Chapter 1

Ecosystem Approach to Managing Water Quality

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Additional information is available at the end of the chapter

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Abstract

This chapter argues for the ecosystem approach to managing water quality, which advocates the management of water, land and the associated living resources at the catchment scale as complex social-ecological systems and proactively defend and protect the ecological health of the ecosystem for the continuing supply of ecosystem services for the benefit of society. It argues for a shift from the engineering-driven command and control approach to water resource management. Environmental water quality (EWQ) is discussed as a holistic and integrated tripod ecosystem approach to managing water quality. Water physico-chemistry, biomonitoring and aquatic ecotoxicology are discussed as and their application and limitation with respect to water quality management, particularly in South Africa, is critically evaluated. The chapter concludes with a case study illustrating the application of biomonitoring for the assessment of ecosystem health in the Swartkops River, Eastern Cape, South Africa. The macroinvertebrates-based South African Scoring System version 5 was applied at three impacted sites and one control site. Two of the three impacted sites downstream of an effluent discharge point had very poor health conditions. The urgent need for ecological restoration was recommended.

Keywords: aquatic ecosystems, biomonitoring, ecotoxicology, macroinvertebrates, pollution, water chemistry

1. Introduction

The sustainability of freshwater ecosystems is being threatened globally [1]. A growing human population, coupled with changing demography, increasing socio-economic development as well as urbanisation and industrialisation of freshwater ecosystems catchments are the major drivers of change, resulting in deteriorating freshwater quality and depleting quantity. Climate change and other human-induced influences will, in the foreseeable future, exacerbate the conditions of the already stressed freshwater ecosystems [2]. Globally, there is a growing recognition that the typical hard-engineering informed 'command-and-control' approach to managing freshwater ecosystems, particularly water quality, is no longer sustainable [3, 4]. The hard engineering command and control approach (CCP) arises out of the insatiable quest for humans to tame, control and command everything in the environment, including nature [4]. Its primacy is the development of water resources for the socio-economic benefits of human with little or no attention to the ecosystems that provide the resource base. It is, however, becoming increasingly clear that an alternative approach that takes account of both ecosystem sustainability and socio-economic development is needed for managing water resources, including water quality.

The ecosystem approach is a holistic and integrated management strategy with an appreciation of the ecosystem as the source of water as well as a water user with specific requirements in terms of water quality, quantity, in-stream ecological and riparian conditions as well as the overall health and functionality of the ecosystem [5]. It advocates the management of water, land and the associated living resources at the catchment scale as complex social-ecological systems [6]. It proactively defends and protects the ecological health of the ecosystem. It is becoming the preferred approach for managing water quality, for example, in Europe [7], Australia [8] and South Africa [9]. For example, the European Union Water Framework Directive (WFD, 2000/60/EC) explicitly recognises and consciously advocates the ecosystem approach to managing the surface water quality of water bodies within the EU member states. It mandates all EU members to maintain surface water quality in 'good status' and to restore degraded systems to 'good conditions'.

2. The ecosystem approach and water quality in South Africa

South Africa's ground-breaking water law provides for an ecosystem approach to managing water resources (National Water Act No. 36 of 1998). The strategies for achieving the ecosystem-oriented objectives of the Act are designed in the National Water Resource Strategy 2 (NWRS2) [5]. The NWRS2 provides for two complementary approaches, the Resource Directed Measures (RDM) and the Source Directed Controls (SDC).

The RDM are directed at protecting and using the water resources sustainably, in terms of water quality, ecological and riparian habitat conditions [5]. The RDM are composed of the national water resource-classification system, the ecological reserve, and the Resource Quality Objectives (RQOs). In South Africa, water resources are classified into three management classes: Class I (a resource with no noticeable or with minimal human impacts); Class II (a resource slightly or moderately impacted by human activities with little deviation from natural conditions); and Class III (a resource with significant impacts resulting in serious deviation from natural conditions) [5, 10]. Water resources in Classes I and II are given high management priority to keep them in good condition; while depending on the scenarios, efforts are made to restore the conditions of those in management Class III. The ecological reserve provides the legal basis for assessing and protecting the quality, quantity and reliability of water needed for the functioning and maintaining the aquatic ecosystem [9]. The RQO provides measurable quantitative and qualitative descriptions/objectives for the physical, biological and chemical attributes that should be protected. The RQOs thus capture the management class and the ecological requirements, giving directions on how a water resource should be managed to protect key ecosystem attributes and functionalities [11]. The determination of the ecological reserve involves derivation of the present ecological state (PES) of the water resource. The PES is determined by integrating biological, physical and chemical information, including fish, macroinvertebrates, geomorphology, vegetation, riparian condition as well as hydrological and physico-chemical variables.

The NWRS2 also provides for measures to control the use of water resources to protect the water quality and ecological conditions needed to ensure the functionality of the aquatic ecosystems. Human activities impacting water quality in terms of abstraction and discharges are regulated through the SDC, which are used in combination with the RDM. The SDC define, and then impose limits, and restrict the use of water resources to achieve the desired levels of protection. Licensing, registration, authorisation and special permit are the tools used to achieve the control of water use impact on water quality. Guidelines and limits, discharges of effluent as well as water abstractions are used to impose limit on water use activities. The combined process of the RDM and the SDC involves integrating biophysical information from multiple components of the ecosystems, and in terms of water quality, environmental water quality (EWQ) provides a sound ecosystem-based methodology for managing aquatic ecosystems in South Africa.

3. Environmental water quality (EWQ)

Environmental water quality is an integrated approach that links the chemical, physical and radiological characteristics of a water resource to the responses of the in-stream assemblage structure, function and processes [12, 13]. The EWQ combines water physico-chemistry, biomonitoring and ecotoxicology. The conventional approach to managing water quality is physico-chemistry, which involves measuring and analysing physical and chemical variables to indicate water quality without taking into account their effects on biological organisms. Biomonitoring is the systematic deployment of resident biota to provide information on aquatic ecosystem health with limited capacity for a cause-effect relationship, while ecotoxicology is the experimental evaluation of the effects of specific toxicants on aquatic biota, adding the potential for causal linkages.

3.1. Water physico-chemistry

Human activities such as agriculture, domestic and industrial wastewater discharges, environmental engineering, and natural factors including geology and soils, hydrology, seasonal patterns, geomorphology, climate and weather, influence the physico-chemical conditions of the aquatic ecosystems. The physico-chemical variable analysis is the traditional approach to controlling pollution and managing water quality. It helps water-resource managers to measure and analyse the concentrations of pollutants, determine their fate and transport, as well as their persistence in the aquatic environment. In South Africa, for example, the National Physico-Chemical Monitoring Programme (NCPM) uses analyses of physico-chemical variables to provide the water quality status of rivers and streams [14].

The physico-chemical approach forms an important component of the EWQ in terms of managing water quality. However, its drawbacks include (i) high analytical costs of monitoring physico-chemical variables, (ii) inexhaustible numbers of both dissolved and suspended chemicals and pollutants, making the choice of variables for analysis difficult and also making it impossible to measure all variables, (iii) lack of spatial and temporal representativeness of water quality conditions, as results are only reflective of the time and place of sampling and (iv) provision of very little or no insights into ecological response of aquatic biota and overall biophysical health of the system. Given that conserving biodiversity and protecting the ecosystem health are critical objectives of the ecosystem approach, the physico-chemical analysis alone is inadequate. The second pillar of the EWQ, biological monitoring also known as biomonitoring, provides the opportunity for detecting ecological impairments and measuring both taxonomic and functional diversity, which are important components of the aquatic ecosystem.

3.2. Biomonitoring

Biomonitoring integrates multiple effects of stressors including chemical (e.g. salinisation), physical (e.g. sedimentation) and biological (e.g. parasitism) to evaluate aquatic ecosystem health [15]. It relies on the sound ecological understanding that in-stream biota, for example, plants, algae, animals and microorganisms integrate the conditions of their environment and are therefore able to provide an indication of the health of the ecosystem in which they live [16]. Biomonitoring can be applied at multiple biological organisations including sub-organismal (e.g. gene mutation and cell alteration), individual species composition, population, community and ecosystem levels. In South Africa, for example, the science of biomonitoring is well developed compared to the rest of sub-Saharan African countries. The design of the National Aquatic Ecosystem Health Monitoring Programme (NAEHMP) is met to generate information needed regarding the ecological conditions of aquatic ecosystems in South Africa [17]. The NAEHMP utilises the responses of in-stream biota and system drivers to characterise the impacts of disturbances in aquatic ecosystems and to determine present ecological states of the systems. The NAEHMP uses fish, macroinvertebrate and riparian vegetation as its primary biological indicators, while abiotic indicators such as habitat, geomorphology, hydrology and water chemistry form the framework for the interpretation of the biotic results. In terms of the NAEHMP, assessment models such as the fish response assessment index (FRAI), vegetation response assessment index (VEGRAI) and macroinvertebrate response assessment index (MIRAI) have been developed for assessing the ecological states of riverine ecosystems [18–20].

At the core of biomonitoring is the search for and identification of suitable biological indicators (i.e. bioindicators), whose presence or absence, abundance and diversity, and behaviour reflect environmental conditions. Over the years, many studies have used bioindicators such as fish, diatoms, algae and macroinvertebrates to assess ecological water quality [21]. However, among the bioindicators, macroinvertebrates are arguably the most widely used groups [22]. Their wide application in biomonitoring can be attributed to their ubiquitous occurrence, abundance and diversity in the aquatic ecosystems. In addition, they can be easily collected and identified to the family level, though species-level identification requires more time and for some taxa may not be possible especially in the Afrotropical region. They have a huge species richness that offers a wide spectrum of environmental responses and they are relatively sedentary, representing local conditions. They provide an indication of environmental conditions over varying times and are differentially sensitive to a variety of pollutants and, consequently, capable of a graded response to stress. They also serve as a critical pathway for transporting and utilising energy and matter in the aquatic ecosystem.

Freshwater macroinvertebrates spend at least part of their lifecycles in the aquatic environment and are large enough to be seen unaided [23]. Depending on the goal of the biomonitoring, they can be monitored for changes in population, community, growth rate and cohorts. They can also be monitored for bioaccumulation of pollutants, as well as for morphological and biochemical changes in cells, tissues, organs and systems. Macroinvertebrates-based biomonitoring approaches include single biotic indices such as the Biological Monitoring Working Party (BMWP) and the South African Scoring System version 5 (SASS5) [24, 25]; multimetric indices, for example, the Index of Biotic Integrity 12 (IBI 12) and the Serra dos Órgãos Multimetric Index (SOMI) [26]; multivariate predictive techniques, for example, the Australian River Assessment System (AUSRIVAS) and the United Kingdom's River Invertebrate Prediction and Classification System (RIVPACS, UK) [27] and finally the traits-based techniques.

A multivariate predictive technique evaluates aquatic ecosystem condition by comparing biota at a site to those expected to occur in the absence of human disturbances [16]. A predictive model is constructed using reference sites' biotic communities and correlating the community to natural environmental variables using multivariate statistics to predict expected communities at the impacted sites. A multimetric approach on the other hand combines metrics representing several aspects of macroinvertebrate attributes (e.g. structure, function and processes) to indicate river health. Bonada et al. [16] assessed the utilities, strengths and weaknesses of both approaches using a set of 12 criteria in 3 categories: rationale, implementation and performance. Out of the 12 criteria evaluated, the multivariate approach satisfies 9, while the multimetric fulfils 10.

3.3. Aquatic ecotoxicology

Protecting water resources requires a thorough understanding of the mechanisms by which pollutant(s) or toxicant(s) influence the aquatic ecosystems. This often involves experimental manipulation to establish an evidence-based cause-effect relationship between the toxicant and the observed effects on the organism. Aquatic ecotoxicology is the third pillar of the EWQ, and it provides data needed to explore a cause-effect relationship between stressors and biota [28]. The traditional approach to aquatic ecotoxicology is the single-species tests in the laboratory. Depending on the duration of the exposure and the endpoints measured, these tests are termed acute or chronic. Acute toxicity tests are short term, usually lasting between 48 and 96 h, measuring mortality as an endpoint [29]. Chronic toxicity tests last longer, and in addition to long-term mortality, sub-lethal effects on organismal attributes such as growth, reproduction, behaviour, enzymatic activities and histology are also measured. Many of these single-species acute and chronic toxicity tests have been standardised and are widely use in the ecosystem-based approach to managing water quality [30]. The strengths of the laboratory single-species tests include (i) precision: they are conducted in a highly regulated environment, where external influences are isolated, so that there is a high level of precision with regard to the toxicant effects on the organism; (ii) repeatability: single-species, laboratory-based experiments are easily reproducible and repeatable, provided that sets, guidelines and protocols are followed; (iii) high level of acceptance in the regulatory circle: these tests still form the cornerstone of risk assessments of harmful chemicals in the environment; (iv) simplicity: these test are usually very simple to undertake, hence their appeal in regulatory circles.

Although the single-species laboratory-based tests are widely used in managing aquatic ecosystems, they are unable to provide direct community or ecosystem-level effects. They rely heavily on laboratory to field extrapolations by applying safety assessment factors or the species sensitivity distribution (SSD) approach [31]. Reducing uncertainties requires using more ecologically relevant and realistic assessments that employ multi-species in experimental settings that are closer to the natural field conditions. The multi-species model-stream ecosystem approach occupies an intermediate space between field biomonitoring studies and the traditional single-species laboratory-based approach. If reasonably controlled, manipulated and replicated, they can simulate community and even ecosystem effects [32]. While the single-species approach offers high degree of precision, repeatability and simplicity, model-stream ecosystems represent a compromise between these factors, and their high environmental realisms [32].

Model-stream ecosystems are termed mesocosms or microcosms depending on their sizes and locations [33–37]. For example, Odum [33] defined mesocosms as outdoor experimental streams bounded and partially closed, which closely simulate the natural conditions. Buikema and Voshell [34] use volume as a factor for differentiating between microcosms and mesocosms, referring to microcosms as experimental streams (usually indoor) with a volume equal or less than 10 m^3 and mesocosms as those (usually outdoor) having a volume greater than 10 m^3. Hill et al. [35] defined mesocosms as experimental streams that are more than 15 m long and microcosms as those that are shorter. However, Belanger [36] review revealed that increased physical sizes of experimental streams did not correspond to increased biological complexity. Since the goal of a multi-species model-stream ecosystem is to achieve an adequate ecological realism irrespective of size, the terms 'microcosm' and 'mesocosm' are actually inappropriate. Instead, the appropriate terminologies should be a 'model-stream ecosystem', 'experimental streams or artificial streams'.

Model-stream ecosystems have some advantages over conventional single-species toxicity tests. They enable the simulation of natural conditions, offering a high degree of environmental realism and enabling complex biophysical interactions. They enable the researcher to evaluate direct effects of pollutants at higher biological organisation such as population, community and even ecosystem levels [37]. Moreover, they enable the study of biotic interaction and community dynamics and measurement of indirect ecosystem effects. Their shortcomings are that they are not easily reproducible, have low precision and are not simple to undertake.

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4. Case study of the application of biomonitoring for the assessment of the ecosystem health in the Swartkops River

This case study illustrates the application of biomonitoring in the Swartkops River using the South African Scoring System version 5.

4.1. The South African Scoring System version 5

The South African Scoring System version 5 (SASS5) is a rapid bioassessment index based on the presence or absence of selected families of aquatic macroinvertebrates and their perceived sensitivity or tolerance to deteriorating water quality [24]. In SASS5, macroinvertebrate families are awarded scores in the range of 1–15 in increasing order of sensitivity to deteriorating water quality. Families considered sensitive are awarded high scores and those considered tolerant low scores. The results are expressed both as an index score, that is, SASS5 score, and as an average score per recorded taxon (ASPT) value. The SASS5 score is calculated by summing the scores of all recorded families, while the ASPT value is obtained by dividing the total SASS5 score by the number of families recorded. In addition to being a useful water quality assessment index, SASS5 is used to assess emerging water quality problems, development impacts, ecological state and spatio-temporal trends of biological assemblages.

4.2. The study area

The Swartkops River originates in the foothills of the Groot Winterhoek Mountains and then meanders through the towns of Uitenhage, Despatch and Perseverance before discharging into the Indian Ocean at Algoa Bay, near the city of Port Elizabeth (**Figure 1**). Climate in the catchment is warm and temperate, and rainfalls vary between the upper and lower regions. The upper region usually receives higher rainfall than the lower region. The catchment geology is mainly of marine, estuarine and fluvial origin. Soils in the upper catchment are not deep and are unsuitable for agriculture. Those in the low-lying floodplain region are deep and well suited for agriculture. The dominant vegetation in the catchment is bushveld and succulent thicket.

Although the river is an important ecological and socio-economic asset, serving as a home to important bird and fish species, and providing water for small-scale irrigation, the health and functionality of the entire system are being threatened by deteriorating water quality. Several sources of pollution including raw sewage run-off from informal settlements, treated wastewater effluent discharges from municipal treatment works, agricultural farmlands, surrounding road and rail networks, and industrial sites were all influencing the water quality of the river and hence the need to assess its health using the SASS5.

4.3. Sampling sites and macroinvertebrates sampling

Four sites within the same ecoregion were selected for the study. Site 1 (33°45′08.4″ S, 25°20′ 32.6″ E), situated in the upper reaches of the river was the least impacted and thus was chosen as the control site. It has a well diverse range of macroinvertebrate sampling habitats. Site 2

(33°47′29.0″ S, 25°24′26.4″ E) was in the industrial town of Uitenhage, where surrounding impacts include run-off from roads and informal settlements, free-ranging livestock and other agricultural practices. All macroinvertebrate sampling biotopes were adequately represented at the site. Site 2 is situated upstream of the discharge point of the Kelvin Jones wastewater treatment work (WWTW) in the town of Uitenhage. Site 3 (33°47′11.8″ S, 25°25′53.97″ E) is further downstream, but also within the industrial town of Uitenhage, where surrounding impacts include industrial and wastewater effluent discharges, run-off from road and rail networks, and agricultural activities. The Kelvin Jones WWTW is the main pollution source at Site 3. Macroinvertebrate sampling biotopes at Site 3 were also adequate. Site 4 (33°47′34.0″ S, 25°27′58.7″ E) further downstream of Site 3 was situated in the residential town of Despatch. Municipal run-off, sand and gravel mining on the riparian zone were the main impacts at Site 4. Although Site 4 was not as polluted as Site 3, it would have been good to select another site further downstream to monitor for potential system recovery. However, the tidal limit at Perseverance between the estuary and the freshwater section is only a short distance downstream of Site 4. Consequently, it was not possible to select a fifth site further downstream because of likely estuarine effects.

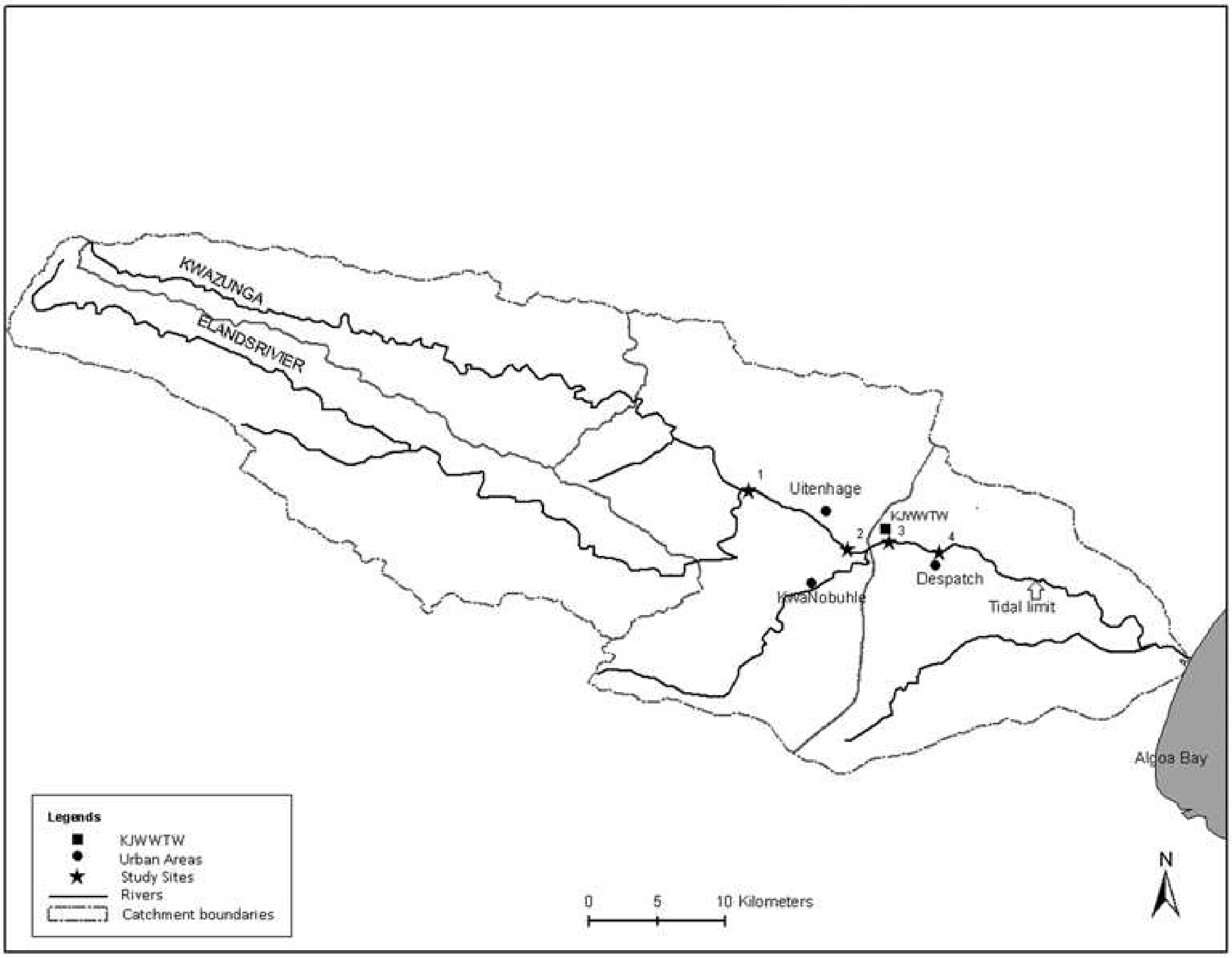

Figure 1. Map of the Swartkops River showing the sampling sites and the relative position of the Kelvin Jones Wastewater Treatment Works.

Macroinvertebrates were sampled using the SASS5 protocol. At each site, over a period of three years, between late August 2009 and September 2012, samples were collected seasonally. A total of eight sampling events were conducted over the sampling period. Macroinvertebrates were collected using a kick net (300 × 300 mm frame, 1000 μm mesh) from three distinct biotope groups: stones (stones-in-and-out-of-current), vegetation (marginal and aquatic vegetation) and sediment (gravel, sand and mud, GSM) as prescribed in the SASS5 protocol.

Sampled macroinvertebrates were tipped into a white rectangular tray, half-filled with river water, and macroinvertebrate families identified on site using identification keys by Gerber and Gabriel [38]. The identified families were recorded on a SASS5 sheet together with their abundance estimates. SASS5 scores, number of taxa and ASPT values were calculated and then interpreted as described in the following section. Time spent on field identification adhered strictly to recommendation in the SASS5 protocol.

4.4. Interpretation of macroinvertebrate data based on the SASS5 protocol for river health

Guidelines developed by Dallas [39] were used for the interpretation of the macroinvertebrate data. The guidelines stipulate range of SASS5 scores and ASPT values indicative of different ecological categories reflective of water quality/river health conditions for the upper and lower areas of each geo-morphological zone in South Africa. The Swartkops River is within the southern eastern coastal belt (lower zone) and the ranges of SASS5 scores and ASPT values for this zone were applied in this study to interpret the SASS5 data in order to determine the Swartkops River health condition (**Table 1**).

4.5. Water sampling and physico-chemical analyses

Basic water physico-chemical analyses were undertaken at each site at the same time when macroinvertebrates were sampled. Dissolved oxygen (DO), electrical conductivity (EC), turbidity, temperature and pH were measured using CyberScan DO 300, CyberScan Con 300, Orbeco-Hellige 966, mercury-in-glass thermometer and CyberScan pH 300 m, respectively. Five-day biochemical oxygen demand (BOD_5) was analysed according to APHA [40].

Ecological category	Water quality category name	Description	Range of SASS5 scores	Range of ASPT values
E/F	Very poor	Seriously/critically modified	<62.9	<5
D	Poor	Largely modified	63–81.9	5.1–5.3
C	Fair	Moderately modified	82–99.9	5.4–5.9
B	Good	Largely natural with few modifications	100–148.9	6.0–7.0
A	Natural	Unmodified	149–180	7.1–8

Table 1. Range of SASS5 scores and ASPT values indicative of the different ecological categories and water quality for the southern eastern coastal belt lower zone ecoregion [39].

4.6. Statistical analysis

One-way analysis of variance (ANOVA) was used to test for differences ($p < 0.05$) in the means of the analysed physico-chemical variables between the four sampling sites. When ANOVA indicated significant differences, a post hoc test, the Tukey's Honestly Significant Different (HSD) test was computed to indicate sites that differed. The basic assumptions of normality and homogeneity of variance were investigated using the Shapiro-Wilk test and the Levene's test, respectively. The nonparametric Kruskal-Wallis multiple comparison test was used to evaluate whether SASS5 scores, ASPT values and the number of taxa differed significantly between the biotope groups. ANOVA and Kruskal-Wallis multiple comparison tests were undertaken using the Statistica software package version 9.

4.7. Results

4.7.1. Water physico-chemical variables

Table 2 shows the mean, standard deviation and range of physico-chemical variables measured during the study period. With the exception of pH and temperature, the measured variables were statistically significantly different between the sampling sites ($p < 0.05$). The lowest value of DO and highest turbidity and BOD_5 values were recorded at Site 3. The Tukey's HSD post hoc test revealed that the mean DO concentration was significantly lower at Site 3 than at Sites 1 and 2. Although pH and temperature were not statistically significantly different between the sampling sites, the highest mean pH and temperature values were at Sites 2 and 3, respectively, and the lowest at Sites 1 and 2, respectively. The Tukey's HSD post hoc test showed that the mean EC concentration was significantly lower at Site 1 than at the rest of the sampling sites and turbidity significantly higher at Site 3. The mean BOD_5 concentrations were significantly higher at Sites 3 and 4 than at Site 1 (**Table 2**).

Variable	Site 1	Site 2	Site 3	Site 4	*p* value	*F* value
Dissolved oxygen (mg/l)	6.99 ± 1.15^{a} (4.73–9.5)	7.4 ± 1.52^{a} (5.53–9.48)	3.19 ± 1.47^{b} (1.81–6.36)	4.81 ± 3.01^{ab} (0.9–8.31)	0.001	7.18
pH	6.53 ± 1.11 (4.69–7.75)	7.37 ± 1.11 (5.69–8.99)	7.29 ± 0.42 (6.56–7.9)	7.27 ± 0.56 (6.31–8.01)	0.201	1.65
Temperature (°C)	17.48 ± 5.46 (7.31–24.0)	17.27 ± 7.17 (6.11–27.3)	20.88 ± 3.29 (14.3–25.2)	18.9 ± 4.14 (12.2–24.0)	0.415	0.98
Electrical conductivity (mS/m)	32.45 ± 17.74^{a} (8.23–62.0)	160.75 ± 146^{b} (30–460)	262.51 ± 76.14^{b} (154.8–333)	259.63 ± 56.28^{b} (171–354)	0.000	22.57
Turbidity (NTU)	5.3 ± 2.22^{a} (3.0–10.1)	6.33 ± 2.44^{a} (3.0–11.2)	72.7 ± 102.36^{b} (10.5–320)	7.08 ± 8.06^{a} (2.2–26)	0.000	15.67
BOD_5 (mg/l)	4.62 ± 1.45^{a} (2.16–6.86)	8.25 ± 4.33^{ab} (4.58–16.68)	14.54 ± 3.57^{c} (8.32–20.62)	11.77 ± 5.28^{bc} (2.24–22.94)	0.002	13.50

Table 2. Mean ± standard deviation and range (in parenthesis) of the physico-chemical variables ($n = 8$) in the Swartkops River during the study period (August 2009–September 2012). *p* and *F* values are indicated by ANOVA. Different superscript letters per variable across sites indicate significant differences ($p < 0.05$) revealed by Tukey's HSD post hoc test. The same superscript letter between sites per variable indicates no significant differences ($p > 0.05$).

4.7.2. Assessing the Swartkops River health using the South African Scoring System version 5 (SASS5)

The interpretation of the SASS5 results were based on the range of SASS5 scores and ASPT values reflecting ecological categories A, B, C, D and E/F indicative of natural, good, fair, poor and very poor water quality conditions, respectively (**Table 1**). The SASS5 scores and ASPT values revealed that the Swartkops river health conditions differed between the sampling sites. Seasonally, with the exception of the autumn and spring (2012) collections, SASS5 scores at Site 1 indicated the B ecological category indicative of good water quality condition (**Figure 2**). The ASPT values on the other hand, in all the sampling seasons, indicated the C ecological category for Site 1, suggesting that the water quality at Site 1 was fair (**Figure 3**). The numbers of taxa vary slightly between the sampling seasons at Site 1 with more taxa occurring in spring (2012) (**Figure 4**). Overall, the SASS5 score showed good water quality (ecological category B) for Site 1, but the ASPT value indicated that the water quality condition at the site was fair (ecological category C) (**Figure 5**).

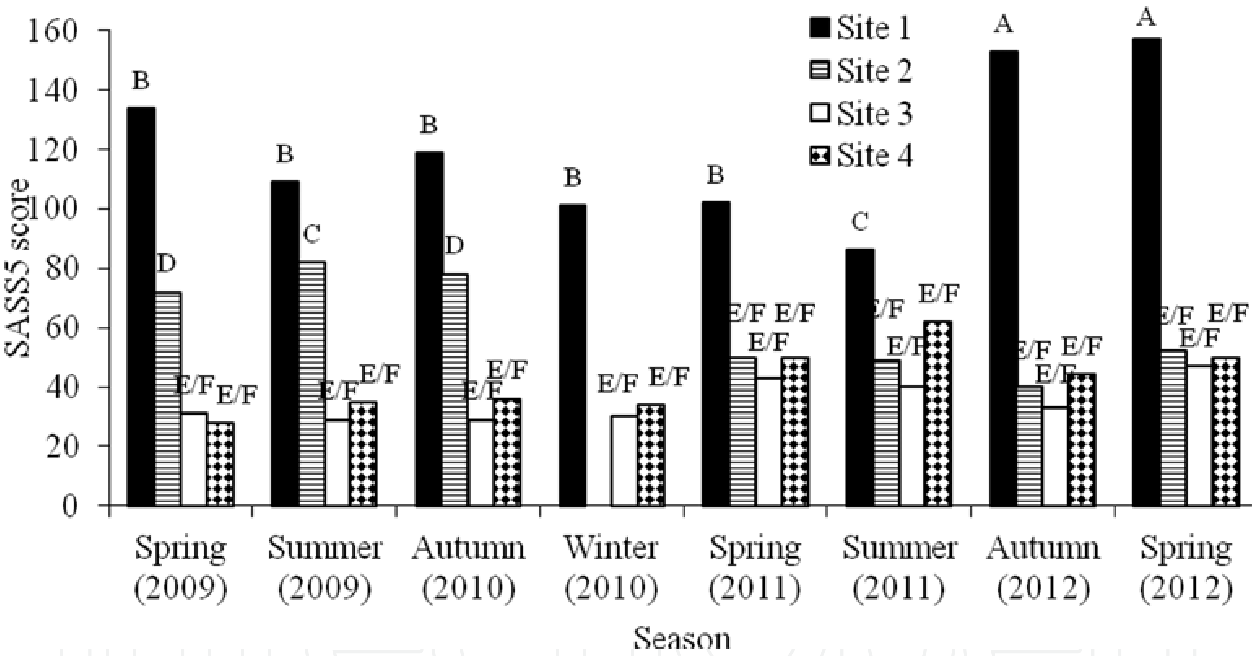

Figure 2. Seasonal variations for the South African Scoring System version 5 (SASS5) score at the four sampling sites in the Swartkops River during the study period (August 2009–September 2012). The ecological categories: A (natural water quality), B (good water quality), C (fair water quality), D (poor water quality) and E/F (very poor water quality) are indicated on the bars.

At Site 2, SASS5 scores indicated the D ecological category, that is, poor water quality in spring (2009) and in autumn (2010), while in summer (2009), it revealed the C category indicative of fair water quality (**Figure 2**). During the rest of the sampling events, SASS5 scores revealed the E/F ecological category indicating very poor water quality. Although the SASS5 scores reflected other ecological categories in addition to the E/F for Site 2, the ASPT values consistently showed that Site 2 was in the E/F ecological category (**Figure 3**). Although the number of taxa did not vary significantly between the sampling seasons at Site 2, the highest number of taxa (20) was recorded during autumn (2010). At Sites 3 and 4, SASS5 scores and ASPT values revealed the E/F ecological category (very poor water quality) throughout the sampling seasons. The overall lowest number of taxa (8) in the river was recorded at Site 3 in winter 2010 (**Figure 4**).

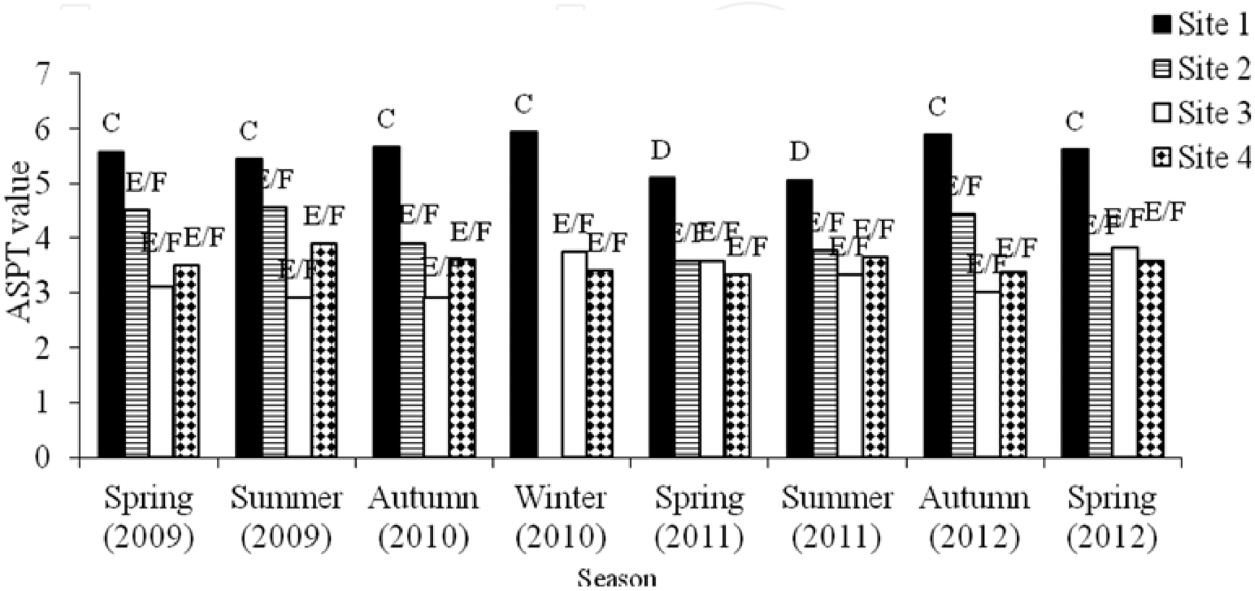

Figure 3. Seasonal variations for the average score per recorded taxon (ASPT) at the four sampling sites in the Swartkops River during the study period (August 2009–September 2012). The ecological categories: C (fair water quality), D (poor water quality) and E/F (very poor water quality) are indicated on the bars.

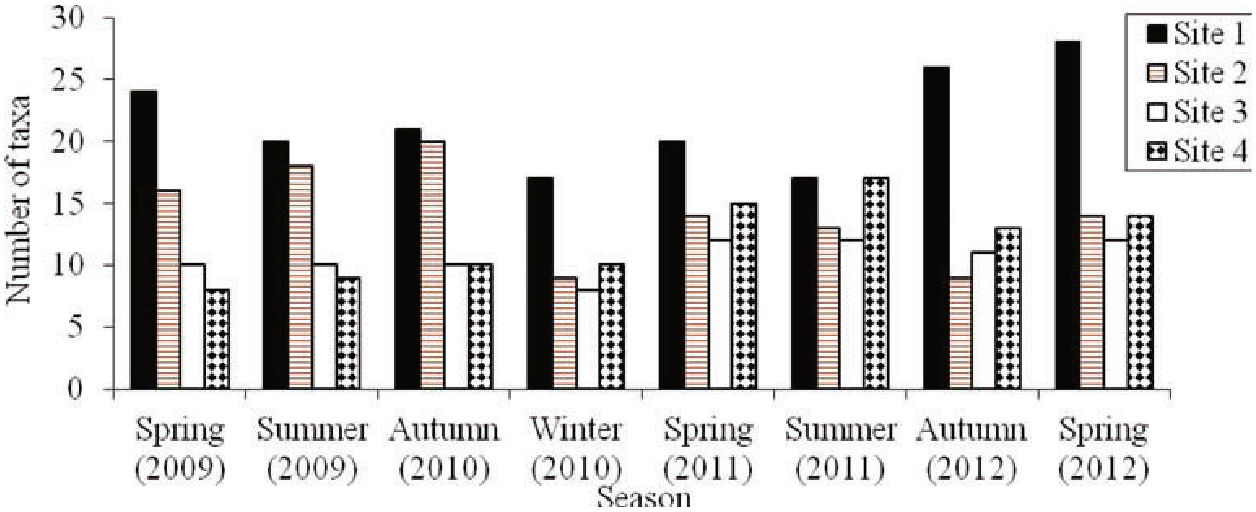

Figure 4. Seasonal variations for the number of taxa at the four sampling sites in the Swartkops River during the study period (August 2009–September 2012).

4.7.3. Comparing SASS5 scores, ASPT values and the numbers of taxa between the sampling biotopes (stone, vegetation and GSM)

The vegetation and stone biotope had higher SASS5 scores, ASPT values and numbers of taxa than the GSM biotope at Site 1 (**Figure 6**). The Kruskal-Wallis multiple comparison test

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revealed that SASS5 scores were significantly higher for the vegetation than for the GSM biotope at Site 1 ($p < 0.05$; KW-H = 7.21). Similarly, at Site 2, SASS5 scores were significantly higher for the vegetation than for the GSM biotope ($p < 0.05$; KW-H = 10.13), and though the stone had higher SASS5 scores, they were not statistically higher than the scores recorded for the GSM biotope. The pattern described for Site 2 was similar to those observed for Sites 3 and 4 where the SASS5 scores were significantly higher for the vegetation biotope than the stone and GSM biotopes (Site 3: $p < 0.05$; KW-H = 40.44), (Site 4: $p < 0.05$; KW-H = 18.14).

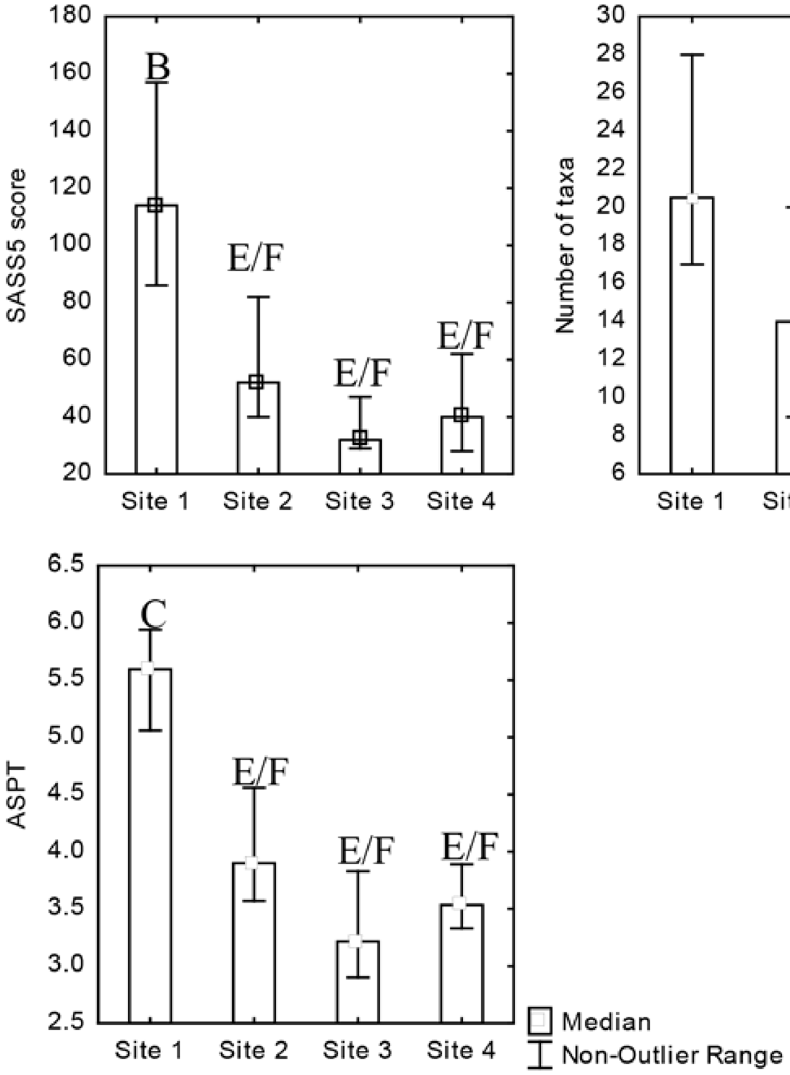

Figure 5. Summary of the SASS5 scores, number of taxa and ASPT values at the four sampling sites in the Swartkops River during the study period (August 2009–September 2012). The overall ecological categories: B (good water quality), C (fair water quality), D (poor water quality) and E/F (very poor water quality) are indicated on the bars.

The average score per recorded taxon (ASPT) values were similar between the three biotopes at Site 1, but at Site 2, the ASPT values were significantly higher for the vegetation than the GSM biotope ($p < 0.05$; KW-H = 9.45). The vegetation had significantly higher ASPT values than the stone and GSM biotopes at Sites 3 ($p < 0.05$; KW-H = 26.9) and 4 ($p < 0.05$; KW-H = 14.25).

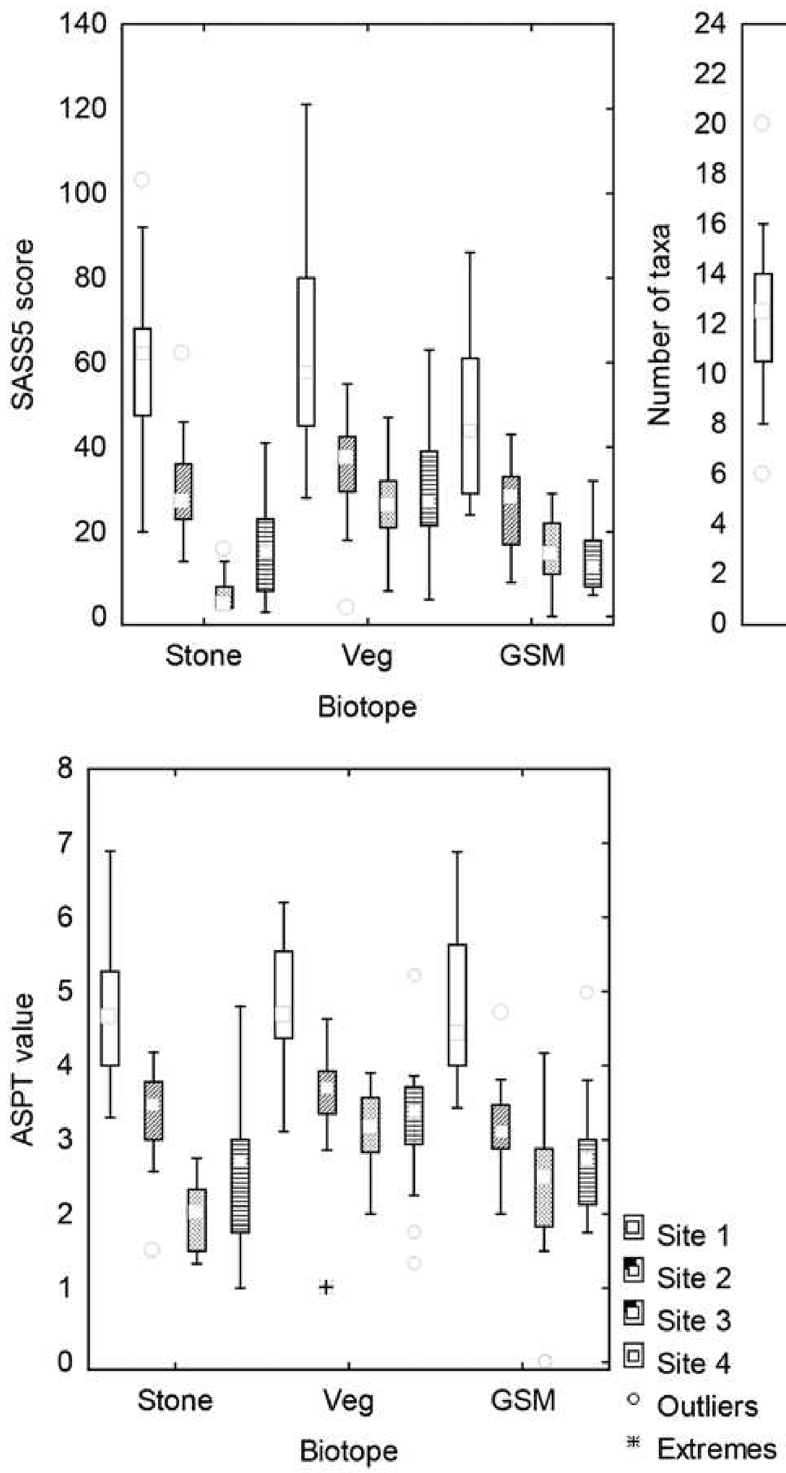

Figure 6. Median (small square), inter-quartile ranges (box), non-outlier ranges (bars) for SASS5 scores, numbers of taxa and ASPT values recorded per biotope at the four sampling sites in the Swartkops River during the study period (August 2009–September 2012).

Stone and vegetation biotopes supported significantly higher numbers of taxa than the GSM biotope at Site 1 ($p < 0.05$; KW-H = 11.89), but at Site 2, only the vegetation supported significantly higher numbers of taxa than the GSM ($p < 0.05$; KW-H = 7.23). More taxa were

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recorded on the vegetation and GSM biotopes than on the stone biotopes at Site 3. The Kruskal-Wallis multiple comparison test indicated that the numbers of taxa for the stone biotope were significantly lower than the taxa recorded for the vegetation and GSM ($p < 0.05$; KW-H = 40.44) at Site 3. At Site 4, the stone and vegetation supported more taxa, but only the numbers of taxa supported by the vegetation biotope were significantly higher than the values recorded for the GSM ($p < 0.05$; KW-H = 16.27).

4.8. Discussion

The ecosystem approach takes into account biodiversity conservation and therefore prioritises the protection of biodiversity as well as the sustainable use of water resources and the associated ecosystems. In the case study provided, the South African Scoring System version 5 (SASS5) was used to evaluate the health of the Swartkops River. In South Africa, SASS5 is one of the tools that contribute ecological information for the determining the ecological reserve and setting Resource Quality Objectives (RQOs). The SASS5 results indicated that water quality in the Swartkops River was critically modified at Sites 3 and 4 throughout the sampling period and the numbers of taxa occurring at these sites were significantly reduced compared to those occurring at Sites 1 and 2. Sites 3 and 4 were situated downstream of a WWTWs, which influenced the health of the river. The values of the measured physico-chemical variables at these sites, that is, Sites 3 and 4, provided evidence for negative impact arising from the discharges of wastewater effluents. For example, at Sites 3 and 4, higher values of turbidity and EC concentrations and lower DO concentrations were recorded. Since highly sensitive taxa have higher scores in the SASS5 sheet, oxygen depletion could easily affect the occurrence and distribution of these taxa. Therefore, it was expected that sites with low concentration of DO would experience the disappearance of sensitive taxa and the dominance of tolerant taxa, and hence, the critically modified health conditions recorded at Sites 3 and 4. In addition to lower DO concentrations at the downstream sites, the elevated turbidity level recorded at Site 3 could be detrimental to oxygen-sensitive biota as decomposition of solids with high organic content could lead to oxygen depletion, as was evident at Sites 3 and 4. The majority of the highly sensitive taxa on the SASS5 sheet use external gills for respiration. Highly turbid water is likely to impact on the breathing apparatus of external gill-bearing organisms, which can then lead to clogging [41]. The river health condition at Site 2, which was upstream of the effluent discharge point, but still situated within the urban and industrial town of Uitenhage, was mostly in the range of fair and very poor conditions. Diffuse pollution sources on the river catchments were the main contributors to deteriorating river health recorded at this site. Site 1, which was used as the control site, had conditions mostly in the good and fair categories. The implication was that the control site had some sensitive taxa, which had disappeared from the impacted sites.

The number of taxa, SASS5 scores and ASPT values were highest mostly in the stone and vegetation biotopes and differed significantly between the three biotopes. These differences could be attributed to differences in hydraulic, substrate and thermal conditions between the three biotopes. The stone and vegetation biotopes are morphologically complex and more stable than the GSM biotope and are therefore more likely to support more food and space resources, and thus more macroinvertebrate families leading to increased SASS5 scores and ASPT values. These results are in agreement with those of Dallas [42] who reported that the stone and vegetation biotopes supported more macroinvertebrate families and higher SASS5 score and ASPT values than the GSM biotope. It is therefore important to sample all available biotopes to capture a wider range of biodiversity when undertaken aquatic biomonitoring.

In summary, the deteriorating environmental water quality in the Swartkops River has impacted on the macroinvertebrate assemblages particularly at the downstream sites. This was expected because of the ranges of impacts these sites receive which include industrial and sewage effluent discharges, run-off from informal settlement and agricultural activities such as livestock farming. Water quality at Site 1 which was used as the control site in this study was indicated as good and fair by the SASS5 score and ASPT value, respectively. This is a cause for concern as the results showed that macroinvertebrates at this site were experiencing noticeable impacts. Overall, both the physico-chemical variable analysis and the biotic index results revealed that the Swartkops River was deteriorating in quality as it flowed downstream, indicating the need for an urgent management intervention.

5. Conclusion

In this chapter, the ecosystem-based approach to managing water quality was critically reviewed with a clear focus on environmental water quality (EWQ). The three pillars to EWQ were discussed and their contributions and limitation highlighted. Of particular interest is that, in this chapter, the relevance of the EWQ approach was discussed with respect to its application to water resources management in South Africa. It is argued that the EWQ is an integrative approach for sound and sustainable management of water quality. The biomonitoring case study illustrated the utility of one of the three pillars of the EWQ approach.

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