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Biological Assessment of the state of the water quality in the Mbuluzi River, Swaziland

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Abstract
Biomonitoring is increasingly becoming important in the monitoring of water resources. A study investigating the water quality of the Mbuluzi River (Swaziland) was done using the South African Scoring System (SASS): a water quality determination index based on the families of aquatic invertebrates at a site. Invertebrate taxa were allocated sensitivity scores according to the water quality conditions they are known to tolerate. Three scoring categories [**SASS Score, Number of Taxa** and **Average Score per Taxon (ASPT)]** were used where both SASS Score and ASPT decreased with declining water quality.

Fourteen sites along the river were identified and SASS sampling carried out. Temperature, pH, conductivity, turbidity, dissolved oxygen (DO), and total dissolved solids (TDS) were measured at each site. Both invertebrate taxa and the physical properties of the water showed distinct regional similarities, grouping sites into the four geographical regions of Swaziland (Highveld, Middleveld, Lowveld and Lubombo Plateau). The mountain streams with DO up to 8mg/l at 21^0c and turbidity <5NTU had most invertebrates (30 types) and the highest ASPT score (7.1). Impacted sites in the Lowveld with low DO levels (3mg/l); high conductivities (>500 µs/cm) and high turbidities (>30NTU) recorded fewer taxa (14 types) and the lowest score (3.57).

Key words: *SASS, South African Scoring System, Bioassessments, Biomonitoring, Benthic macro invertebrates, and biotopes*

Introduction

Water is a basic human resource upon which society relies hence aquatic ecosystems must be protected and properly managed. Global environmental policies increasingly emphasise the need to protect ecosystems rather than to rely on their ability to recover from disturbances. This necessitates the adoption of response measurements to quantify ecological conditions and monitor ecological change. Using biological field assessments such as macro invertebrates provides an integrated and sensitive measurement of environmental problems and signifies progress in management of water resources through the assessment of ecological impacts.

This work presents a study whose objective was to carry out biological assessment using SASS version 5 to determine the water quality "state" of the Mbuluzi River and to identify potential problem areas in the Mbuluzi basin. The intent was to demonstrate whether SASS was a useful water quality-monitoring tool that could be applied confidently in Swaziland. Relationships between SASS results obtained in the Mbuluzi and those obtained in the Incomati in South Africa were explored. The aquatic macro invertebrate community of the Mbuluzi River was examined and physical parameters (Dissolved Oxygen, pH, Conductivity, Turbidity, Total Dissolved Solids, Salinity and Temperature) measured along side the biomonitoring. Water quality conditions in the river were then established based on the macro invertebrates and the physical characteristics.

The study area

The Mbuluzi river basin covering an area of about 3100 km^2 extends from the Ngwenya hills, through the north-central part of Swaziland and into Mozambique. The Mbuluzi River is a major source of water for agricultural activities in the basin, irrigating about 15 000 ha of sugarcane, Swaziland's largest foreign exchange earner, and the most important cash crop. It is also a major source of water for domestic rural and urban water supplies. The Ngwenya town and the Mbabane city, Swaziland's capital are supplied from the Hawane dam, located along the river. Mbuluzi is also a source of water supply to Ngomane, Tambankulu and Simunye towns as well as other sugar cane and citrus irrigation schemes through the Mnjoli dam. Major development activities in the catchment are sugar cane plantations, sugar cane processing plants and the settlements which came about as a result of the afore mentioned.

According to the 1986 census, the average population density in the less densely populated areas (on Swazi National Land) was 43 people/km^2 and Population density in company towns within the catchment was recorded at over 240 people/km^2. The national growth rate for the 1986 census was estimated at 3.4 percent per year while the 1996 census estimated a growth rate of about 2.7 percent.

A total of fourteen (14) sampling points were established throughout the basin putting careful consideration to ensuring that selected sites represent the full spectrum of sub regions within the river. Fig 1 below presents a map of the study area.

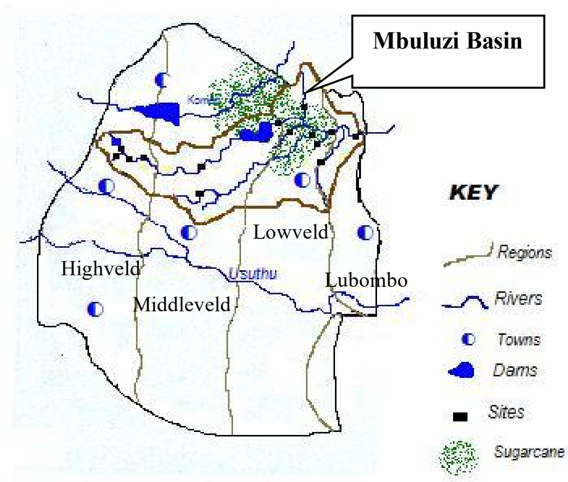

***Fig 1**. Map of study area*

Materials and methods

Site selection

Map based information and local knowledge played a major role in the selection of sites. Regular flow, accessibility and safety during sampling operations were also considered. Ground-validation of potential sites was done to assess the suitability of sites with respect to habitat/ biotope availability, accessibility, safety, and anthropogenic activities such as land use and water quality conditions. Site codes were given following the standard RSA Rivers Health Programe method where each code begins with the secondary catchment code, the river basin code then an abbreviation of the location. For example **W60AMBU-HAW** (Mbuluzi river at Hawane area). For ease of location and reference, sites were then labeled 1 to 14 based on their spatial location in the basin.

Once sites were established, the biomonitoring commenced. In accordance with the recommended seasonal SASS sampling procedures, each site was assessed twice within a four-month period (Summer season). The first sampling was done in 7 days in January (24th –31st) after the first summer rains and the second sampling was conducted in March (3rd -8th) towards the end of the rainy season.

Physical characteristics

Onsite physical analyses were undertaken to assess existing water quality conditions in the river during sampling. In situ measurements of temperature, dissolved oxygen (mg/l and % saturation), conductivity and salinity were done using the YSI 85 Dissolved Oxygen Meter. A probing pH meter was also used to record pH on site. Water samples were collected from each site and total dissolved solids and turbidity were then analysed for at the Water Resources Branch laboratory in Mbabane. Based on flows at gauging stations along the Mbuluzi River, an estimation of water flows in the river at the time of sampling was also made to help in the analysis and interpretation of the results. Results were recorded in the standard SASS 5 form (extracted from Dickens and Graham 2002) as well as the Ecological Reference Condition Field-data Sheets (designed by Dallas 2000).

Macro-invertebrates

Benthic macro invertebrates were sampled using the general SASS 5 sampling procedure as outlined by Dickens and Graham (2002). Biotopes at each site were separated into three SASS biotope-groups namely stones in current (SIC)/ stones out of current (SOOC), marginal vegetation (MV)/ aquatic vegetation (AQV) and gravel, sand and mud (GSM). The ecological reference condition field manual (Dallas 2000) was followed to complete the sampling. Results for each sampling site were recorded in the Ecological Reference Condition Field-data Sheets and later entered into the South African Rivers Database designed by Ewart-Smith *et al* 2003.

Data Analysis

Multivariate procedures were selected for analyses of macro invertebrate assemblages and the *Primer Version 5*-software package for windows was used. The Bray-Curtis coefficient was used for community structure analysis of the biological data. In accordance with Clark & Warwick 1994, cluster analysis aimed at finding 'natural groupings' of samples and non-parametric multidimensional scaling (MDS), which maps samples to reflect the similarity of their biological communities were used. Hierarchical agglomerative clustering, using group average linking was used to produce dendograms.

Results and Discussion

The results obtained in this study were divided according to the sites in the different geographic regions, which also happen to cover the different river reaches. Similar sites located within each region were grouped and the results analysed for the whole region before being compared to the other regions.

Table 1: Physical Analysis Results-January and March 2004

Site No	*Site Code*	*Locality name*	*Temp*		*PH*		*Conductivity*		*Tot Diss Solids*		*Salinity*		*Diss Oxy*		*Diss oxy*		*Turbidity*	
	Units		(^{0}c)		(pH units)		(µs/cm)		(mg/l)		(ppt)		(mg/l)		(%)		(NTU)	
HIGH VELD																		
	Sampling Period		Jan	Mar	Jan	Mar	Jan	Mar	Jan	Mar	Jan	Mar	Jan	Mar	Jan	Mar	Jan	Mar
1	W60AMBU-HAW	Hawane	23.7	21.2	6.8	6.8	5.2	5.6	3.3	3.6	0	0	6.8	6.9	81	78	7	5
2	W60AMBU-MAN	Mantjolo	20.4	20.3	6.8	6.8	3.4	3.2	2.2	2.1	0	0	7.2	6.5	80	71	6	4
3	W60AMBU-MAB	Mabhala	22.8	19.4	6.8	6.8	5.0	5.4	3.2	3.5	0	0	7.1	7.0	83	77	14	5
4	W60BMBU-MAH	Mahebedla	21.8	19.1	6.8	6.8	4.2	5.0	2.7	3.2	0	0	7.5	7.2	85	79	4	10

MIDDLE VELD																		
5	W60GMBZ-NYA	Nyakeni	34.0	24.2	7.2	7.2	21.8	15.0	13.9	9.6	0.1	0	10.4	6.8	132	81	39	60
6	W60CMBU-KUT	Kutsimleni	30.5	26.2	7.0	7.2	8.8	8.8	5.6	5.6	0	0	7.1	10.6	94	130	50	24
7	W60FMBU-MNJ	Mnjoli	29.5	28.0	7.4	7.4	22.4	11.6	14.3	7.4	0.1	0	6.8	9.7	89	124	80	32
LOW VELD																		
8	W60FMBU-MPF	Manzampofu	28.6	26.0	8.0	8.0	538.0	370.0	344	237	1.3	0.9	13.5	11.3	166	139	17	51
9	W60JMBZ-CONF	Mbuluzana	27.6	25.6	7.8	8.0	209.8	94.6	134	61	0.5	0.2	12.0	10.0	142	123	14	47
10	W60KMBU-DIST	Distillery	25.6	24.3	7.8	7.8	337.0	336.0	215	215	0.8	0.9	3.1	5.7	38	68	2	2
11	W60FMBU-MHL	Mhlume	25.6	24.7	7.8	7.8	204.0	127.0	131	81	0.5	0.3	12.6	11.5	147	139	11	30
12	W60KMBU-NOK	Nokwane	28.3	26.5	7.8	7.8	168.0	117.0	107	75	0.4	0.3	12.1	9.9	146	124	13	75
LUBOMBO PLATEAU																		
13	W60KMBU-MLW	Mlawula	30.8	26.9	8.0	8.2	200.0	193.8	128	124	0.4	0.5	9.3	11.1	125	133	7	7
14	W60KMBU-SIW	Siweni	30.5	26.8	7.8	8.0	167.2	115.6	107	74	0.4	0.3	7.9	10.4	106	129	13	35

Temperature and pH

Average temperature values were 21^0c for the Highveld, 29^0c for the Middleveld, 26^0c for the Lowveld and 28^0c in the Lubombo. The mountain streams of the Mbuluzi River were cool owing to the cool climate of the Highveld and the forest vegetation that shades the water from direct sunlight. The widening of the river due to feeding tributaries in the Middleveld, Lowveld and the Lubombo enabled more sunlight to penetrate, increasing water temperatures.

pH values ranged from 6.8 in the Highveld to 8.2 in the Lubombo (refer to table 1). The pH ranges were observed to be natural, owing to the natural geology of the areas. No influence of land use activities was observed. Results conformed with the observations of Davies and Day, (1998), that most fresh waters have pH values ranging between about 6 and 8.

Conductivity, Total Dissolved Solids and Salinity

Conductivity ranged from 3.4 to 5.2 µs/cm in the Highveld while in the Middleveld it was from 8.8 µs/cm to 22.4 µs/cm. Much higher conductivity values were observed in the lowveld. Manzampofu (site8) had the highest conductivity at 538 µs/cm followed by Distilery (site10) at 337 µs/cm. Other Lowveld sites had comparable results (Table 1 refers). A reduction in the conductivity was observed at the Lubombo. Conductivity values were lower during the second visit after experiencing several rainfall events.

As observed with conductivity, total dissolved solids were very low in the Highveld increasing slightly in the Middleveld, rising considerably in the Lowveld and then dropping again in the Lubombo. Saline water conditions occurred only in the lowveld and Lubombo as a result of the leaching rock surfaces that underlie those areas. Distillery and Manzampofu were the most saline measuring 0.8ppt and1.1ppt respectively.

The low conductivities in the Highveld were because mountain streams drain rocky areas with very little loose soil and comprise hard rocks that weather slowly hence the minimal leaching of minerals into the water. The Middleveld had slight differences due to abiotic processes like leaching of minerals and the activities of the living communities upstream. Increased leaching of minerals, the washing away of material, agricultural activity and pollution from the Distillery factory resulted in the high conductivities and total dissolved solids in the Lowveld. Increased volumes of water in the Lubombo facilitated dilution and there was natural purification of the river as it flowed undisturbed through the Mlawula nature reserve.

Turbidity

Low turbidities were measured in the Highveld. In the Middleveld, values ranged from 37 NTU at Kutsimleni (site6) to 80 NTU at Mnjoli (site7), located, a kilometre downstream of the Mnjoli Dam. The Distillery site (site10), measuring effluent from the Distillery factory had the lowest turbidity value (2 NTU), which was much lower than that of the mountain streams. The river water was most turbid during the second sampling visit where rains had been experienced four days before sampling.

The high turbidities of the Mnjoli site were a result of the nature of Mnjoli dam, an earth dam with releasing valves only located at the bottom of the dam. Due to the absence of multiple release valves along the profile of the dam, only the bottom water (muddy) is released. The very low turbidity values at the Distillery site resulted from the extensive artificial purification of the effluent from the distillery factory, removing the suspended material, leaving the pollutants in dissolved form.

Dissolved Oxygen

Average DO values ranged between 6.8 mg/l to 7.1 mg/l in the Highveld and the Middleveld varied from 8.3mg/l to 8.9 mg/l. The Lowveld recorded the highest levels on both occasions. Distillery (site10) had the lowest DO of all fourteen sites on both occasions. For most of the Lowveld sites, the percentage saturation was well above 100%.

Re-aeration was high in the Highveld and the Middleveld due to the turbulence caused by the steep mountainous terrain that exist there. Bubbles of air from the atmosphere into the river were incorporated as it tumbled over the boulders and stones of the mountain streams. Nutrient enrichment from the sugar cane fields caused the DO levels above 100% saturation in the Lowveld by increasing the vegetation and algal growth in the river. As these photosynthesised, the water became highly supersaturated with oxygen during the day. Excessive amounts of organic material loaded from the Distillery factory resulted in an increase in bacterial populations in the river thereby increasing oxygen use as these organisms respired.

Macro-invertebrate assemblages

Most of the life forms of invertebrates were found in the mountain streams. These comprised of mayflies (ephemeroptera), stoneflies (plecoptera), caddisflies (trichoptera), damselflies and dragonflies (odonata) and a variety of true flies/ diptera. The most sensitive families found in this river such as Oligoneuridae, Heptagenaide, Perlidae, Telaganodidae and Pyralidae occurred here. The middle reaches (Middleveld) had different taxa such as water penny beetles (Psephenidae) and the damselflies (Chlorocyphidae and Calopergygidae) still indicating good water quality. Leeches, shrimps (Atyidae), the cainflies (Caenidae) and the gastropods Lymnaeidae, Physidae, Planorbinae, Thiaridae, Corbiculidae and Sphaeridae were characteristic of the lower reaches (Lowveld and the Lubombo Plateau). Two sensitive taxa, Oligoneuridae and Heptageniide occurred at Nokwane (site12) much further downstream after being last observed at Kutsimleni (site6) in the Middleveld.

The heterogeneous nature of the river provided different biotopes for specialized species to dwell in hence the differences in the distribution of macro invertebrates. Commonly occurring families throughout the regions were crabs (Potamonautidae) at 12 sites, worms (Oligochaeta) at 13 sites, the damselflies (Coenagrionidae) at all sites, dragonflies (Libellulidae) at 13 sites, the creeping water bugs (Naucoridae) at 12 sites, the riffle beetles (Elmidae) at 13 sites as well as the midges (Chironomidae) at all sites.

SASS 5 scores

On average, the mountain streams of Hawane (site1) and Mantjolo (site 2) had the highest species richness with ASPT scores of 6.7 and 6.6 respectively. Mabhala (site 3) and Mahebedla (site 4) had lower scores (both taxa and ASPT) despite being in the Highveld. On average, Mabhala had 15 taxa with an ASPT of 5.1 and Mahebedla also had 15 taxa with an ASPT of 5.6. Pumping of excessively large volumes of water from the river to supply the city of Mbabane to the detriment of the river's natural ecosystem at Mabhala caused a reduction in invertebrate taxa and in SASS Scores. Habitat alteration by the sedimentation of the river resulting from overgrazing and leaching of minerals from nearby small-scale agricultural fields caused the disparity in Mahebedla (site 4).

Within the Middleveld, more taxa and the most sensitive were found at Kutsimleni. Since the widest range of invertebrates was found in this region, the ASPT scores for all these sites were all above 6. In the Lowveld, number of taxa ranged from 15 to 20 with the exception of Distillery, which had 14 during first sampling. The ASPT scores were also comparable with Distillery recording the lowest on both occasions. As a result of the sensitive taxa, Oligoneuridae and Heptageniide, Nokwane, recorded high scores (6.53 and 6.25 respectively) on both occasions despite being in the Lowveld.

High conductivities and TDS occurring within the sugarcane fields indicate impairment in the water quality. This explains the lower numbers of taxa and SASS scores found in the Lowveld. Microorganisms thrived until the dissolved oxygen in the water became a limiting factor to their survival as shown by results from the Distillery site. The occurrence of pollution sensitive species in Nokwane indicate improving water quality conditions as shown by the results. This implies that even though the water quality of the river generally deteriorates in the Lowveld, it picks up again soon after leaving the sugarcane fields.

Whilst very high numbers of taxa (25 and 26), were recorded at Mlawula in the Lubombo, low ASPT scores resulted implying that most of the invertebrates there had low sensitivity scores. Measuring taxa above 20 and ASPTs above 5 at Siweni implies that the river is not in a bad state as it leaves Swaziland for Mozambique. Figure 2 below shows a graphic presentation of the SASS 5 data (SASS Scores Vs ASPT) for all sites recorded in both visits.

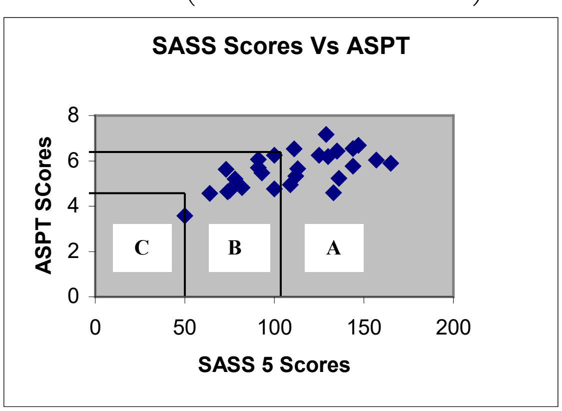

Fig 2: *A graphic presentation of the SASS 5 data*

Of the 28 records from the 14 sites, 17 fell in Class A. These were generally all sites with SASS scores >100 and ASPT >6. Within the same category, some sites had ASPTs below 6 yet still recording SASS scores >100, implying natural water quality conditions according to Chutter, 1998. Class B comprised of sites with SASS scores between 50 and 100 and ASPT <6. Ten records fell within this category and these were the sites within the sugarcane fields. Chutter describes these as borderline cases between natural water quality and some deterioration in the water quality. Class C characterized by SASS scores <50 and ASPT <4 had only one record from the Distillery site. Such scores indicate a major deterioration in water quality. Overall, invertebrate communities and SASS scores indicate that natural water quality conditions exist in the Highveld and Middleveld of the Mbuluzi and some deterioration occurs in the Lowveld but the conditions improve again once the river leaves the sugarcane fields. Major deterioration in water quality conditions is observed at the Distillery site. The same is supported by the physical analyses of the Mbuluzi River.

Community analyses

In the analysis of the data to test its statistical significance, it was found that macro invertebrate assemblages clustered largely by geographical region and formed distinct groups. One group comprised of sites from the Highveld and the Middleveld, with similar invertebrates and comparable physical and chemical properties. Another comprised of the minimally impacted sites from the Lowveld. The sites from the Lubombo region also grouped together. Comparison of ecoregional data between the Swaziland rivers (Mbuluzi and Mbuluzana) and the South African rivers (Komati, Crocodile and Sabie) revealed that similar invertebrates occurred in these rivers but there were differences in terms of abundances and scores. Factors such as stream widths and depths, substratum composition, biotope availability as well as the seasons in which the sampling was done may be responsible for these differences. The direct comparison of sites using different SASS versions contributes to these differences as SASS 4 was primarily used to collect all the data in Mpumalanga while SASS 5 has been used in Swaziland. Additional SASS assessments will provide greater insight into these observed differences.

Conclusions

1. SASS is an effective tool for bioassessments. Although the tool was initially derived for use in South Africa, it can be applied outside the South African borders with meaningful results. Although originally intended for assessing organic pollution, SASS appears to be sensitive to other riverine perturbations such as water abstraction and habitat degradation.
2. The Highveld and Middleveld of the Mbuluzi are more similar to each other in terms of their river conditions as well as their macro invertebrate communities. Similarly, the Lowveld sites within the sugarcane fields share similar characteristics. Different conditions from those of the Lowveld exist in the Lubombo Plateau.
3. Invertebrate communities, SASS scores and Physical characteristics of the river indicate that natural water quality conditions exist in the Highveld and Middleveld of the Mbuluzi and some deterioration occurs in the Lowveld but the conditions improve again once the river leaves the sugarcane fields into the Lubombo. Major deterioration in water quality conditions occurs at the Distillery site.
4. Ecoregional similarities between the Swaziland Rivers and South African rivers (Komati, Sabie and Crocodile) in the Mpumalanga exist. SASS has shown that similar

invertebrate types occur in all these rivers within the different ecoregions. However, there are differences in terms of invertebrate abundances and scores.

Recommendations

There is a need for continued sampling of the Mbuluzi River over the other seasons (autumn, winter, spring) that were not sampled to have complete seasonal variation records and to be able to compare with the South African rivers data properly. Once complete records, incorporating seasonal variations have been ascertained, further investigation has to be conducted to check the strength of similarities and differences in the data from these rivers. This would be useful in determining whether the established reference sites in Mpumalanga can be used as reference for Swaziland Rivers or if Swaziland specific reference sites need to be established.

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