Long-term deterioration of water quality of the Mvoti Estuary, KwaZulu-Natal, South Africa

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The Mvoti Estuary located on the eastern seaboard of South Africa is known for its poor water quality. In the present study, concentrations of dissolved oxygen (DO), ammonia, nitrates, chloride, sulphates, sodium and calcium were assessed together with conductivity and pH, compared to legislated guidelines and to previous studies of 1964 and 2000. The results indicate that with the exception of calcium, the Mvoti system has been experiencing long-term deterioration. Presently, ammonium ions, nitrate and chloride exceed the acceptable guideline target limits, and DO levels are extremely low. The biotic integrity of the system is therefore seriously compromised with the threat of detrimental effects to all users if mitigation measures aimed at improving water quality are not implemented.

Keywords: Aquatic ecosystems, deterioration, domestic use, estuary, water quality.

THE South African coastline boasts of some 343 estuaries, 292 of which lie along the wetter Indian Ocean coastline[1], most of which are relatively small by global standards[2]. More than 70 estuarine systems occur along the KwaZulu-Natal coastline on the eastern seaboard of South Africa, many of which have been intensely developed[3]. River-dominated estuaries, maintained principally by fluvial discharge, are especially well-developed in the province and a large number of the open estuaries located here are dominated by fluvial discharge[4].

The Mvoti Estuary geographically located at 29°24′S; 31°21′E (Figure 1) is a river-dominated estuary on the subtropical, microtidal coast of KwaZulu-Natal[5]. Despite being relatively small, the approximately 197 km long Mvoti River which feeds the estuary, serves as a principal resource for many towns and various informal settlements along its course, as well as the sugar processing industry, the pulp and paper industry, and chemical industry in its lower reaches[4]. About 1% of the 2730 km^2 Mvoti catchment[6] is urbanized and approximately 57% has been modified from its original state for agricultural purposes, predominantly commercial sugarcane farming and forestry[7]. Subsistence agriculture is also a common practice throughout the catchment.

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Geologically, the catchment is varied containing dominantly sedimentary rock formaions (shales and sandstones) with some outcrops of granite and gneiss. The estuary itself is surrounded by recent sediments (Berea Red Sand, siltstones and shale) with some dolerite outcrops close to the coastline[8]. A southward-extending sand barrier is present at the estuary mouth, making it a typical bar-built estuary[8,9]. This sand barrier is over 1 km long and is capable of detaching the estuary from the marine environment during low flow periods[9]. A northward-extending sand barrier (Figure 2) is sometimes formed during winter closing off a section of the estuary and leading to the formation of a lagoon. This barrier is often breached to prevent flooding of the adjacent sugarcane fields. Breaching is sometimes necessary as the lagoon formation leads to a minimal outflow rate and consequently, a rapid accumulation of pollutants within the estuary[9]. With time, further degradation of the estuary, which is already in a poor condition, is imminent.

The river is presently experiencing a number of environmental problems resulting from poor catchment practices and irresponsible utilization of the river itself[10].

Sukdeo *et al.*[10] identified some of these environmental concerns as modifications of the river channel and riparian zones to facilitate water abstraction and sand-mining activities, excessive siltation of the river and estuary, as

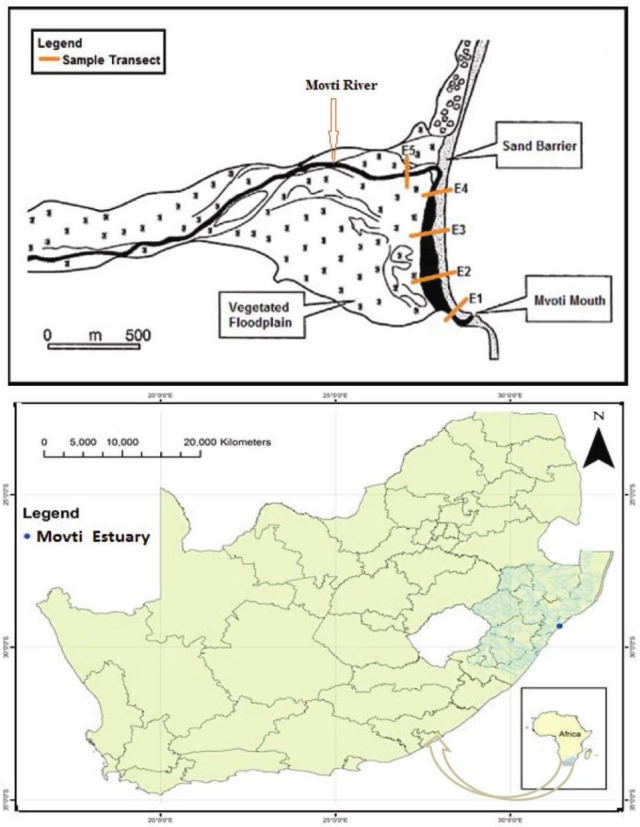

Figure 1. Schematic representation of the Mvoti Estuary and sampling transects (adapted from Cooper[3]).

well as industrial and municipal discharges into the system. As noted by Russell[11], all these factors inevitably influence the water quality of the system.

The large number of functions and services that the estuary provides relative to its size, and the fact that it is severely degraded and fed by a 'working river'[4] emphasize the urgency with which it needs to be prioritized in terms of protection, conservation and rehabilitation. According to Tharme[12], the habitat integrity of the Mvoti River has been reduced to a very low level with the river ecosystem being severely modified. While previous studies into the water quality of this system have been documented, a number of them have been fairly brief and short-term.

The aim of the present study was to assess the current water quality within the Mvoti Estuary (averaged for the period between 2010 and 2012), and compare these results against South African Water Quality Guidelines[13], as well as available water quality data for the estuary dating back to 1964 and 2000. Further, results of the study are used to assess the implications presented by poor water quality upon human utilization of the resource and prevailing aquatic ecosystems.

Concentrations of nutrients, dissolved oxygen (DO), ammonia (NH_4), nitrate (NO_3), chloride (Cl), sulphate (SO_4), sodium (Na), calcium (Ca), as well as the levels of DO, conductivity and pH values in the Mvoti Estuary were recorded and averaged for the period between 2010 and 2012 (shown as 2012 in Figure 3 *a–i*). The Mvoti Estuary itself is fairly small with an area of approximately 18.04 ha and length of approximately 2.40 km (ref. 9) and five sample sites were selected for this study (Figure 1). The sites are located within close proximity to sample sites of the previous studies to facilitate comparative assessment.

Onsite recordings were carried out for DO, pH, NH_4 and conductivity using the YSI 6920 Multi-parameter Sonde and the 650 MDS Multi-parameter Display System. For laboratory analysis, water samples were collected in sterile sample jars and stored on ice until analysis. Concentrations of Cl, NO_3 and SO_4 were measured using ion chromatography, while Ca and Na concentrations were measured using via inductively coupled plasma optical emission spectroscopy (ICP-OES) and flame photometry methods respectively.

Comparison of the results from the present study with previous studies[8], done on the estuary in 1964 was statistically assessed using *t*-test. The results were also graphically compared with data collected in 2000 (ref. 5). Data obtained in the present study were further evaluated against guidelines set out by the Department of Water Affairs and Forestry (DWAF), South Africa[12,13], the objective of which was to highlight the implications of the current estuarine water quality for aquatic ecosystems and human use. Accordingly, standards for aquatic ecosystems within the DWAF guidelines[13] were used. These are also the most appropriate standards as, to date, no comprehensive guidelines governing estuarine contaminants have been developed for South Africa[3]. For human utilization, results of the water quality analysis were also evaluated in accordance with the guidelines stipulated for domestic use[14]. All statistical analysis was conducted using SPSS 15.0® for Windows®.

Waters of the Mvoti catchment are used by the agricultural, industrial and domestic sectors, resulting in a range of impacts on water quality[4]. Concentrations of the measured parameters extracted from secondary data presented by Begg[8] for analysis done in 1964; MacKay *et al.*[5] and primary data of the present study are presented in Table 1 together with statistically significant results. The results presented in Table 1 indicate statistically significant differences in the water quality parameters between 1964 and 2012.

With the exception of Ca, which recorded a decrease in concentration over time, all other parameters yielded statistically significant increase in concentration over the period of comparison (Figure 3). This overall increase in contaminant levels has been accompanied by a concomitant decrease in DO. Levels of contaminants closer to the Mvoti mouth (E1) were lower than those recorded in the

Figure 2. The mouth of the Mvoti Estuary showing the well-developed sand barrier and the deceptively pristine-looking estuary.

Table 1. Measurements of the water quality parameters recorded at the Mvoti Estuary in 1964 (after Begg[8]), 2000 (ref. 2) and 2012. The *P* values associated with the *t*-tests between 1964 and 2012 are also given

Parameter	1964	2000	2012	Significance (*P* value)
Dissolved oxygen (mg/l)	2.7	5.03	1.11	0.000
Conductivity (μS cm)	409	960.67	674.33	0.000
Nitrate (mg/l)	0.125	0.22	1.04	0.006
Ammonium (mg/l)	0.1	0.24	498.69	0.041
Chloride (mg/l)	34.75	200.58	119.31	0.000
Sulphate (mg/l)	2.75	21.07	49.99	0.000
Sodium (mg/l)	26.3	138	60.62	0.010
Calcium (mg/l)	50.8	22	18.77	0.000
pH	7.05	7.55	7.8	0.02

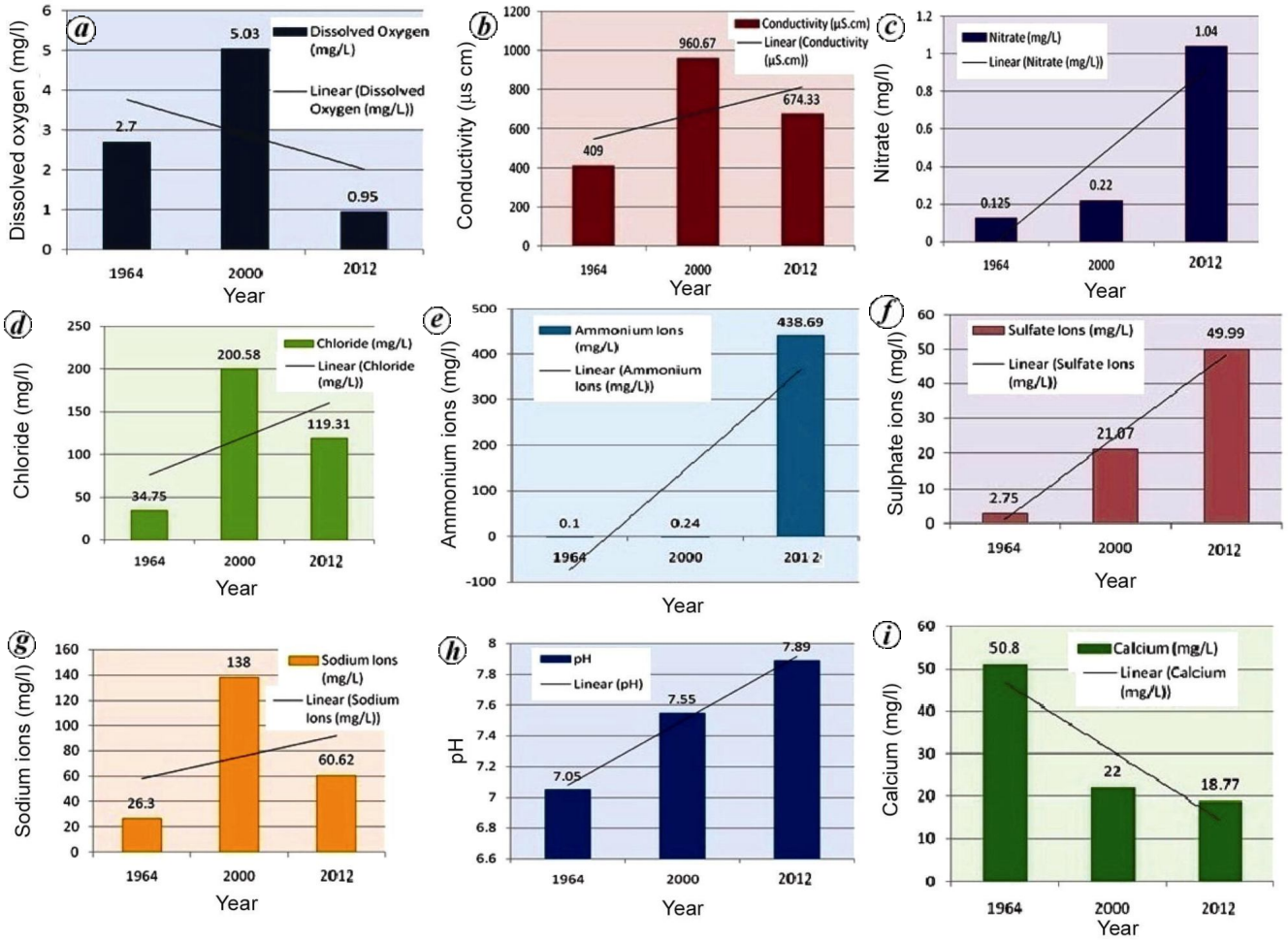

Figure 3. Changes in the level of water quality in the Mvoti Estuary between 1964 and 2012. ***a***, Dissolved oxygen; ***b***, Conductivity; ***c***, Nitrate; ***d***, Chloride; ***e***, Ammonium ions; ***f***, Sulphate ions, ***g***, Sodium ions; ***h***, pH; ***i***, Calcium.

mid and upper sections of the estuary (E2, E3 and E4), and generally displayed an increasing trend in the upstream direction indicative of catchment-derived sources.

In unpolluted surface waters, DO concentrations are usually close to saturation[13]. Shortages of DO, as is the case in polluted aquatic systems, could be lethal for aquatic aerobic organisms. Historically, the Mvoti system has been known to be highly polluted with effluents emanating from informal settlements, and the town of Stanger located between 5 and 10 km upstream of the estuary. During the present study, extremely low levels of DO, averaging at 1.11 mg/l, were recorded in the estuary, making it hypoxic (DO concentration < 2 mg/l). Comparisons of DO levels show significant differences in the estuary over the past decade. There is a marked decrease of approximately 22% in the levels of DO between 2000 and 2012, and a drop of approximately 41% between 1964 and 2012 (Figure 3 *a*).

The presence of excessive organic matter in aquatic systems increases the biochemical oxygen demand (BOD) and chemical oxygen demand (COD) during its breakdown. The main industries with the potential for increasing organic loading in the Mvoti Estuary are the sugar milling and the paper and pulp processing plants located approximately 4 km upstream. These plants discharge a considerable amount of treated effluent and wastewater into the Mvoti River. Sewage effluent may also cause reduction of DO in aquatic systems[14]. The Mvoti system receives treated sewage effluent from the adjacent town of Stanger via the Mbozambo River approximately 5 km upstream of the estuary. Nutrient loading from all of these sources requires quantification and regulation, if necessary.

In general, the conductivity of the Mvoti estuarine water has increased over the years, as seen in Figure 3 *b*. The waters of the Mvoti Estuary are known to contain high levels of nutrients, particularly nitrates, sulphates and sodium, enhancing electrical conductivity levels[9]. The local municipality has recently forbidden any recreational activity in the Mvoti Estuary; therefore, the variations in conductivity levels are most likely a reflection of the changing nutrient inputs from anthropogenic activities in the catchment.

Significant increases in nitrate concentrations have occurred between 2000 and 2012 (Figure 3 *c*). High nitrate levels present a range of effects on aquatic ecosystems. The South African water quality guidelines provide no specific target water quality ranges for nitrate levels in aquatic ecosystems, but do prescribe optimum levels for ecosystem functioning at below 0.5 mg/l (ref. 13). According to the guidelines, mesotrophic conditions ensue at levels between 0.5 and 2.5 mg/l (ref. 13).

In oligotrophic conditions, such as those occurring in 2000, moderate species diversity can be expected, together with low productivity, rapid nutrient cycling and no excessive growth of aquatic plants or algal blooms. In mesotrophic conditions, high species diversity and high productivity with nuisance growth of aquatic plants and blue-green algal blooms occur. However, these are seldom toxic.

Eutrophic conditions ensue at nitrate levels of 2.5–10.0 mg/l. Here, species diversity is low and productivity of the system is high[13]. Excessive growth of aquatic plants and blue-green algal blooms, some species of which are toxic to humans, livestock and wildlife may also occur. The same effects can be noticed for hypertrophic conditions, such as those experienced in the Mvoti Estuary in 2012 when nitrate levels were > 10mg/l (ref. 13).

Major sources of nitrates in aquatic systems are effluent containing human and animal excreta, organic industrial wastes and agricultural fertilizers[13]. Unimpacted surface waters in South Africa usually have levels of nitrate that are below 0.5 mg/l (ref. 13). However, heavy utilization of the Mvoti catchment and river system has led to considerable enrichment of nitrates in the estuarine waters.

Levels of ammonium ions in the Mvoti Estuary have increased considerably between 1964 and 2012 (Figure 3 *e*). The recorded values have greatly exceeded the target water quality range of ≤ 7 µg/l for aquatic ecosystems[13], reaching levels that are grossly unacceptable according to DWAF guidelines. Concentrations between 7 and 15 µg/l often result in reduced growth and morphological development rate for aquatic organisms, and impairment of hatching success. There is also the possibility of pathological changes in the tissues of gills, liver and kidneys. At levels of > 100 mg/l, ammonia affects the respiratory systems of many animals and often results in fish death[14].

In terms of domestic use, high ammonia levels have rendered the estuarine water unfit for domestic use. Levels between 2 and 10 mg/l are likely to compromise the taste and odour of the water, and levels > 10 mg/l are completely unacceptable[14].

Levels of chloride in the estuary have also experienced an overall increase over the years. There is a decrease noted between 2000 and 2012 (Figure 3 *d*). This, however, does not have much significance for overall health of the estuary, as the levels have always exceeded the target water quality range of 0.2 µg/l for aquatic ecosystems[12]. Exposure to chloride levels > 0.35 µg/l may result in gill damage, changes in blood chemistry, hampered growth rates, loss of equilibrium and death of fish, while in invertebrates, immobility and reduced reproduction and survival have been noted[13].

With regards to flora, aquatic plants may become chlorotic, and photosynthesis and respiration are hindered in phytoplankton[13].

The target water quality range for domestic use is 100 mg/l (ref. 14). When chloride values range between 100 and 200 mg/l, there are no health or aesthetic effects but there is an increase in the corrosion rate of domestic appliances. At levels between 200 and 600 mg/l, as observed in 2000 and 2012, corrosion rate would increase with no health effects but the water develops a distinct salty taste[14].

Chlorides are often used to remove unwanted tastes and odours, and to disinfect water. Large amounts of chloride-containing compounds are commonly present as bleaching agents and slimicide in the textile, and pulp and paper industries. One of the most prominent industries on the lower Mvoti floodplain is a large pulp and paper mill. This mill had recently upgraded part of its chemical treatment process to reduce odour emissions[9]. While no point source data are available, a water quality survey of the estuarine waters by Chili[9], before and after the implementation of the new process, showed a considerable increase in the levels of chloride present in the estuary after the implementation of the new process.

Increases in sulphate ions have also been noted within the system between 1964 and 2012 to almost 50 mg/l (Figure 3 *f*). According to DWAF[13], there are no health hazards for human consumption presented by concentrations of sulphate between 0 and 200 mg/l. However, as this concentration increases, so too does the likelihood of digestive system complications, if the water is consumed[14].

The concentrations of sodium recorded in the estuary for 2012 have increased by approximately 230% in comparison to 1964 (Figure 3 *g*). There are no health effects associated with use of water containing sodium levels < 200 mg/l for domestic purposes[14]. However, concentrations between 200 and 400 mg/l are not suitable for consumers on a sodium-restricted diet, and levels exceeding this range are also not suitable for infants[14].

Calcium concentrations have actually decreased within the estuarine waters over the study period (Figure 3 *i*). There are no health effects associated with higher levels of calcium in water used for domestic purposes[14]. However, high levels of calcium when present with magnesium, usually in the form of magnesium carbonate and calcium carbonate, may render the water hard.

As shown in Figure 3 *h*, while the pH of the estuary water has experienced very small variations over the years, these differences are statistically significant (Table 1).

Figure 4. Discoloured, highly polluted waters of the Mvoti Estuary.

The waters have remained more or less neutral, while in some instances reaching mildly alkaline and mildly acidic conditions. Acidification of water, according to DWAF[13], is commonly attributed to effluents from the pulp and paper, tanning and leather industries.

The Mvoti Estuary is a typical South African freshwater system which remains predominantly neutral, with pH values ranging between 6 and 8 (ref. 13). In terms of the target water quality range for domestic use, all values fall within the acceptable limits of 6–9 pH units.

If one considers that the Mvoti system has had a history of high pollutant levels from anthropogenic sources, it is important that regular flushing of the system occurs to reduce the potential for long-term damage to the biota of the system.

The Mvoti is currently in a degraded state in terms of its water quality. It is also evident that this deterioration is not new to the system. The pollution in this disturbed estuary has been increasing over the years, consequently deteriorating the water quality. Despite the fact that pH values are within acceptable limits, the estuary contains very high levels of nutrients and correspondingly low levels of DO. The Mvoti system is known to be polluted with effluents from formal and informal settlements, the towns and industries located on its floodplain causing major degradation. This is clearly evident in the distribution of pollutants in the estuary, where the highest concentrations were recorded at the upper reaches of the system, indicating that pollution sources are most likely upstream of the estuary and not within it.

Since majority of the water quality parameter values did not comply with the target ranges according to the South African water quality guidelines, there are serious negative implications for estuarine biota and human health. Hence, the system is in urgent need of monitoring, rehabilitation and management. While at times, visually the estuary may appear to look aesthetically pleasing, alarming signs of pollution abound on a closer examination (Figure 4).

There appear to be signs of eutrophication in the system signalled by significant algal growth; the water and visible underlying sediments appear discoloured, and unpleasant odours continuously emanate from the system. Other visible signs of pollution, particularly along the river banks, include flocculation and foaming of the water at numerous sites.

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