Assessment of the impact of point source pollution from the Keiskammahoek Sewage Treatment Plant on the Keiskamma River - pH, electrical conductivity, oxygen- demanding substance (COD) and nutrients

G Morrison[1], OS Fatoki[2*], L Persson[1] and A Ekberg[1]
[1]Water Environment Transport, Chalmers University of Technology, Goteborg, Sweden
[2]Department of Chemistry, University of Fort Hare, Alice 5700, South Africa

Abstract

The treatment performance of the Keiskammahoek Sewage Treatment Plant (KSTP), was assessed in terms of pH, conductivity, and COD and nutrients removal from the influent. The contributions from this and other smaller point sources in the town to these parameters in the receiving Keiskamma River were determined by simultaneously monitoring the parameters in the river over a period of about 1 month. The COD and orthophosphate in effluents exceed the SA Effluent Quality Standards for these parameters in effluents to be discharged into a river. Also, significant pollution of the receiving Keiskamma River was indicated for orthophosphate, COD and NH_4-N.

Introduction

The old South African Water Act (Act 54 of 1956) made it mandatory that effluents be treated to acceptable standards and returned to the watercourse from where the water was originally obtained. Thus, effluent discharge investigation is one of the water quality management tools the Department of Water Affairs and Forestry (DWAF) uses for the management of point-source effluent and the assessment of risks from point sources is an increasingly important tool in the hand of decision-makers (DWAF and WRC, 1995, WRC, 1997).

Sewage discharges are a major component of water pollution, contributing to oxygen demand and nutrient loading of the water bodies, promoting toxic algal blooms and leading to a destabilised aquatic ecosystem (DWAF and WRC, 1995; WRC, 2000). The problem is compounded in areas where wastewater treatment systems are simple and not efficient. Such is the case in the town of Keiskammahoek in the Eastern Cape (Fig. 1) that has inadequate water-borne sanitation. The domestic water supply for the community comes from the Keiskamma River which, owing to lack of proper sanitation, is polluted continually. Problems experienced by the Transitional Local Government with sewage discharges into the river escalated when RDP-housing units were connected to the Keiskammahoek Sewage Treatment Plant (KSTP) without any enlargement of the reticulation system. Bypassing due to overflows has occurred regularly since then. The existing treatment works was built as an anaerobic/aerobic pond system, which means that the sewage treatment occurs naturally without added chemicals. The problem of too high an inflow load results in a poor level of sewage purification and, as a result, pollution of the receiving river, the Keiskamma River.

Other point sources exist in Keiskammahoek, which also contribute to the pollution of the river. These include the SS Gida pump station (during malfunctioning of this pump station, raw wastewater bypasses the pumps and discharges straight into Gxulu River, a tributary of the Keiskamma River) and a waste dumpsite situated on a slope close to the riverbank (Fig. 1). A pump station connected to the RDP-housing units also poses a threat to the water quality in the Keiskamma River because it malfunctions regularly. During these circumstances, a small pond is supposed to store leaking wastewater, but within a few days overflow occurs and wastewater seeps down into the Gxulu River, which discharges into the Keiskamma River (Fig. 1).

The community of Keiskammakoek uses water from the Keiskamma River for a variety of purposes such as drinking, fishing, livestock watering and recreational purposes. The Sandile Dam is situated downstream of the town. Water from this dam is treated and supplied to the whole of the Keiskammahoek Transitional Local Council (TLC) area and the Middledrift District. Although it is possible to renovate polluted surface waters to potable standards, this would be both complex and very expensive (*Quality of Domestic Water Supplies*, 1998), which may make the supply unsustainable. Moreover, several communities use water from the Keiskamma River for domestic use without prior treatment and it is of great importance that the river remains in a "healthy" state. However, fears have been raised that due to the potential discharges from the KSTP, the river could be polluted excessively. This study attempts to investigate the short-term impact of pollution from the KSTP on the Keiskamma River using the water quality parameters – pH, electrical conductivity, chemical oxygen-demanding substances (COD) and nutrients as indicators of pollution.

Low pH values in a river affect aquatic life and impair recreational uses of water (DWAF, 1996b;1996c). A change in pH from that normally encountered in unimpacted streams affects the biota (DWAF 1996c). High pH values could also alter the toxicity of other pollutants in the river. For example, ammonia is much more toxic in alkaline water than acid because free ammonia (NH_3) at high pH values (pH > 8.5) is more toxic to aquatic biota than when it is in the oxidised form (NH_4^+) (DWAF, 1996c; Hammer 1975). It also "strips" out into the atmosphere and is lost from the

* To whom all correspondence should be addressed.
☎(040) 602-2094; fax: (040) 60 2-2094; e-mail: OFatoki@ufh.ac.za
Received 19 February 2001; accepted in revised form 13 August 2001.

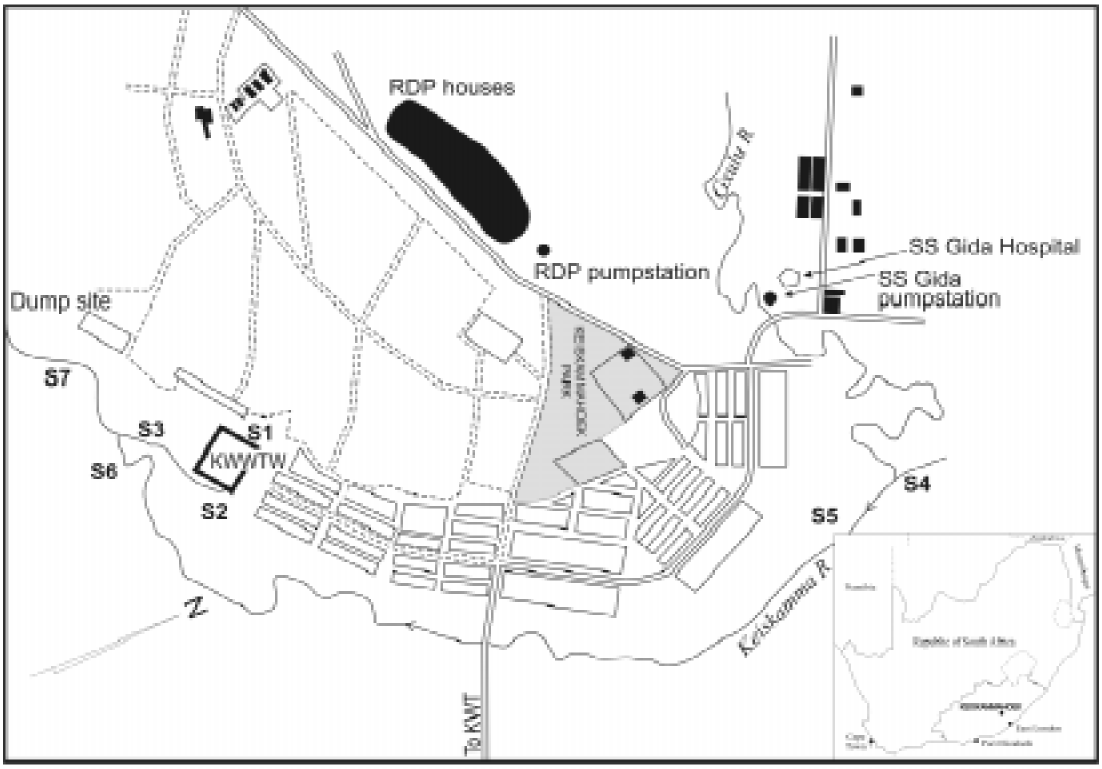

Figure 1
Map of Keiskammahoek showing the sampling sites

water. A decrease in pH could also decrease the solubility of certain essential elements such as selenium. Human populations from areas polluted by acid rain are at risk of being subject to selenium deficiencies (DWAF, 1996a). Low pH also increases the solubility of many other elements such as Al, B, Cu, Cd, Hg, Mn and Fe (DWAF, 1996c).

Electrical conductivity of water is a useful and easy indicator of its salinity or total salt content. Wastewater effluents often contain high amounts of dissolved salts from domestic sewage. Other sources of salts include windblown sea salt, municipal storm water drainage and industrial effluent discharges. Build-up of salts from domestic wastes and waste brines can interfere with water reuse by municipalities, industries manufacturing textiles, paper and food products, and agriculture for irrigation. Salts such as sodium chloride, and potassium sulphate pass through conventional water and wastewater-treatment plants unaffected (Hammer, 1975). High salt concentrations in waste effluents can increase the salinity of the receiving water, which may result in adverse ecological effects on aquatic biota (Fried, 1991). Also, a very high salt concentration (> 1 000 mg/ℓ) imparts a brackish, salty taste to water and is discouraged because of the potential health hazard (WHO, 1979, Quality of Domestic Water Supplies, 1998). For this reason electrical conductivity can serve as a useful salinity indicator when considered with other factors and when a natural geological origin does not apply in terms of the source of dissolved salts.

COD measures the equivalent of that portion of the organic matter in a sample that is susceptible to oxidation by a strong chemical oxidant. It is an important parameter for stream and industrial waste studies and control of waste treatment plants (*Standard Methods*, 1976). The old SA guideline for COD in wastewater effluents that were to be discharged into the river is 30 mg/ℓ (*Government Gazette*, 1984). There are no water quality criteria for COD in the new *SA Water Quality Guidelines* for domestic, recreational or aquatic ecosystem uses (DWAF, 1996a-c).

Nitrate in waste effluents can originate from domestic and agricultural wastes, especially from N-containing fertilizers. High nitrate concentrations are frequently encountered in treated wastewater, as a result of ammonium nitrogen (which is prevalent in raw waste) being totally or partially oxidised to nitrate by microbiological action. Significant nitrate contamination of raw drinking water is found in areas of high population pressure and agricultural development (Fried, 1991). High nitrate levels in waste effluents could also contribute to the nutrient load of the receiving waters and so contribute to eutrophication effects, particularly in freshwater (Fried, 1991; OECD, 1982; WRC, 2000). Also, high (natural) nitrate levels (up to 145 mg/ℓ as N) are found in some areas of South Africa. Phosphate in sewage effluents arises from human wastes and domestic phosphate-based detergents. Phosphates are undesirable anions in receiving waters and act as the most important growth-limiting factor in eutrophication and result in a variety of adverse ecological effects (OECD, 1982; WRC, 2000).

The potential health risk from nitrate in drinking water is linked to the condition known as methaemoglobinemia in infants and pregnant women (Bush and Meyer, 1982; Canter, 1987). Whilst this condition occurs very rarely, and only with water containing more than 30 mg NO_3^--N/ℓ, it is still a cause for concern.

Ammonium-N is extremely soluble and is readily transported by surface runoff from cultivated lands (DFID, 1999) and it is also a major component of raw sewage. It occurs in water as a breakdown product of nitrogenous material. Ammonia, formed only at high pH values (pH > 8.5) is extremely toxic to fish and other aquatic life at high concentration (> 2.0 mg/ℓ N).

Realisation of these undesirable consequences has led many local and national authorities, including South Africa, to set up stringent guidelines for their control in surface waters and wastewater. This study reports the levels of pH, conductivity, COD, nitrates, phosphates, ammonium-N in the wastewater effluents from the KSTP and in the receiving Keiskamma River. It also assesses the impact of discharges from the KSTP and other sources on the river by comparing these indicator values with the South African guidelines.

Materials and methods

Sampling and sample location

The sampling points were chosen to evaluate the environmental impact on Keiskamma River of point source pollution from the TLC area, particularly from the town's main sewage treatment plant (i.e. KSTP). The measurement points are designated S1 to S7 (Fig. 1) and they reflect different activities along the watercourse of the receiving Keiskamma River. The study was carried out in November 1999.

Site S1 was located at the inlet to the Keiskammahoek STP where influent samples were collected. Due to a low flow after the grit screen, samples were taken in the inlet to the primary settling ponds. Site S2 was located at the effluent discharge point from the Keiskammahoek STP before it reaches the wetland (the qualities of influents and effluents were measured at these two points to determine the efficiency of the treatment plants in removing those parameters from the influents). Site S3 was a point located approximately 135 m after the effluent discharge point in a wetland area. There has been considerable interest on the potential of the use of wetlands to purify wastewater effluents and so it is important to know its impact on the effluent quality. Site S4 was the reference point and was located about 110 m upstream of the junction between Keiskamma and Gxulu River. Site S5 was located 230 m downstream of the merging point of the Keiskamma and Gxulu Rivers at an old constructed dam to investigate the impact of the drains from the SS Gida pump-station. Measurement point S6 was chosen in order to investigate the impact of settlement activities from the town of Keiskammahoek on the river. The point was situated downstream of Vaal Draai, but upstream of the merging point of the Keiskamma River and the effluent from the Keiskamma STP. Site S7 was a point approximately 100 m downstream the KSTP effluent discharge point to the river. This was to assess the impact of the effluent discharge on the river.

Water samples were collected at the different sampling sites between 1 and 18 November 1999. The sampling period was short because the investigation of the impact of pollution from the KSTP on the river demanded urgent attention. People's health is at stake so are our water resources and ecosystem health. A short-term study would give an indication of the impact of pollution from the KSTP on the river. Samples were collected in glass containers, pre-cleaned by washing with non-ionic detergents, rinsed in tap water, in 1:1 hydrochloric acid and finally with deionised water before usage. Before sampling, the bottles were rinsed three times with sample water and then filled. Samples from all measurement points were filtered for all parameters except for pH, conductivity and COD analysis. Blank determinations were performed for COD, nitrate, phosphate and NH_4-N and results were adjusted for blank measurements in the presented results. New standards were created for each parameter during every measuring week.

Determination of pH, conductivity, COD, NO_3^-, PO_4^{3-} and NH_4-N in samples

The pH of water was measured with the Labinnet pH meter HI 8424 immediately after sample collection. The pH was temperature-adjusted with an electrode in 3M KCl + AgCl electrolyte. The electrode was calibrated with 2 solutions - pH 4 and 7 before use.

A Hanna HI 8333 conductivity meter was used to measure the conductivity values of samples. These were also temperature-adjusted. The instrument was calibrated with 0.001 M KCl to give a value of 14.7 μS/m at 25°C.

The concentrations of COD, phosphate, nitrate and ammonia-nitrogen were determined using a DR/890 HACH instrument. For the COD determinations (range 0 to 1 500 mg/ℓ COD), 2 mℓ of water sample was added to a COD digestion reagent vial containing $K_2Cr_2O_7$ and heated for 2 h before measurement was done with the meter (DWAF, 1992). Detection limit was estimated as 30 mg/ℓ.

The concentrations of orthophosphate in samples were determined using the ascorbic acid method by reacting it with added reagent containing molybdate and an acid to give a blue-coloured complex (*Standard Methods*, 1976; DWAF, 1992). The detection limit for the procedure was 0.05 mg/ℓ PO_4^{3-}. The orthophosphate values obtained were converted to dissolved phosphorus concentrations using a conversion factor of 0.3261 following the instrument's instructions.

Nitrate as N was determined by the cadmium metal method (*Standard Methods*, 1976; DWAF, 1992). The cadmium metal in the added reagent reduced all nitrate in the sample to nitrite. The detection limit for the method was 0.2 mg/ℓ NO_3^- as N. Ammonium-N was determined with the instrument by the salicylic acid method (DWAF, 1992). The detection limit for the procedure was estimated as 0.01 mg NH_3-N/ℓ.

Results and discussion

The results of the short measurement campaign are shown in Tables 1 and 2. The pH values varied between 6.6 and 7.4 in the influent stream and between 6.9 and 8.0 in the effluent from the STP. The old SA guidelines for pH in effluents that are allowed to be discharged into a river are in the range of 5.5 to 7.5 (*Government Gazette*, 1984). The pH values of effluents are slightly above this range. The passage of effluents through the wetland had some effect on the pH with values varying between 6.9 and 7.3 after passage through the wetland, which is lower than 8.0 quoted above (S3) (Table 1).

The pH values in the river also varied between 6.6 and 7.4. The SA target water quality range for pH in water for domestic use is 6 to 9 (DWAF, 1996a, *Quality of Domestic Water Supplies*, 1998) and the target water quality range for pH in water for full contact recreation is 6.5 to 8.5 (DWAF, 1996b). The pH values obtained for the river fell within this range. Based on these guidelines, the pH of the river water would not adversely affect its use for domestic or recreational purposes.

A comparison with an earlier report by Stemele Bosch & Associates (1999) on the study sites shows some similarities with a maximum pH of 8.1 obtained at Site S7 in their study. There are neither major industries nor mining activities in the area that could cause extreme changes in the pH of the effluents or of the receiving river. Thus, the results obtained for pH measurements in the river and in the effluent discharges were as expected.

Electrical conductivity values varied between 105.0 mS/m and 111.0 mS/m in influent (S1) and ranged from 61.0 to 76.0 mS/m in effluent (S2). The old SA guideline for conductivity in effluent that

TABLE 1
pH, conductivity, COD and nutrients levels in influent and effluent from the Keiskammahoek Sewage Treatment Plant for samples taken in November 1999

Sampling sites	Date	Parameters					
		PH	Conductivity, µS/m	COD, mg/ℓ	PO_4^{3-} as P, mg/ℓ	NO_3^- as N, mg/ℓ	NH_3 as N, mg/ℓ
S_1	1/11	6.6	N.D.	605.0	2.2	0.6	10.9
	11/11	7.4	111.0	793.0	11.9	1.1	70.4
	15/11	6.9	105.0	1 001.0	13.7	1.2	94.4
	18/11	6.8	N.D	N.D	3.9	0.6	N.D
Average ± S.D.		**6.9±0.3**	**113.0±2.8**	**799.7±198.1**	**7.9±5.7**	**0.9±0.3**	**58.6±43.0**
S_2	1/11	8.0	76.0	351.0	7.5	2.5	32.7
	11/11	7.5	63.0	230.0	3.8	<0.2	23.3
	15/11	7.2	61.0	238.0	6.8	<0.2	53.3
	18/11	7.2	N.D	N.D	3.4	0.2	N.D
Average ± S.D.		**7.5±0.4**	**66.7±8.1**	**273.0±67.7**	**5.4±2.1**	**1.4±1.6**	**36.4±15.3**
S_3	1/11	7.3	78.0	548.0	6.1	0.6	29.5
	11/11	7.8	61.0	296.0	3.9	1.3	24.7
	15/11	6.9	31.0	116.0	1.6	<0.2	3.7
	18/11	7.4	N.D	N.D	3.0	0.9	N.D
Average ± S. D.		**7.4±0.4**	**56.7±23.8**	**320.0±217.0**	**3.7±1.9**	**0.9±0.4**	**19.3±13.7**

TABLE 2
pH, conductivity, COD and nutrients levels in the receiving Keiskamma River for samples taken in November 1999

Sampling sites	Date	Parameters					
		PH	Conductivity, µS/m	COD, mg/ℓ	PO_4^{3-} as P, mg/ℓ	NO_3^- as N, mg/ℓ	NH_3 as N, mg/ℓ
S_4	4/11	6.6	21.0	38.0	0.2	0.9	0.1
	9/11	6.8	22.0	74.0	0.03	0.7	<0.1
	18/11	7.3	19.0	N.D	0.05	0.3	<0.1
Average ± S.D.		**6.9±0.4**	**20.7±1.5**	**56.0±25.5**	**0.1±0.1**	**0.6±0.3**	**-**
S_5	4/11	6.7	22.0	N.D	0.1	0.9	0.1
	9/11	6.9	23.0	N.D	0.04	0.8	<0.1
	18/11	7.2	21.0	40.0	0.1	0.3	<0.1
Average ± S. D.		**6.9±0.3**	**22.0±1.0**	**-**	**0.1±0.03**	**0.7±0.3**	**-**
S_6	4/11	7.1	26.0	N.D	0.2	0.8	<0.1
	9/11	7.1	26.0	41.0	0.03	0.8	<0.1
	18/11	7.3	24.0	N.D	0.1	0.3	<0.1
Average ± S.D		**7.2±0.1**	**25.3±1.2**	**-**	**0.1±0.1**	**0.6±0.3**	**-**
S_7	4/11	7.4	24.0	48.0	0.2	0.9	0.1
	9/11	7.3	30.0	32.0	0.2	0.8	0.6
	18/11	7.2	26.0	63.0	0.3	0.5	0.5
Average ± S. D.		**7.3±0.1**	**26.7±3.1**	**47.6±15.5**	**0.2±0.1**	**0.7±0.2**	**0.4±0.3**

will be discharged into the river is 250 mS/m (*Government Gazette*, 1984). The effluent conductivity values are within this acceptable limit. Further removal of salts contributing to conductivity occurs during passage of the effluent through the wetland as the values decreased further to an average value of 56.7 mS/m at Site S3 (Table 1).

Electrical conductivity values in the river varied between 19 .7 mS/m at S4 (i.e., reference site) and 30.0 µS/m at S7. These values also compared well with values obtained by Stemele Bosch & Associates (1999) in their earlier studies proving that environmental conditions in the TLC have not changed drastically since the last study. The South African acceptable limit for conductivity in domestic water supply is 70.0 mS/m (*Quality of Domestic Water Supplies*, 1998). This limit was not exceeded in the river water samples and the parameter does not give cause for concern, but the effluent discharge doubled the electrical conductivity in the river (compared to values at the reference site), which indicates a large impact.

Influent concentrations of COD varied between 605.0 mg/ℓ and 1001.0 mg/ℓ. Though there was some purification (50 % reduction) regarding COD in the treatment plant, the values are still extremely high in effluent and varied between 230.0 mg/ℓ and 351.0 mg/ℓ. The passage of the effluent through the wetland did not seem to significantly improve the removal of chemical oxygen-demanding substances from the effluent before they enter the river course, because COD levels at S3 averaged 320 mg/ℓ (Table 1). The old South African guideline for COD in effluents to be discharged into the river is 30 mg/ℓ (*Government Gazette*, 1984). The effluent values were almost ten times higher than the acceptable limit. This indicates the inefficiency of the treatment plant in removing chemical oxygen-demanding substances in the influent.

Analysed samples for COD in river water were at concentrations ranging from 32.0 mg/ℓ to 74.0 mg/ℓ. Though there are no COD guidelines in the new *SA Water Quality Guidelines* (DWAF 1996a-d), the oxygen-free water entering the Sandile Dam, downstream would have negative effects on the freshwater quality as well as cause harm to the aquatic life in the dam with potentially dire consequences on the aquatic biota (e.g. fish).

Nitrate values were low both in influent and in effluent. The influent nitrate values ranged from 0.6 to 1.2 mg NO_3^- as N/ℓ and the effluent values varied between <0.2 mg NO_3^- as N/ℓ and 2.5 mg NO_3^- as N/ℓ. The low values of nitrate in the influent might possibly be due to loss of NO_3^- via denitrification. The old South African guideline for nitrate in sewage effluents is 1.5 mg/ℓ NO_3^- as N (*Government Gazette*, 1984) and this guideline was met in 87% of the effluent samples.

Nitrate levels in the river water varied between 0.3 mg NO_3^-/ℓ as N and 0.9 mg NO_3^-/ℓ as N for all the sites sampled (Table 2). Owing to toxicity (Bush and Mayer, 1982), due to risk of anaemia in infants and pregnant women and formation of carcinogenic nitrosamines, the nitrate content of domestic water supply is regulated by national and international bodies. The South African guideline for domestic water supply (DWAF, 1996a) states a limit of 6 mg NO_3^- as N/ℓ as a safe limit for babies. None of the samples from the Keiskamma River exceeds this limit. Thus, nitrate concentration is not considered to pose a problem for the domestic use of water from the river. However, nitrate is a problem for other uses because of eutrophication (OECD, 1982).

Orthophosphate levels in effluent varied between 3.4 mg PO_4^{3-} as P/ℓ and 7.5 mg PO_4^{3-} as P/ℓ. The South African guideline for phosphate in effluent is 130 g/ℓ PO_4^{3-} as P. (DWAF, 1988). This limit was exceeded by at least 26 order of magnitude in all the effluent sewage samples.

The levels of phosphate in the river water ranged from 0.03 to 2 mg/ℓ PO_4^{3-} as P (Table 2). The SA guideline for P in water systems that will reduce the likelihood of algal and other plant growth is 5 µg/ℓ (DWAF, 1996c). This guideline value was always exceeded in the river and would cause eutrophication in the river; especially in the Sandile Dam situated downstream of the effluent discharge point.

Water from the Sandile Dam is abstracted and treated to supply water to Keiskammahoek and eutrophication could increase treatment costs through filter clogging in water treatment works (WRC, 2000). Also, the incidence of eutrophication could adversely affect the use of the river for recreational purposes as the covering of large areas by macrophytes could prevent access to waterways and could cause unsightly and malodorous scums, which would make recreation unpleasant. In addition, the high nutrient values could lead to the growth of blue-green algae, which could release toxic substances (cyanotoxins) into the water. Cyanotoxins are known to have caused the death of farm livestock (Holdsworth, 1991).

Ammonium-N concentration in the influent stream ranged from 10.9 to 94.4 mg/ℓ NH_4-N while in the effluent the values averaged 36.4 mg/ℓ NH_4-N. The passage of the effluent over the wetland further removed the ammonia in the effluent as the concentration in the effluent dropped to an average of 19.3 mg NH_4-N/ℓ with values varying between 3.7 mg/ℓ NH_4-N and 29.5 mg NH_4-N/ℓ. The old South African guideline for ammonia in effluent was 1.5 mg/ℓ at pH > 8.5 (*Government Gazette*, 1984). Due to the toxicity to fisheries and aquatic life, the European Union has set a safe limit of 0.005 – 0.025 mg NH_3-N/ℓ (Chapman, 1996). The South African guideline for ammonia in water for domestic use is 1 mg NH_3/ℓ (DWAF, 1996a) while the guideline in water for the use of aquatic ecosystem is 7 µg NH_3/ℓ (DWAF, 1996c). At the pH values at which measurements were taken in the effluent and in the river water samples (< 8.5), there was no free ammonia present in the system (DWAF, 1996c; Hammer, 1975). Therefore, this parameter would not be likely to pose a problem in the river if the water is used for domestic and aquatic ecosystem purposes. However, diurnal pH changes (caused by algal and macrophyte photosynthesis) would be expected to raise pH values to between 8.4 and 9.0 in the period around midday each day. Thus, NH_4-N would pose temporary toxicity with the NH_4-N ion being transformed into NH_3.

Significant pollution of the river was indicated for orthophosphate, COD and NH_4-N due to the point-source discharge. There is a need to monitor this parameter regularly in the effluents and in the river water and this should be given urgent attention by the water authorities in the area. It is also important to upgrade the sewage treatment plant to improve its treatment performance for these parameters. The KSTP in its present state seems to do very little in the way of “treatment’ and people’s health is at stake and so are our water resources and the health of the ecosystem.

Conclusion

The pH, electrical conductivity and nitrate levels in effluents were below guideline values. However, significant pollution of the river was indicated for orthophosphate, COD and NH_4-N from the point source. The high orthophosphate levels would be very harmful to the river, as it would encourage eutrophication, especially at Sandile Dam situated downstream of the effluent discharge point. This could increase the treatment cost of water withdrawn from this dam, which may adversely affect the supply of water to local communities. The high nutrient values in the river would also affect its uses for other purposes, e.g. recreational and livestock watering. The KSTP needs to be upgraded to improve its treatment performance.

Acknowledgment

We thank SIDA for the MFS scholarship offered to L. Persson and A. Ekberg for their minor field study at the University of Fort Hare.

References

BUSH D and MEYER M (1982) A case of infantile methemoglobinemia in South Dakota. *J. Environ. Health* **44** 310-311.

CANTER LW (1978) Nitrate and pesticides in groundwater: An analysis of a computer-based literature search. In: Fairchild-Lewis DM (eds.) *Ground Water Quantity and Agricultural Practises*. Clesea MI.

CHAPMAN D (1996) *Water Quality Assessments* (2nd edn.) E & FN, Spon, London.

DFID (1999) *A Simple Methodology for Water Quality Monitoring*. Pearce GR, Chaudhry MR and Ghulum S (eds.). Department for International Development, Wallingford.

DWAF (1988) Important Announcement on Implementation of the Special Phosphate Standard in Sensitive Catchments. IMIESA (Johannesburg) **13** (9).

DWAF (1992) Analytical Methods Manual, TR151. Department of Water Affairs and Forestry, Pretoria.

DWAF and WRC (1995) South African Water Quality Management Series. Procedures to Assess Effluent Discharge Impacts. WRC Report No TT 64/94. Department of Water Affairs & Forestry and Water Research Commission, Pretoria.

DAWF (1996a) South African Water Quality Guidelines.**1**: Domestic Water Use (2nd edn.) Department of Water Affairs & Forestry, Pretoria.

DWAF, 1996b) South African Water Quality Guidelines. **2**: Recreational Water Use (2nd edn.) Department of Water Affairs & Forestry, Pretoria.

DWAF (1996c) South African Water Quality Guideline. **7**: Aquatic Ecosystems (1st edn.) Department of Water Affairs & Forestry, Pretoria.

FRIED J J (1991) Nitrates and their control in the EEC aquatic environment. In: Borgadi I and Kuzelka D (eds.) *Nitrate Contamination, Exposure, Consequences and Control*. NATO ASI Series G30, Ecological Sciences. Springer-Verlag, Berlin. 55-63

GOVERNMENT GAZETTE(1984) Requirements for the Purification of Wastewater or Effluent. Gazette No 9225, Regulation No 991, 18 May.

HAMMER M J (1975) *Water and Waste-Water Technology*. John Wiley & Sons, Inc. New York.

OECD (1982) Eutrophication of Waters: Monitoring, Assessment and Control. Technical Report, Organization for Economic Cooperation and Development, Paris.

QUALITY OF DOMESTIC WATER SUPPLIES (1998) Assessment Guide. **1**. DWAF, WRC and Department of Health, Pretoria.

RAST W and JA THORNTON (1996) Trends in eutrophication research and control. *Hydrol. Processes* **10** 295-313.

STANDARD METHODS (1976) *Standard Methods for the Examination of Water and Wastewater* (14th edn.) Jointly published by the American Public Health Association, America Water Works Association and Water Pollution Control Federation, Washington, DC.

STEMELE BOSCH & ASSOCIATES (1999) Environmental Scoping Report for the Conveyance, Treatment and Disposal of Wastewater for the Town of Keiskammahoek, in the Eastern Cape. CEN Integrated Environmental Management Unit, Port Elizabeth.

WRC (1997) Risk Assessment for Water Quality Management. Report No TT 90/97.

WRC (2000) National Eutrophication Monitoring Programme. Implementation Manual. Draft Report, Water Research Commission, Pretoria.

WRC (2001) Perspectives on Eutrophication of Surface Waters: Policy / Research Needs. Water Research Commission, Pretoria.

WHO (1979) *Sodium Chlorides and Conductivity in Drinking Waters*. World Health Organization, Copenhagen.