variation of Fe concentrations in natural dam water was found but from insignificant quantities to 0.593 $mg \cdot \ell^{-1}$. During autumn the Fe concentrations of both localities increased slightly whereafter it again decreased in both cases during the winter months. Despite the irregular monthly fluctuation of Fe concentrations, a significant difference between the mean values of Fe in the water of the two different localities was found ($p<0.05$).

As was the case for Fe, no fixed seasonal pattern was found for concentrations of Mn determined in the water of both localities. However, the concentration of manganese in treated sewage effluent was found to be approximately three times that of natural dam water during June 1991. In contrast, that of natural dam water was twice as high as that for treated sewage effluent during December 1991. Notwithstanding these differences, no significant differences were found in the average monthly Mn concentrations of treated effluent water and natural dam water respectively ($p>0.05$).

The mean concentrations of both Mn and Fe in the sediment of the Krugersdrift Dam were higher than the means calculated for these elements in the sediment of the first maturation pond of the Bloemspruit Sewage Works (Table 1).



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Mn and Fe concentrations in fish tissue

Iron concentrations in the liver of *Clarias gariepinus* in both treated sewage water and natural dam water were higher than in the kidney and muscle tissue (Fig. 3). With the exception of the higher Fe concentrations measured in the livers of fish from the Krugersdrift Dam during December, no significant differences could be found

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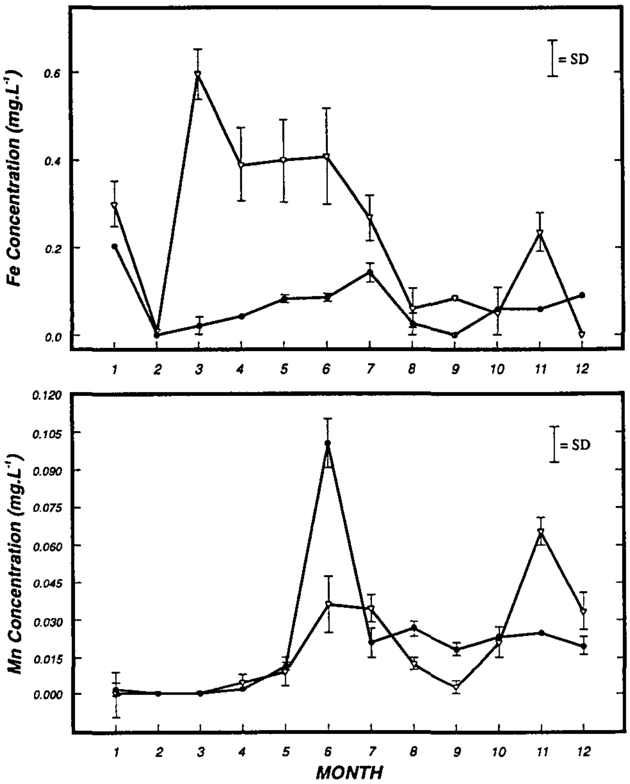

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TABLE 2
A COMPARISON BETWEEN THE CONCENTRATIONS OF Fe AND Mn (mg·ℓ⁻¹) MEASURED FOR SOME SOUTH AFRICAN RIVERS AND FOR WATER OF THE KRUGERSDRIFT DAM AND TREATED SEWAGE EFFLUENT OF THE BLOEMSPRUIT SEWAGE WORKS

River	Vaal River		12 Cape rivers	Transkei rivers	Maturation dam	Natural dam
Period	Oct 1981	Sept 1982	May 1975-Aug 1981	Sept 1980-Jan 1982	Jan 1991-Dec 1991	Jan 1991-Dec 1991
Source	Rand Water Board (1982)		Watling (1982a-f)	Du Preez (1985)		
Fe	350	230	328	481	68	229
Mn	60	120	27.3	54	23	19.4

(1973), Wood (1975), Overhoff and Forth (1978), Duffus (1983) and Moriarty (1991). According to Sollman (1957) an adult human ingests approximately 7 to 35 mg Fe·d⁻¹ on a normal diet with an average intake of more or less 16 mg·d⁻¹. The recommended daily intake for males is 10 mg and for females 18 mg (NAS, 1980). The concentrations of Fe measured in the muscle tissue of *Clarias gariepinus* in both habitats investigated in this study were insignificantly low and therefore pose no health hazard to the consumer. The same cannot be said regarding the liver and kidneys of this fish (Fig. 3). Due to the relatively high concentrations of Fe found in the kidneys and especially the livers of *Clarias gariepinus* (>35 mg·g⁻¹), these organs are not recommended for human consumption. The intake of only 1 g of the liver or kidney of *Clarias gariepinus* per day during chronic exposure, will, according to Carson et al. (1991), exceed the prescribed concentrations which could lead to haemosiderosis or even haemochromatosis. The significantly higher Fe concentrations measured in the sediment (Table 1) and water (Fig. 2) of the Krugersdrift Dam, compared to that for treated sewage effluent, also correlate well with the higher values of this metal found in the liver of fish sampled from the dam (Fig. 3).

Complaints are usually made by the public when Mn concentrations in water exceed 150 μg·ℓ⁻¹ (Griffen, 1960; WHO, 1984). These complaints mostly have to do with brown stains on washing and the unpleasant taste of the water. Small concentrations of Fe in the water could possibly increase the adverse effects of Mn (WHO, 1984). Maximum Mn concentrations of 50 μg·ℓ⁻¹ and 100 μg·ℓ⁻¹ are recommended for domestic drinking water by the USEPA (1976) and the WHO (1984) respectively. The average concentration of Mn in treated sewage effluent (22.8 μg·ℓ⁻¹) and that of natural dam water (19.4 μg·ℓ⁻¹) measured during the course of this study was in fact considerably lower.

Sollman (1957) set human average daily Mn intake at approximately 10 mg, while the NAS (1973) claimed it to be 3 to 7 mg·d⁻¹. An adult person actually needs only 2.5 to 5 mg·d⁻¹ (NAS, 1980). Excess intake of this metal can cause liver damage, but only a few cases have been reported world-wide (McKee and Wolf, 1963). The mean concentrations of Mn in the muscle tissue of *Clarias gariepinus* kept in treated sewage effluent (24.5μg·g⁻¹) and in the Krugersdrift Dam (17.6 μg·g⁻¹) are such that a normal daily diet including this fish species poses no health risk to man. However, the same cannot be said for the consumption of the liver and kidneys of this species in both habitats as bioaccumulation of Mn by these organs is very apparent (Fig. 3).

Conclusions

No set seasonal patterns could be established regarding the incidence of Fe and Mn in the water of both localities. Generally the occurrence of these elements in the water of both localities was very low and the water of both habitats could therefore not be considered toxic to aquatic life.

As was the case for the Krugersdrift Dam, no toxic levels were recorded for either Fe or Mn in the muscle tissue of catfish kept in treated sewage effluent of the Bloemspruit purification plant. However, concentrations of Fe and Mn found in the livers and kidneys of *C. gariepinus* in both habitats may well pose a health risk when eaten. Human consumption of these organs is therefore not recommended. Fish must first be gutted and gills removed before cooking and eating.

Acknowledgements

The authors wish to thank the Foundation for Research Development and the Technikon Free State for financial support which made this study possible.

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