Impact on water quality of land uses along Thamalakane-Boteti River: An outlet of the Okavango Delta

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ABSTRACT

Botswana is a semiarid country and yet has one of the world's famous wetlands: the Okavango Delta. The Thamalakane-Boteti River is one of the Delta's outlets. The water quality of the Thamalakane-Boteti River was determined and related to its utilisation. The major land uses along the Thamalakane River within Maun are residential areas, lodges, hotels, and grazing by cattle and donkeys. The water is used as a source of water for livestock, wildlife in a game park, horticulture and domestic applications including drinking. The river is also used for fishing.

To check whether these activities negatively impact on the water quality, pH, electrical conductivity, dissolved oxygen, temperature, total dissolved nitrogen and phosphorus, *Faecal coliforms* and *Faecal streptococci* and selected metals were determined from July 2005 to January 2006. The pH was near neutral except for the southern most sampling sites where values of up to 10.3 were determined. Dissolved oxygen varied from 2 mg/l to 8 mg/l. Sodium (range 0.6–3.2 mg/l), K (0.3–3.6 mg/l), Fe (1.6–6.9 mg/l) conductivity (56–430 μS/cm) and Mg (0.2–6.7 mg/l) increased with increased distance from the Delta, whereas lead showed a slight decline. Total dissolved phosphorus was low (up to 0.02 mg/l) whereas total dissolved nitrogen was in the range 0.08–1.5 mg/l. *Faecal coliform* (range 0–48 CFU/100 ml) and *Faecal streptococci* (40–260 CFU/100 ml) were low for open waters with multiple uses. The results indicate that there is possibility of pollution with organic matter and nitrogen. It is recommended that more monitoring of water quality needs to be done and the sources of pollution identified.

1. Introduction

Integrated water resources management (IWRM) requires consideration of both the quantity and quality of water. Human activities have the potential to impair water quality and thereby reduce the utility of water as a resources, and degrading aquatic ecosystems. Impairment of water quality adversely affects attainment of socio-economic sustainability. A study carried out by Nhapi et al. (2002) established that due to water pollution, costs of water treatment had increased for Harare, Zimbabwe, and the costs of financing of water and wastewater treatment per household had increased beyond acceptable levels. Coordination of planning and management of land and water is one of the IWRM objectives formulated after realising that land uses affect both the quantity and quality of water. There is however inadequate understanding and ability to predict how human activities in different physiographic settings affect water quality especially in southern Africa. Studies aiming at improving our understanding of the linkages between human activities and water quality such as mining (Ravengai et al., 2004, 2005; Ntengwe and Maseka, 2006; Lupankwa et al., 2006; Meck et al., 2006) urbanization and settlements (Mapani, 2005; Mwiganga and Kansiime; 2005; Nsubuga et al., 2004; Zingoni et al., 2005; Alemaw et al., 2004) irrigation and other land use (Basima et al., 2006; Mhlanga et al., 2006; Ngoye and Machiwa; 2004; Dzwairo et al., 2006; Ntengwe 2006) are important since outputs of such studies form the basis of designing measures for controlling water contamination, and water quality monitoring programmes.

The ability of wetlands to modify water quality is increasingly being appreciated (Nichols, 1983; Kadlec and Knight, 1996; Mugisha et al, 2007; Verhoeven et al., 2006). The Okavango Delta is one of the major freshwater wetlands of the world, within which evapotranspiration and chemical precipitation results in improvement of surface water quality of water (McCarthy 2006). Surface water within most parts of the delta is in the pH range 6.1–7.5, with acidic water occurring due to decomposition of aquatic plants (Ashton et al., 2003). Ashton et al. (2003) also found the electrical conductivity (EC) to be general low, 33–75 μS/cm, and an indication of low total dissolved solids. Other water quality parameters revealed that water within the delta had no significant contamination. The Okavango Delta is largely a wildlife management area

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with controlled development of tourism facilities. What is however not known are the effects on water quality of human activities occurring immediately downstream of the delta along some of the rivers draining from it. Agricultural, industrial and urban activities such as those occurring within and around Maun, an urban village located along one of the outlets from the delta, have elsewhere been shown to adversely affect water quality (Nhapi et al, 2002; Ouyanga et al., 2006). Van der Post (2004) highlighted the potential for solid and liquid waste emanating from Maun polluting Thamalakane River which passes through this settlement. High concentrations of toxic chemicals and nutrients can lead to diverse problems such as toxic algal blooms, loss of oxygen, fish kills, loss of biodiversity, and loss of aquatic plant beds and coal reefs (Voutsa et al., 2001). Several studies elsewhere have investigated effects of human activities on water quality (e.g. Irmer et al., 1995; Arambarri et al., 1996; Fisher et al., 2000; Tong and Chen, 2002; Cheung et al., 2003; Barros et al. 1995; Xue et al., 2003; Simeonova et al., 2003).

This study was conducted to determine effects of human activities within and around an urban village, Maun, on water quality of the Thamalakane-Boteti River which drains from the Okavango Delta. Information derived from this study can be used to determine if the water quality of the Thamalakane-Boteti River is being impacted upon by activities being carried out around it, recommend water quality parameters to be monitored and measures for controlling water contamination that may have been detected.

2. Materials and methods

2.1. Study area

The study was conducted along the Thamalakane and Boteti Rivers which for about 20 km passes through Maun Village in north-western Botswana (Fig. 1). This river bifurcates downstream of Maun to form the Nhabe River which drains into Lake Ngami on the south-west, and Boteti River draining into Makadikgadi Pan to the south-east. The combined Thamalakane River and Boteti River is referred to as the Thamalakane-Boteti River. The river, is located in an almost flat area with Kalahari sands. Its gradient is about 0.006%. The Thamalakane-Boteti River has a channel width of 20–60 m within a 120 to 500 m wide valley. Flows in the Thamalakane-Boteti River comprise mostly of outflows from the Okavango Delta (Gieske, 1997; Wolski and Savenije, 2006; Mazvimavi and Motshalapheko, in press). A distinctive characteristic of this river is that it floods during the dry season, June to September. The average peak flow during May to August is 7.2–8.1 $m^3 s^{-1}$, and 1.2 to 2.0 $m^3 s^{-1}$ during the December to February low flow period. There are times when the river runs dry mostly from January to June during dry years. Due to the low gradient along the Thamalakane River, flows have very low velocities and the flood flows can take up to 14 days to flow over 9 km along a previously dry channel. The average annual rainfall occurs during the November to March period and is about 450 mm/yr, while the A-pan evaporation is 2010 mm/yr. Maximum monthly temperatures range from 22°C to 34 °C while the maximum daily temperatures are in the order of 30°C to 32 °C (Scudder et al., 1993).

Maun is a rapidly growing urban village which had a population of 4591 in 1964 and 49,822 in 2001(CSO, 2003; van der Post, 2004). This village serves as the administrative centre for the North-West District Council, a major commercial centre, and the gate-way for tourists visiting the Okavango Delta. Commercial activities are mostly aimed at supporting government departments, district headquarters, and the thriving tourism industry with about 50,000–60,000 visitors passing through Maun every year (Mbaiwa, 2003; Magole and Gojamang, 2005). Land uses along the Thamalakane River in Maun comprise flood recession cultivation, vegetable gardens, lodges, hotels, and low and high income residential areas. These land uses have the potential to affect water quality

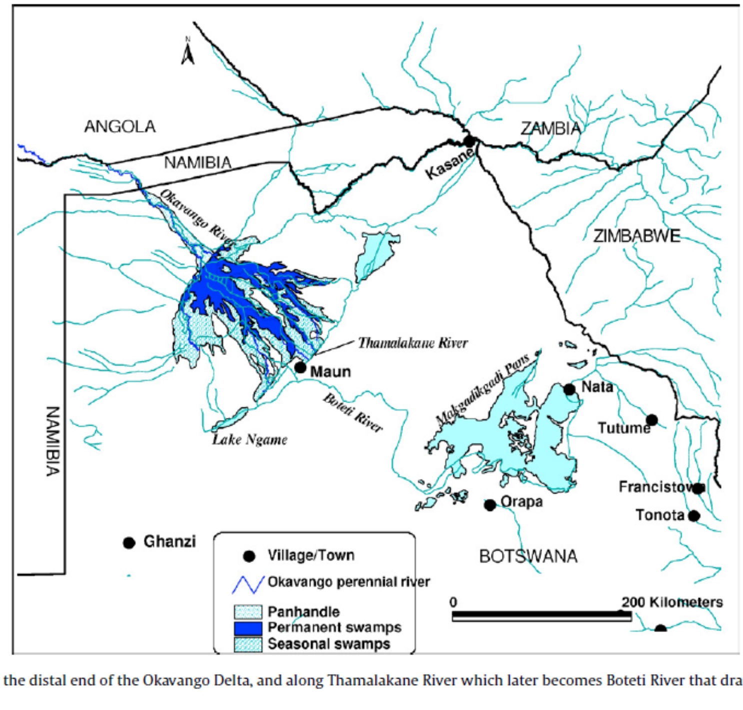

Fig. 1. Location of the Maun at the distal end of the Okavango Delta, and along Thamalakane River which later becomes Boteti River that drains into the Makgadikgadi Pans.

of this river. Van der Post (2004) noted that 39% of the households were in 1991 using pit latrines, which have the potential to contaminate surface water when located close to rivers (Palamuleni, 2002; Kulabako et al., 2007). Livestock grazing and watering occurs along the whole stretch of the Thamalakane-Boteti River and some studies established that livestock contaminated water (Kienzle et al., 1997; Fatoki et al., 2001; Kulabako et al., 2007; Graves et al., 2007).

A study carried out along the Boteti River downstream of Maun, established that some of the residents considered the river water to have some objectionable attributes such as presence of particles, offensive odour and colour (Mazvimavi and Mmopelwa, 2006).

2.2. Sampling sites and water quality analysis

Water samples were collected once a month during the June 2005 to January 2006 period from 11 sites A to K along a 75 km stretch of the Thamalakane-Boteti River (Fig. 2). The main features or land uses around each of the sampling sites are presented in Table 1.

Standard methods for water quality analysis were used for the determination of chemical parameters (Clesceri et al., 1998). Electrical conductivity (EC), pH and dissolved oxygen (DO) were measured on site with field meters (Hanna HI 9034, HI 9143 and 19910001 EC, DO and pH meters, respectively). Total dissolved nitrogen and phosphorus were measured by an air segmented continuous flow Auto analyzer 3 (Bran + Luebbe GmbH, Germany) and metals were analysed by an atomic absorption spectrophotometer (Varian Spectra AA 220, Australia). The membrane filtration method was used for the determination of *F. coliforms* (FC) and *F. streptococci* (FS) (Clesceri et al., 1998).

Table 1
Land uses around the sampling site along the Thamalakane and Boteti Rivers

Sampling site	Features and land uses
A	Site located upstream of Maun. Vegetable gardens and rainfed cultivation on the left bank. Heavy grazing on riparian lands
B	Four lodges are located along the river bank around this site
C	Vegetable garden on the right bank and medium to high income houses. Immediately downstream of the four lodges
D	Vegetable gardens and houses
E	At a pool occasionally inhabited by hippopotamus. Camp site and medium to high income houses along both river banks
F	Downstream of a water treatment plant in an area with middle to high income houses
G	School and hotel. Houses for low to high income groups
H	Downstream of Maun. Flood recession cultivation. Livestock grazing
I	Flood recession cultivation. Livestock grazing
J	Pool where fishing is regularly carried out. Livestock grazing. Flood recession cultivation
K	Pool with a lodge along the river bank. Flood recession cultivation. Livestock grazing

Features and land uses around sites where water samples were collected from the Thamalakane-Boteti River.

3. Results and discussion

3.1. Major land uses along the thamalakene river and flow variation

The major land uses along the Thamalakane River within Maun are residential areas, lodges, hotels, and grazing by cattle and donkeys (Fig. 2). Middle to high income houses is located mostly along this river. A game sanctuary which is about 1 km by 3 km is located along the left bank. Water from this river is occasionally abstracted into bowsers for construction purposes. There are about 80 small electrical water pumps for abstracting water for garden watering at individual homesteads. Washing of cars is occasionally undertaken at some locations especially during week-ends. During the high flow period (June–September), some of the lodges do boat trips along the Thamalakane River for their clients. Flood recession cultivation and livestock grazing are also significant land uses carried out along the Thamalakane-Boteti River. Fishing, livestock watering, water supply for domestic use are the major uses of the river downstream of Maun (Mazvimavi and Mmopelwa, 2006). There is no direct discharge of wastewater along the Thamalakane-Boteti River. Littering along the Thamalakane River especially at locations where picnics are held during week-ends is a problem that the local authority has highlighted.

The first sample was collected on 9 June 2005 when the outflows from the delta were wetting a previously dry channel. Flow then

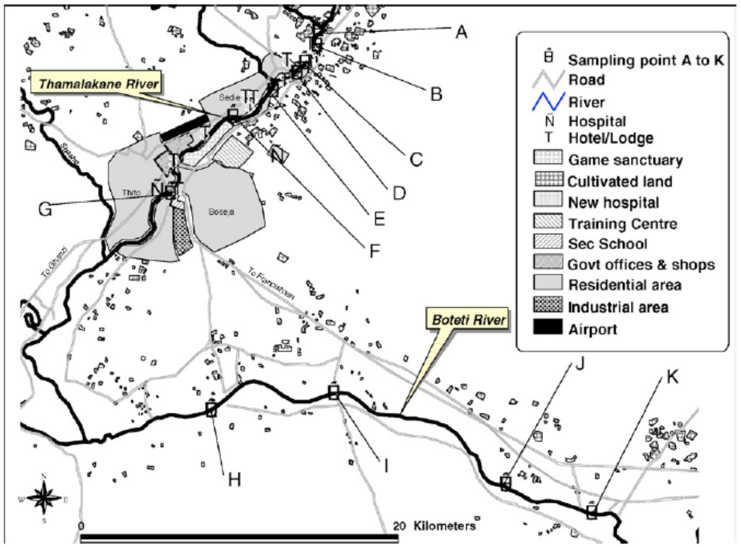

Fig. 2. Location of sampling points for water quality analysis within and downstream of Maun, Botswana. The different land uses along the river are also shown.

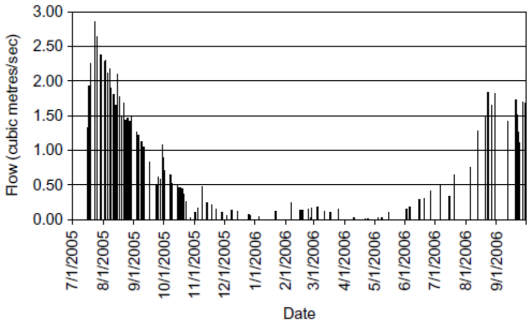

Fig. 3. Flow variation during the sampling period along the Thamalakane River.

increased to a monthly average of 2.23 $m^3 s^{-1}$ in July 2005, and then declined to 0.05 $m^3 s^{-1}$ in January 2006 (Fig. 3). Runoff due to rainfall caused an increase of flows to 0.24 $m^3 s^{-1}$ in February 2006.

3.2. Faecal coliforms and Faecal streptococci

Faecal coliform and *streptococci* are commonly used as indicator organisms for the microbiological quality of water and wastewater (Clesceri et al., 1998). Fig. 4a shows the results for FC and FS during high (6/9/2005) and low (26/1/2006) flow periods at five sampling points, A, C, E, J and K.

FC counts are low in the range 0–48 CFU/100 ml during the high flow period which coincides with dry season with no runoff from the riparian area. Lowest values were obtained at the furthest downstream points, J and K. The low FC counts could be as a result of the high volumes of water causing dilution of bacteria that may be introduced into the water as well as existence of no runoff during this dry season. The FS, however, shows a different pattern during the same period. Low values were determined up to location E and then high values were observed at point J (152 CFU/100 ml) and K (260 CFU/100 ml). During the low flow period (rainy season), FC counts are higher than those during the high flow period. The flow rate increased from 0.00 $m^3 s^{-1}$ on 7 January 2006 to 0.24 $m^3 s^{-1}$ on 6 February 2006, and at the time sampling was done in January 2006 the flow rate was 0.11 $m^3 s^{-1}$. Therefore, high FC counts during the wet season is due to runoff introducing faecal matter into the water. It would appear from this data that sources of FS are prevalent in the downstream areas during periods of high flow and the opposite is true for FC.

During the low flow period (rainy season), FC were always found to be higher than in the dry season. Similar results have been found elsewhere (Palamuleni et al., 2004; Elmanama et al., 2006). However, the values obtained in this work are still low compared to other values for open waters. Values for the Gangetic River system for FC and FS were found to be 2–1600 CFU/100 ml (Baghel et al., 2005). A range of 0–642 CFU/100 ml FC was recorded from 19 streams in Oregon (Bracken et al., 2006), whereas a range of 345 to 2558 CFU/ml were found in Kitwe Stream, Zambia (Ntengwe, 2006) and 154–1000 CFU/100 ml were determined in Marimba River, Zimbabwe (Mvungi et al., 2003). Fatoki et al. (2001) recorded high FC counts (200–1000 CFU/100 ml) on the Umtata River in South Africa which were attributed to informal settlements with no proper sanitation. In Malawi, FC and FS were found to be in the ranges 400–18,500 and 0–15,500 CFU/100 ml for Lunzu Stream (Palamuleni et al., 2004). The low FC and FS counts in this area may be a result of low runoff during the rainy season due to low rainfall, sandy soils with high infiltration rates and low slopes prevalent in the area.

3.3. pH

The pH of all the sampling sites and periods ranged from 6.91 to 10.33, with a mean of 8.20 (Fig. 4b). There is little variation in pH between points A to F which are located within Maun on any given sampling date. A slight decrease from point F to H was observed during the sampling conducted on 29/11/05 and 19/8/05 indicating possible introduction of acidic matter in the water. An increase was observed from points G to H and H to I for samples collected on 29/07/2005 and 19/8/05, respectively, indicating possible introduction of basis substances during this periods at these points. This is supported by the fact that the pH subsequently decreased. The density of sampling points decreases after sampling point G (Fig. 2). Sampling points H and I are located downstream of Maun with the major land uses being flood recession cultivation and livestock grazing. Values of pH that do not follow trends e.g. high pH at sites H on 29/11/05, F on 25/10/05, I on 19/08/05 and low pH at point H on 19/08/05 may result from the introduction of basic substances (high pH) and acidic substances (low pH) upstream of these locations, and may warrant further investigations Only one value (10.33) exceeded the Botswana Bureau of standards guideline for drinking water (Botswana Bureau of Standard, 2000). The pH values along the Thamalakane River are similar (pH 6.3–7.7) to those observed in 2000 at several locations within the Okavango Delta (Ashton et al., 2003). This suggests that human activities in and around Maun are not modifying the pH of water except for the cases where anomalous results were observed.

3.4. Electrical conductivity

The electrical conductivity (EC) was low, less than 200 μS/cm, except in few cases (Fig. 4c). All samples except for samples of 25/10/05 for sites J and K, had conductivities that fall in the ideal range of less than 700 μS/cm based on Botswana Bureau of Standards drinking water standard (Botswana Bureau of standard (2000). For the sampling carried out on 9/6/2005, the flood water had just arrived into Maun and had not reached points downstream of point F. The flood front (points D and E) had high EC, about 600 μS/cm, as the flood water had dissolved salts that had dried out previously or flushed water, concentrated in salts by evaporation, from the previous season. At point K, salt accumulation over the years would lead to high EC since flows had not gone beyond this point for over 5 years due to inadequate flow. Sawula and Martins (1991) determined that there was an increase in the concentration of solutes along the Boro from the upper reaches of the delta to the Boro–Thamalakane junction. The variation of EC over the whole period is discussed with reference to point E. Initially (9/6/2005), the floods had just passed this point. The EC was high (584 μS/cm) as a result of the flood front dissolving solutes or flushing salts. The EC quickly decreased as the main flood water, which had had most of its solutes removed by the Okavango Delta, passes through (31 μS/cm on 29/07/05). The conductivity then increased to 36 μS/cm on 19/08/05 and 99 μS/cm on 25/10/05 due to evaporative effects. A decrease was observed on 29/11/05 as the water diluted by rain water. There does not seem to be any introduction of material of high EC into the water system by run off or human activities.

3.5. Dissolved oxygen

The dissolved oxygen was in the range 1.85–8.81 mg/l for all sampling sites and dates (Fig. 4d). The initial sampling in June gave a dissolved oxygen content of 5.3–6.1 mg/l. This dropped to 1.85–4.22 mg/l in July, probably as a result of decomposition of organic matter. Subsequent sampling in August and September saw an increase of the dissolved oxygen but a sharp decrease in

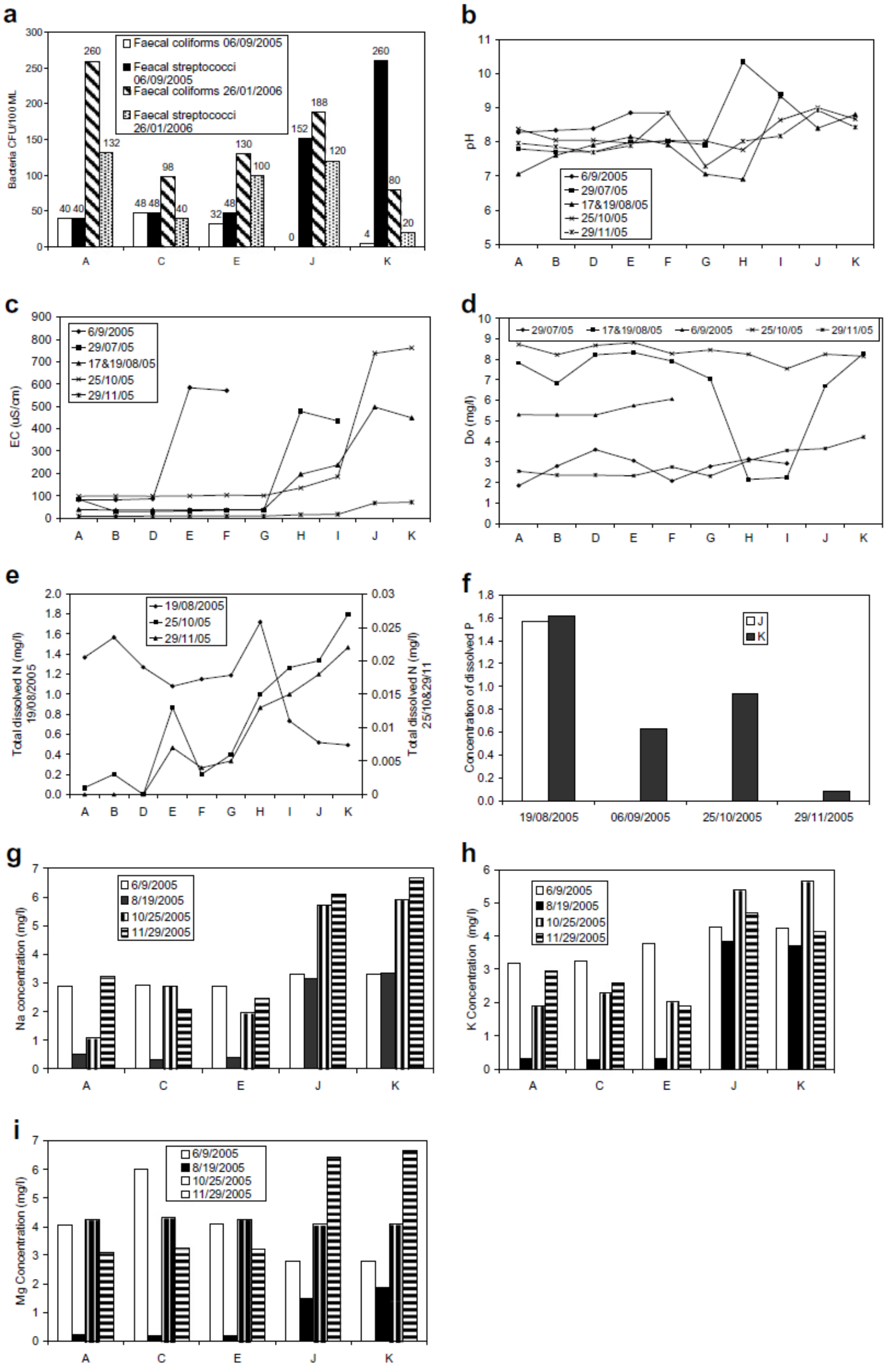

Fig. 4. Variation of *Faecal coliforms/streptococci* (a), pH (b), EC (c), dissolved oxygen (d), total dissolved nitrogen (e), total dissolved phosphorus (f), sodium (g), potassium (h) and magnesium (i) from June 2005 to January 2006 along the Thamalakane and Boteti Rivers.

November when the water levels were low. It should be noted that in August, there was a sharp decline in the dissolved oxygen between points G and I, probably indicating introduction of organic matter in the water which consumed oxygen during decomposition. The decrease in dissolved oxygen generally was accompanied by a corresponding decrease in pH. Decomposition of organic matter results in the lowering of the pH as acidic products are formed in the process. It should be noted that there was a sharp decline in the dissolved oxygen concentration from point F to I for the sampling conducted on 17th and 19th of August and a small dip from point H to point I for 25th October, probably as a result of anthropogenic introduction of oxygen consuming material into the water. The same material may also be responsible for the sharp reduction in pH at the same times (Fig. 4b).

3.6. Total dissolved Nitrogen and phosphorus

Due to instrument problems, total dissolved nitrogen (TN) and phosphorus (TP) were determined only for the months of August, October and November 2005. The results are shown in Fig. 4e and f. The highest concentrations of TN were observed in August (range 0.49–1.72 mg/l, mean 1.11 mg/l). For this month, there was a general decreasing trend from points A to point J, except for points B, E and H. The increase at these points may indicate introduction of nitrogen containing material, probably as fertilisers at point B, since this point was close to a vegetable garden. The increase at point H coincides with the decrease in DO and pH noted above. The organic-rich material that was introduced in the vicinity of point H also had high nitrogen levels. This point is downstream of two hotels. The activities of these hotels and water quality at this point need to be monitored further. Since the river is an outlet of a wetland, it is expected that the water in the study area would be low in nutrients. This is not borne out by the results of samples collected in September. It would appear that either nitrogen is introduced into the water by activities upstream of the study area (there are some vegetable fields) or the delta might act as a reservoir of nitrogen, which are flushed out during the early part of the flood. The concentration of dissolved N for the October and November 2005 samples were low, probably as a result of depletion of the nitrogen by aquatic organisms and dilution by the rains. Concern from fertilisers use has been reported in interviews with residents in Maun (Kgomotso and Swatuk, 2006).

Total dissolve phosphorus (TP) was only detected at Points J and K (Fig. 4f), all the other points registering concentrations less than 0.01 mg/l. At point J, the only sample with detectable TP was that collected in August 2005. At point K, the samples had high TP early in the flood (August 2005) due to concentration of materials containing phosphorus in the flood front. This decreased in September 2005 as the rest of the flood water came through, with possible P consumption by aquatic organisms and or deposition in sediments. The concentration increased in November 2005 due to evaporation effects exceeding depletion, and decreases in November due to dilution by rain.

3.7. Metal ions

The following metals were determined: Fe, Mn, Mg, Na, K, and Pb to investigate if any of these metals may be introduced into the water by activities along the river.

3.7.1. Na and K

Sodium may be introduced into water from detergents, soaps, bleaches and food. Water treatment may also introduce Na. K is used as a fertiliser and in food and drinks. Similar trends are observed for these metal ions. The concentrations of these metal was high with the onset of the floods, decreased as the flood front passed the sampling point and then increased again due to evaporative concentration (Fig. 4g and h). The highest concentrations were at points J and K, which would tend to accumulate salts as the pools at these points were not flushed during previous years (flood water did not flow past point K for at least 5 years). Masamba and Muzila (2005) found a general increase of these metals as the distance from Mohembo increased downstream along the Okavango–Maunachira–Khwai Channel of the Okavango Delta. Generally, anthropogenic introduction of these metals is not evident.

3.7.2. Mg

Mg is used in fertilisers, pharmaceuticals and food. It is also present in nature e.g. as magnesite and dolomite. Silcrete containing Mg was present along the river, especially around points J and K. The concentration of Mg follows a similar trend to that of Na and K, except that for the June 2005 sampling, the concentration decreased from point A to K with an anomalously high value at point C (Fig. 4i). The reason for this initial decrease is not clear. There is possibility that Mg containing substances were introduced into the water around point C around the June 2205 sampling.

3.7.3. Fe and Mn

Mn is used in steel alloys, batteries and food additives (Clesceri et al., 1998) where as iron is used in steel and other alloys. Mn was detected only three times, and in all cases, the values were rather low (Table 2). The highest value of 0.53 mg/l was observes at point K in the rainy season. Anthropogenic introduction of Mn is therefore not established, although the source of the Mn at point K would warrant further work. High values of Fe were observed during the rainy season, with point K giving the maximum Fe concentration of 6.89 mg/l (Table 2). For Fe, it appears that the dilution effects of rainwater are not sufficient to decrease the iron concentration, or rain water washes iron – containing substances into the water. No introduction of iron by human activities is indicated in this work, but it is possible that some iron containing minerals, such as silcrete, present along the river near points J and K may be responsible for the elevated Fe levels in the rainy season.

3.7.4. Pb

Lead compounds are known to be toxic. Lead is used in pigments, batteries, solder, insecticides and until recently, as an additive in petrol. The concentration of Pb was highest at the onset of the floods, and then decreased to low levels as the flood front passed through. The concentration increased again due to evaporative concentration, and then decreased due to dilution due to rainwater (Table 2). The maximum concentration was determined at point K on 29/11/2006. The reason for this is not understood.

Table 2

Concentration of iron (Fe), manganese (Mg), and lead (Pb) at each of the sampling sites along the Thamalakane and Boteti Rivers

Site	Date	Fe (mg/l)	Mn (mg/l)	Pb (mg/l)
A	9/06/2005	<0.01	<0.01	0.25
	19/08/05	<0.01	0.02	<0.01
	25/10/05	0.13	<0.01	0.25
	29/11/05	1.66	<0.01	0.08
C	9/6/2005	<0.01	<0.01	0.25
	19/08/05	<0.01	<0.01	<0.01
	25/10/05	<0.01	<0.01	0.24
	29/11/2005	1.65	<0.01	0.09
E	9/06/2005	<0.01	<0.01	0.25
	19/08/05	<0.01	<0.01	<0.01
	25/10/05	<0.01	<0.01	0.24
	29/11/2005	1.76	<0.01	0.12
J	9/06/2005	<0.01	<0.01	0.23
	19/08/05	<0.01	<0.01	<0.01
	25/10/05	<0.01	<0.01	0.24
	29/11/2005	6.67	0.17	0.21
K	9/06/2005	<0.01	<0.01	0.24
	19/08/05	<0.01	0.04	<0.01
	25/10/05	<0.01	<0.01	0.24
	29/11/2006	6.89	0.53	0.37

4. Conclusions

This work has shown that the Thamalakane shows temporal and spatial fluctuation in water quality. The water is generally of acceptable quality but in some cases guidelines set by Botswana Bureau of Standard (2000) are exceeded. This was the case with pH, Pb and electrical conductivity. The activities taking place in Maun seem to have little effect on the water quality. Effects that were observed that could be attributed to human activity include pH, total nitrogen and dissolved oxygen changes. For example, both the pH and dissolved oxygen decreased at points F to H in August 2005, and concentration of dissolved nitrogen increased around the same area. It is possible that organic material containing nitrogen was introduced at this time. Seasonal changes that occur e.g. for Na, K, total dissolved N, EC and dissolved oxygen can be explained by the fact that the area receives flood water during the dry season, the water then reduces in volume due to evaporation and then increases again due to rain water from November onwards. Concentrations therefore are high at the flood front, reduce when the front has passed and then increase again as the water evaporates in the hot summer months. During the rainy season, the concentrations of these parameters decrease. *F. coliforms* and *streptococci* were found to be low for open waters, probably because water flows are high during the dry season and there is little runoff due to low rainfall and the sandy soils prevalent in the area. The pH was fairly constant whereas concentration of Pb was low.

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