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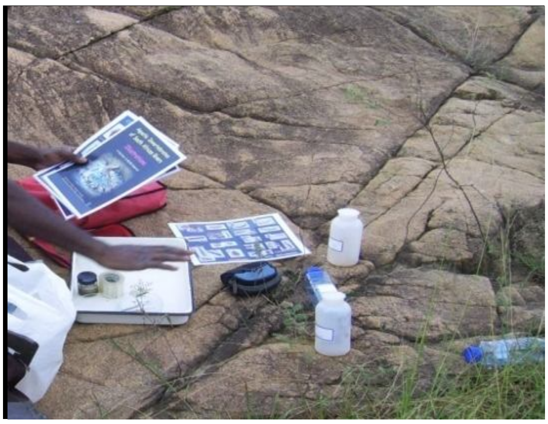


ASSESSMENT OF THE STATE OF THE WATER QUALITY OF THE LUSUSHWANA RIVER, SWAZILAND, USING SELECTED WATER QUALITY INDICES

by

LUCKY NHLANHLA MNISI

M.Sc. THESIS IN IWRM

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In collaboration with

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A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Integrated Water Resources Management of the University of Zimbabwe

July 2010

DECLARATION

I, **Lucky Nhlanhla Mnisi** declare that this research report is my own work. It is being submitted for the degree of Master of Science in Integrated Water Resources Management (MSc IWRM) in the University of Zimbabwe. It has not been submitted before for any degree of examination in any other University.

The findings, interpretations and conclusions expressed in this study do neither reflect the views of the University of Zimbabwe, Department of Civil Engineering nor of the individual members of the MSc Examination Committee, nor of their respective employers.

Signed: .... Date: ....

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ABBREVIATIONS AND ACCRONYMS

APHA:	American Public Health Association
ASPT:	Average Score Per Taxon
ATI:	Aquatic Toxicity Index
BOD:	Biochemical Oxygen Demand
BPI:	Bacterial Pollution Index
CCME:	Canadian Council of Ministers of Environment
$CaCO_{3}$:	Calcium Carbonate
Cr:	Chromium
Cu:	Copper
DO:	Dissolved Oxygen
EWQI:	Estuarine Water Quality Index
F:	Fluoride
F.COLI.	Faecal Coliform
FAII:	Fish Assemblage Integrity Index
GoS:	Government of Swaziland
GWP:	Global Water Partnership
IWRM:	Integrated Water Resources Management
K:	Potassium
MO:	Minimum Operator
Mn:	Manganese
NASS:	Namibian Scoring System
NH_{4}:	Ammonium
Ni:	Nickel
NRHP:	National River Health Programme

NSF:	National Sanitation Foundation
NTU:	Nephelometric Turbidity units
OWQI:	Oregon Water Quality Index
Pb:	Lead
PO_4:	Phosphate
RAU:	Rand Afrikaans University
SASS:	South African Scoring System
SC:	Specific Conductivity
SPSS:	Statistical Package for Social Scientists
SWQI:	Surface Water Quality Index
TDS:	Total Dissolved Solids
TMDL:	Total Maximum Daily Load
TP:	Total Phosphorus
TS:	Total Solids
TSS:	Total Suspended Solids
Turb:	Turbidity
UNEP:	United Nations Environmental Programme
WQI:	Water Quality Index
WREM:	Water Resources Engineering and Management
WU:	Wilkes University
Zn:	Zinc

DEDICATION

To all the incredible people who contributed meaningfully towards this project. Your unconditional support never went unnoticed.

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ABSTRACT

Water quality indices are one of the major developments that have taken place in water quality monitoring. Since the development of the first water quality index various other water quality indices have been developed, utilised, modified and infused into policies by various environmental monitoring agencies. The Aquatic Toxicity Index (ATI), National Sanitation Foundation Water Quality Index (NSFWQI), Idaho Water Quality Index and the South African Scoring System (SASS) were used to evaluate the quality of the water of the Lusushwana River in Swaziland.

Bimonthly samples of water and macro invertebrates were collected over a period of two months (February and March, 2010). The data was collected from five sampling points (T1 to T5) along the Lusushwna River, covering points upstream and downstream of the Matsapha Industrial Complex. The physico chemical water quality data was used to derive the physico chemical water quality indices' scores and for comparing their concentration with the Swaziland Water Quality Objectives (SWQO) for surface water and the South African Aquatic Ecosytem Water Quality Guidelines (SAAEWQG). Aquatic macro-invertebrates were sampled and identified for the South African Scoring System version 5, devised by Chutter (1998). The ATI was calculated using the RAUWATER 2 Software, the NSFWQI was calculated using the Wilkes University online calculator for the index and the Idaho WQI was calculated using a logarithmic equation developed by Said *et al.* (2004). After deriving scores for these indices their values were further correlated to establish possible relationships amongst them.

From this study it was concluded that the water quality of the Lusushwana River was polluted due to faecal contamination, turbidity and iron with respect to the SWQO, whilst DO (% saturation) was below the SAAEWQG stipulated range. The indices on the other hand indicated decline in water quality from site T3 to site T5. With respect to correlations between the indices it was concluded that they were all positively correlated. The correlations were, however, significant for the relationships between all physico chemical water quality indices ($p < 0.05$). For relationships with the indices of the SASS 5 Biotic Index the correlations were only significant between the NSFWQI and the SASS score and between the Idaho WQI and the ASPT. The other correlations (between the NSFWQI and the ASPT, the ATI and the ASPT, ATI and SASS score, Idaho WQI and SASS score) were not significant ($p < 0.05$).

It was recommended that the study be carried out covering more sampling sessions and sampling points, covering both the rainy and dry seasons and to monitor effluent and waste water effluent downstream of the Matsapha Industrial Complex.

Key Words: Lusushwana River, Water Quality Indices, Aquatic Toxicity Index, National Sanitation Foundation Water Quality Index, Idaho Water Quality Index, SASS 5 Biotic Index

1: INTRODUCTION

1.1: Background

Water of good quality is necessary to sustain the needs of human populations and other ecosystems. There are, however, many threats to the quality of water. Anthropogenic activities can impact negatively on the water quality of the freshwater bodies thereby limiting their scope of usage (GWP, 2000; Gyau-Boakye, 2002). Within a catchment there are various such activities, as argued by Ntengwe (2006), polluted surface waters cannot achieve a balanced ecosystem. In which case a balanced ecosystem refers to a system in which living things and the environment interact for the beneficial use of the other.

Traditionally, water quality management has principally used the measurement of the magnitude and concentrations of chemical substances in water to explain the status of the water for the intended use (Day, 2000). Such an approach has equated water quality to water chemistry. As argued by Day (2000), water quality is not just water chemistry. To give a holistic and or an integrated picture of the status of the quality of water bodies, new trends in water quality management has seen the move towards biomonitoring (Gratwicke 1998; Smith *et al*., 2006). Biomonitoring refers to the techniques that utilise one or more components of the biota such as fish, macro invertebrates, diatoms and others, to provide a time- and constituent-integrated assessment of the system under consideration (Dallas, 2000). Biomonitoring data, however, have to be integrated with chemical and physical data in order to provide meaningful environmental information (Roux *et al*., 1993). This is important because physical and chemical features of the environment affect biological indicators (Norris and Thorms, 1999).

Water resources professionals mainly communicate water quality status, trends regulations and guidelines in terms of the evaluation of individual water quality variables. As noted by Cude (2001), such technical language can readily be understood by water quality professionals but it does not readily translate to communities having profound influence on water resources policy, the general public and policy makers. Of note is that communities as users of the water resources expect a comprehensible response to their right to know about the status of the environment (Nasirian, 2007).

The strengths of using water quality indices as opposed to the evaluation of individual water quality variables are mainly on the ability of indices to reduce the bulk of the information into a single value in order to convey the data in a simplified and understandable manner. These two greatly enhances the understanding of water quality issues by the policy makers and the public as users of water resources (Wepener *et al*., 1992; Cude, 2001; Nasirian, 2007). In addition (House, 1989) recommends the use of Water quality indices because they make it possible to bridge the gap between the extremes of water quality monitoring and reporting. House (1989) further, states that water quality indices are favoured also on their ability to demonstrate annual cycles and trends in water quality even at low concentrations in an efficient and timely manner. They are therefore accredited for their ability to capture spatial and temporal variations in water quality. On another level, they can also be applied to polluted and unpolluted streams with the ability of ranking streams in pollutions terms and it is also an important tool in indicating possible water use in terms of guideline water use and or legal standards.

It is of note, however, that in as much as indices have these advantages, various scholars have noted their limitations. McClelland (1974) states that indices by design contain less information than the raw data they summarise. Secondly, most water quality indices are based on a pre-identified set of water quality constituents, whereby a particular station may receive a good water quality score and yet have water quality impaired by constituents not included in the index. Thirdly, the aggregation of data may mask short term problems. It is of note therefore that when using water quality indices, site specific decisions should be based on the analysis of the original water quality data. Water quality indices therefore are most useful for comparative purpose and for general questions than specific questions on the water quality. On the basis of such shortcomings it is clear why in most cases the assessment of water quality still follows the traditional parameter by parameter evaluation. On the same line, Ott (1978) states that given such shortcomings of water quality indices professionals prefer to give no answer rather than an imperfect answer that could lead to misunderstanding whilst layman usually prefers an imperfect answer to no answer at all. For a comprehensive assessment of water quality therefore the use of water quality indices must be coupled with the analysis of individual water quality parameters. It is mainly because of such issues that water quality indices have over the years gained popularity Fernandez *et al.* (2004).

Most water quality studies in Swaziland focus on the measurement and statistical presentation of water quality data. On the basis of reviewed literature, it indicates that no physico chemical water quality index has been used for the assessment of any water body in Swaziland. Certain Biotic Indices, however, have been used in to explain water quality. Such include work by Muthimkhulu *et al.* (2005) through the use of the SASS5 Biotic Index.

To explain the status of the water quality of the Lusushwana River (Little Usuthu), an integrated approach has been taken. This approach integrates both physico chemical and biological indicators of water quality. The status has been expressed through various water quality indices such are the South African Scoring System version 5 (SASS), (Dickens and Grahams, 2002), National Sanitation Foundation Water Quality index (NSFWQI) (Samantray *et al*., 2009) Idaho Water Quality Index (Said *et al*., 2004) and the Aquatic Toxicity Index (ATI) (Wepener *et al*., 1992). The index route has been followed because indices are one of the most effective ways of communicating environmental trends and river water quality (Bai *et al*., 2009).

1.2: Justification

The Lusushwana River has multiple uses; it supplies the Matsapha Industrial Complex, Manzini City and surrounding areas with water. Other uses include fishing, recreation, irrigation and the river being a sink of urban and industrial waste of the biggest industrial area in Swaziland. With varying public concerns and previous studies indicating that the river is polluted (*eg*. Mtetwa, 1996; Mansuetus *et al*., 2004; Fadiran and Mamba, 2005). It is on such basis that a reliable monitoring system is required for an effective monitoring of the river.

1.3: Problem Statement

There is an outcry from the general public and environmental management agencies on the state of the quality of the Lusushwana River (Swaziland Environment Authority, 2008). Such conclusions have been mainly drawn on the analysis of individual water quality parameters, while others have focused on the bacterial pollution of the river. Such an approach does not give an overall state of the river, as it excludes pathogenic pollution and pays no focus on the assemblages of biotic indicators in the general assessment of the status of the river. A different approach in the assessment of the Lusushwana River is necessary, as a similar or a different picture about the river may be revealed. With Muthimkhulu *et al.* (2005) having shown that the SASS 5 Biotic Index can be used as a monitoring tool for the water quality of Swaziland's rivers It is important therefore to understand what results the SASS5 Biotic Index can show about the status of the Lusushwana River, when used alongside various physico chemical water quality indices.

1.4: Rationale

The Swaziland Water Act (2003) which has been in force since March 2003 encompasses the main principles of Integrated Water Resources Management (IWRM) (Swaziland Water Partners, 2008). The principles of IWRM require that water resources be managed at catchment level and decision making at the lowest appropriate level with full participation of stakeholders (GWP, 2000). To the water quality monitoring of the Lusushwana catchment this implies that any monitoring system for the catchment must adopt these principles. Water quality indices are necessary in increasing stakeholder participation since they are capable of reducing the jargon from water quality information; making water quality to be understood not only by water resources professionals but by all stakeholders and the general public. The understanding of water quality information is important in enabling the full participation of stakeholders which is bound to ensure that all stakeholders are part of decision making as stipulated by principle 2 of IWRM (GWP, 2000).

1.5: Objectives of the Study

1.5.1: General Objectives

The general objective of this study was to assess the status of the water of the Lusushwana River using and comparing biological and physico chemical water quality indices.

1. 5.2: Specific Objectives

1. To assess the water quality of the Lusushwana River based on physico chemical criteria and three selected water quality indices.
2. To assess the water quality the Lusushwana River based on the SASS 5 Biotic Index.
3. To investigate the extent of correlation between the water quality indices.

1.6: Scope and Limitations

The National Sanitation Foundation Water Quality index, Aquatic Toxicity Index, the Idaho Water Quality Index and the SASS 5 Biotic Index, were used in the assessment of the water quality of the Lusushwana River. These indices input different water quality parameters; therefore the selection of the parameters for this study was primarily on the basis of the required variables to derive values for these indices. Land use patterns and other determining factors for water quality did not play any role in the selection of the considered variables in this research. It is partly because of these reasons that other important determinants of water quality were not considered such as pathogens and like viruses. This makes the assessment more biased towards physico chemical variables rather than the wholesomeness of the water quality of the river. On another level the data from this study was further compared with the Swaziland Water Quality Objectives for surface water and the South African guidelines for aquatic ecosystems, not all the parameters from these criteria tally with those measured in this study. In addition, this was an MSc thesis and it only allowed the collection of data only within the rainy season (specified data collection period). The results from this study were made from data collected from four sampling campaigns in which case more sessions of data collection would have been ideal for capturing temporal variations. On another note the status of the Lusushwana River is mainly based on the water quality of the points from which the water was collected. This is in recognition of the fact that there could be spatial variations in water quality between the selected points that could not have been captured by this study.

1.7: Structure of the Thesis

This thesis is divided into five chapters. The first chapter introduces the thesis by giving the background, objectives, problem statement and justification. Chapter 2 is the literature review, this chapter deals with the review of literature on various aspects of water quality indices narrowing down to the specific indices used in the study. The third chapter deals with materials and methods; in this chapter the focus is on the study area, the methods of data collection, processing and data analysis. Chapter 4 deals with the presentation, analysis and discussion of the results objective by objective. The last chapter is on the conclusions and recommendations which are also presented on objective by objective basis.

2: LITERATURE REVIEW

2.1: Water Quality Indices*: A* Historical Overview

A water quality index is a simple expression of a more or less complex combination of a number of water quality parameters which serve as a measure of water quality. In most cases it combines two or more parameters. The output from an index is presented as a number, a class, a verbal description, a unique symbol or a colour code. Water quality indices take information from a number of sources and combine them to develop an overall snapshot of the state of the water system. They are important tools as they provide a benchmark for evaluating successes and failures of management strategies aimed at improving water quality (UNEP, 2007).

The science of water quality indices is not new. As indicated by Shafiri (1990), the first institution to have used an indexing system to express water quality was the British Commission on Sewage Disposal in 1912. Their classification was based upon a single parameter, the Biological Oxygen Demand (BOD).

After this indexing system, various developments within this field have taken place. These include work done by (Horton 1965), whereby he proposed a water quality index which in most literature appears to be the first water quality index (Nasirian, 2007). In 1965 Horton selected 10 most commonly measured water quality variables for this index, such include, dissolved oxygen, pH, coliforms, specific conductance, alkalinity, chloride, total dissolved solids and carbon chloroform extracts. The index score was obtained with a linear sum aggregation function. The index structure, its weights and rating scale were highly subjective as they were based on the judgement of the author and a few of his associates.

After Horton's index Brown *et al*. (1970) developed another water quality index known as the National Sanitation Foundation Water Quality Index (NSFWQI). This index was similar in structure to Horton's index but with much greater rigour in selecting parameters, developing a common scale and assigning weights as it employed the Delphic methodology. This methodology refers to an opinion research technique developed by the Rand Corporation. In this method questionnaires are sent to a panel of water quality experts for the selection of analytes and the significance of each analyte then followed by the drawing of a rating curve for each analyte. In the early 1970s, as well, Shafiri (1990) developed an index known as the Prati Index. This index considered 13 different parameters. The major weakness of this index was that the parameters were given equal weights to their system. These parameters are rated from 0- 13 with values more than 8 denoting heavy pollution and a 0 value for best water quality.

Another index developed in the 1970s is the Oregon Water Quality Index (OWQI). The purpose of this index was to improve understanding of water quality issues by integrating complex data and generating a score that describes water quality status and evaluates water quality trends (Cude, 2001). This index was modelled according to the NSFWQI. The major similarities between the two indices are that they both apply the Delphic methods in selecting parameters, developing a common scale and assigning weights. As a follow up to these indices various other indices were developed in the late 1970s. Such indices include an index developed by (Stoner, 1978). This index was meant for use in public water supply and irrigation, and employed a single aggregation function, which selects from two sets of recommended limits and sub index equations. Although Stoner applied the index to just two water uses, it could be adapted to additional water uses as well.

Up do date various water quality indices have been developed and implemented by many institutions in the world. Most of such indices are often variations of the NSFWQI (Palupi *et al*., 1995; Wills and Irvine, 1996). However, most recently (during the 1990s and 1980s) non-specific water quality indices seem to have gained favour in application for developing countries than with the developed nations. This has been the case because non-specific indices like the NSFWQI the main reason for the limited application of the non-specific WQI's is that during the data handling process, information can be lost. For example, if eight of the analytes under the NSF WQI indicate pristine scores, but pH scores 0, a water body might have an index value of 85. This rates as a 'good' score, but clearly, a water body with extreme high or low pH would not be capable of supporting certain aquatic life and may be unsuitable for recreation, drinking, or irrigation (Irvine *et al.* 2008).

2.2: Classification of Water Quality Indices

Water quality indices differ in various ways, the major differences between indices are summarised by Fernandez (2004), (Table 2.1). Such differences are in the number of parameters they consider. Water Quality Indices consider varying number of parameters, ranging from a single parameter for example the Bacterial Pollution Index (BPI) to indices that use up 47 water quality parameters like the British Columbia. Indices may use the same number of water quality parameters but different sets of parameters. Other noticeable differences in indices are in the aggregation formulae as some use sum (Miami River index), proportion weighted sum (Dalmatia WQI), quadratic equation (Washington WQI) and many more. Even in structure indices are different as some use diagrams (Nutrient Pollution Index, Pesticide Pollution Index), tables (Benthic Saprobity Index, Biological Diversity Index, Miami River Index and others), equations (Oregon WQI, Malaysia WQI), formulas (British Columbia) and many more. Table 2.1 shows a total of 36 indices and how they differ from each other mainly with emphasis on the three aspects, the number of parameters, structures and aggregation formulae.

Table 2.1: Comparative structure of each index

Index	*No of para.*	*Structur e*	*Aggregation formula*	*Index*	*No of Para.*	*Structure*	*Aggregation formula*
Water quality indices				Organic poll index	5	diagrams	Weighted average modified
Bacterial pollution index (BPI)	1	Diagram	Direct reading	Oregon	8	equation	Un weighted harmonic square mean
Bentic Saprobity index	At lest 30	table	Percentage average	Pesticide pollution index	2 to 7	diagrams	Weighted average modified
Biological Diversity index	Indetermi nate	table	proportion	Poland	6	formula	Sqr of harmonic average
British Columbia	Up to 47	formulas	Harmonic sqr sum	Prati	8 to13	formula	Un weighted average
Dalmatia	9	formulas	Proportion of weighted sum	Production Respiratory index	2 to 3	diagrams	Direct reading
Dinius(1987)	12	equation	Weighted average	Washingto n	8	equation	Quadratic equation
DRM	7	diagrams	Weighted ave.	**Water Pollution Indices**			
Greensboro	9	diagrams	Un weighted multiplicative	ICOMI Mineralisat ion	3	equation	Arithmetic average
Idaho	5	Equation	Logarithmic proportion	ICOMO Organic matter	3	equation	Arithmetic average
Leo n(1998)	15	fomulas	Weighted geo average	ICOSUS Suspended solids	1	Diagram + equation	Direct reading
Industrial pollution index	5 a 14	diagrams	Weighted geo. modified	ICOTRO Trophic state	1		Direct reading
Malaysia	6	Equation	Weighted average	ICOTEMP Temperatur e	1	Diagram + equation	Direct reading
Montoya(1997)	17	equation	Weighed av.	ICOpH pH	1	Diagram + equation	Direct reading
Miami River index	7	table	sum	ICOTOX Toxicity	1 toxic per time	equation	Equation
Nutrient pollution index	9	Weighte d av. modified	Weighted average modified	ICOBIO Biological	indeter minates	equation	Equation

Source: Fernandez et al. (2004)

Indices also differ with respect to their scope of application. This is the case as some indices are region specific; such include the Oregon Water Quality index. This index according to Cude (2001) was designed to assess rivers of the Oregon State; its application beyond this state must be with caution. Also on the basis of scope some indices have been developed on a global level. Such include the Environmental Performance index (Levy *et al.*, 2006). Other such indices are those that use national water quality standards including the Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI) (CCME, 2001), the Overall index of pollution (Sagaonkar and Deshpande, 2003) as indicated in Table 2.2. This table shows few water quality indices against their objectives, methods and where these indices have been applied.

Beside indices being region specific there are those that are objective driven such include the CCME WQI. According to the CCME (2001), this index in Canada for example different jurisdictions use different objectives for water quality and there are different objectives for different water uses. Objectives for irrigation water are different from those of the protection of sensitive aquatic life. In this case an index value is calculated and compared specifically to the set objective for the specified user.

Table 2.2: Summary of indices developed which assess water quality either on a national or global level

Index	*Objective*	*Method*	*Use*
The Scatter Score Index[a]	Water quality	Assesses increases or decreases in parameters over time and/or space	Mining sites, USA
Environmental Performance Index[b]	Environmental health and ecosystem vitality	Uses a proximity-to-target measure for sixteen indices categorized into six policy objectives	Globally
Index of River Water Quality[c]	River health	Uses multiplicative aggregate function of standardized scores for a number of water quality parameters	Taiwan
Overall Index of Pollution[d]	River health	Assessment and classification of a number of water quality parameters by comparing observations against Indian standards and/or other accepted guidelines *e.g.* WHO	India
Chemical Water Quality Index[e]	Lake basin	Assesses a number of water quality parameters by standardizing each observation to the maximum concentration for each parameter	USA
Water Quality Index for Freshwater Life(CCME)[f]	Inland waters	Assesses quality of water against guidelines for freshwater life	Canada

[a] Kim and Cardone (2005) [b] Levy et al. (2006) [c] Liou et al. (2004) [d] Sargaonkar and Deshpande (2003) [e] Tsengaye et al. (2006) [f] CCME (2001)

2.3: Description and application of the Four Indices Used in the Study

Different water quality indices input different physical, chemical and biological water quality parameters that are necessary for deriving an index value. However, there is no physico chemical index that uses particular analytes as there are overlaps in the parameters they input in their calculations. Such overlaps are in the fashion as shown in Table 2.3.

Table 2.3: Water quality indices with their parameters

Parameter	*Idaho WQI*[a]	*NSF WQI* [C]	*ATI*[b]
Faecal (counts /100ml)	☺	☺	
Change in temperature from 1mile upstream (^oC)		☺	
DO (mg/l,% sat)	☺	☺	☺
pH (units)		☺	☺
EC @ 25^{o}C	☺		
Potassium (mg/l)			☺
Ammonium (mg/l)			☺
Total phosphates (mg/l)	☺	☺	
Orthophosphates (mg/l)			☺
Total Dissolved Salts (mg/l)		☺	☺
Turbidity (NTU)	☺	☺	☺
Nitrates (mg/l)		☺	
BOD_5 (mg/l)		☺	
Metals			☺

☺ *Parameters considered by each index*
[a] *Said et al. (2004)* [b] *Wepener et al. (1992)* [c] *Fenendez et al. (2009)*

Each of the four indices used in this study: National Sanitation Foundation Water Quality Index (NSFWQI), Idaho Water Quality index, Aquatic Toxicity Index (ATI) and the South African Scoring System (SASS 5) have its advantages and disadvantages as indicated in Table 2.4. The use or application of each of these indices for water quality monitoring purposes must take into account these advantages and disadvantages.

Table 2.4: Advantages and disadvantages of indices used in the study

Index	*Advantage(s)*	*Disadvantage (s)*
National sanitation foundation (NSF) WQI[a]	1. Summarises data in a single index value in an objective, rapid and reproducible manner; 2. Evaluation between areas and identifying changes in water quality; 3. Index value relate to a potential water use; 4. Facilitates communication with lay person.	1. Represent general water quality, it does not represent specific use of the water; 2. Loss of data during data handling, *e.g.* eight parameters may say the water is pristine may be one indicate a bad case the index value will indicate pristine condition.
SASS 5 Biotic Index[b]	1. Use of macro invertebrates as indicators of WQ and reflect pollution in recent history; 2. Relatively cheap and quicker; 3. Not destructive as the specimen are returned into the system; 4. Assesses WQ for general water use.	1. Does not identify pollutants; 2. No bacteriological information; 3. Useful when we know much about the biota in question; 4. Cannot be used in large rivers; 5. Difficult to identify macro invertebrates into species.
Idaho WQI[e]	1.Uses few parameters (5 parameters); 2. Can be used in basins with less WQ data; 3. Fast does not need weighting and calculation of sub indices; 4. Gives proposal of what should be done to improve WQ.	1. Cannot be used in making regulatory decisions; 2. .No indication of WQ for specific use; 3.Cannot indicate contamination from, trace elements, organic contamination and toxic substances; 4. The localized changes in water quality may not be immediately reflected; 5. Another change not necessarily reflected in the index is the stream habitat; 6. For the index measurement should not be performed downstream of a waste water treatment plant; 7. It cannot always show the impact of random short-term changes, such as a spill, except if it occurs repeatedly or for a long time.
Aquatic Toxicity Index (ATI)[d]	1. Measures toxicity and suitability of the water for aquatic and riparian animals with particular considerations of toxicity; 2. Summarises water quality data into a single index value; 3. Provide greater certainty when making management decisions; 4. No loss of information in aggregation as it implements a minimum operator function when deriving of the final index value.	1. Interpretation of water quality is in reference to suitability of fish and silent on other uses.

[a] *Wills and Irvine (1996)* [b] *Day (2000)* [d] *Wepener et al. (1992)* [e] *Said et al.(2004)*

2.3.1: The National Sanitation Foundation Water Quality Index

The National Sanitation Foundation Water Quality Index (NSFWQI) is the most commonly utilised water quality index in the United States. It was developed by the United States National

Sanitation Foundation in 1970. This index was mainly developed to provide a standardised method for comparing the water quality of various bodies of water (Said *et al.,* 2004). It can be used to monitor water quality changes in a particular water supply over time. Results obtained from the use of this index can be used to determine if a particular stretch of water is considered to be healthy (Rajankar *et al.,* 2009). It is, however, a non specific water quality index and it does not recognize and incorporate specific water functions like drinking water supply, agriculture and industry.

The initial development of this index employed the Delphic method whereby a panel of 142 water quality experts were asked to select parameters for inclusion into the index (Alam *et al*., 2006). In addition these experts were tasked to rank these parameters according to their significant contribution to the overall quality of the water with a rating of 1to 5. The parameters included in the calculation of the index are a set of nine parameters and these are, dissolved oxygen, fecal coliform, biochemical oxygen demand (BOD_5), temperature change from 1mile upstream, total phosphate, pH, nitrates, turbidity and total solids.

Various water quality indices have been developed and some borrowed certain aspects of this index. Such indices include the Idaho Water Quality Index (Said *et al*., 2004); the Iowa water Quality Index, the index system designed for the Anzali Basin (Shafiri, 1990). The Canadian Council of Ministers of the Environment (CCME) water quality index developed for various water quality institutions in Canada. The Surface Water Quality Index (SWQI) is another index that used some aspects of the NSFWQI when applied to Sylhet. The calculation of the SWQI adopted the NSFWQI (Alam *et al*., 2006). According to Said *et al.* (2004) this index has helped in various divisions in the United States, Canada and Malaysia.

In addition the NSFWQI has been used alongside several indices with the aim of finding out if results it produces are consistent with other indices. In the process it has shown consistency with results produced by the Idaho water quality index, Watershed Enhancement Program Water Quality index Said *et al*. (2004) and consistency with the a new water quality index for environmental contamination contributed by mineral processing in Amang tin tailing processing activity. This index was designed specifically to characterise water as a result of mining activities and it considers different parameters from those considered by the NSFWQI Nasirian (2007).

Beside this index used alongside indices that input physico chemical parameters of water quality, it has been also used alongside biotic indices. The NSFWQI has been used alongside the Shannon Weiner diversity measure which is based on richness of benthic macro invertebrates present in river sampled. Palupi *et al.* (1995) applied both indices to explain water quality of rivers in the vicinity of Jakarta. The results produced by these indices were in agreement as they both showed that the water of the rivers studied was of poor quality. However, the NSFWQI used a different aggregation method from the usual as it used the ninth root of the product of the nine individual parameters' scale numbers.

The NSFWQI has also been utilised in various rivers as a water quality monitoring tool. According to Palupi *et al*. (1995), the NSFWQI has been used in the vicinity of Jakarta for monitoring of Ciliwung, Sunter, and Krukut Rivers. In this case the Bankside residents use the rivers as their excreta and solid waste disposal sites. Various industries located in adjacent areas also discharging their waste into the rivers without adequate treatment. The index in this case was applied as part of a monitoring system by the Health Ecology Research Centre in 1987and 1988. The index was used to characterise the rivers' overall water quality. Considered in this study were nine physico chemical and microbiological parameters required in the calculation of the index value and in addition certain heavy metals were considered, however, the analysis of the metals were not part of the index.

Beside the index being used in the assessment of these rivers, it has been used by the Iowa Department of Natural Resources in their ambient water quality monitoring program, between 2000 and 2003, (Water Fact Sheet, 2006 - 2008). The results produced by the NSFWQI for this region, however, showed various weaknesses. This as cited in the Water Fact Sheet (2006-2008), was due to the mathematical averaging function it uses which tended to suggest better water quality conditions than the actual conditions. This therefore, led to the birth of the Iowa Water Quality Index (WQI), an index developed to incorporate the specific conditions of the Iowa Rivers.

The NSFWQI is derived from nine water quality parameters as indicated in Table 2.5. The parameters in this index are given weights as indicated in the Table 2.5. The weight of each analyte indicates the effect of each analyte to the water quality compared to the other parameters.

Table 2.5: National Sanitation Foundation Water Quality Index parameters and their weights

Parameter	*NSF WQI weight*
DO	0.17
Faecal coliform	0.15
pH	0.12
BOD_5	0.10
Nitrates	0.10
Total Phosphates	0.10
$\Delta t\ ^0C$ from equilibrium(1mile upstream)	0.10
Turbidity	0.08
Total solids	0.08

Source: Wills and Irvine (1996)

The mathematical expression for NSF WQI is given as follows:

$$\sum_{i=I}^{p} WiIi \qquad \textit{Equation 2.1}$$

Where:
I_i is the sub index for the i_{th} water quality parameters
W_i is the weight in terms importance associated with i^{th} water quality parameter
p is the number of water quality parameters

This index categorises water into levels from 0 to 100, whereby 0 indicates very bad water quality status and 100 indicating excellent condition as indicated in Table 2.6. This table also show corresponding categories ranging from the best state being category A to the Worst category being E and the corresponding suitability which is in five levels as well.

Table 2.6: National Sanitation Foundation Water Quality Index' numerical ranges and descriptor words

Numerical range	Category	Descriptor word
91-100	A	Excellent water quality
71-90	B	Good water quality
51-70	C	Medium/ average water quality
26-50	D	Bad/ Fair water quality
0-25	E	Very bad/ Poor water quality

Source: Samantray (2009)

2.3.2: Idaho Water Quality Index

This index measures the suitability of in-stream water for the designated beneficial use to be protected in the stream. It has been applied in the Big Lost River watershed in Idaho. The index results give a quantitative picture for the water quality. If the water is suitable for a higher beneficial use such as salmonid spawning or primary contact, it would be confidently suitable for use in agriculture and other uses that do not require high quality water. The index was developed for the purpose of providing a simple method for expressing the significance of water quality data, and was designed to aid in the assessment of water quality for general uses.

It was developed from the NSFWQI with the aim of making certain improvements from it. The Idaho uses only 5 water quality parameters (Fernandez *et al*., 2009). The parameters considered for the calculation of this index are, dissolved (DO % saturation), total phosphates (mg/l), fecal coliforms (counts/100ml), turbidity (mg/l) and specific conductivity (µs/cm).

This index has various advantages over other water quality indices. It is very simple, fast, does not need to standardize the water quality variables or to calculate sub-indices, and it requires fewer water quality variables that are needed to evaluate the water quality situation. This index contains five variables compared to eight or more variables for other indices. The index can also be used to compare sites and it can be applied in most watersheds than most indices. This is the case because most indices in use require more parameters that most watersheds do not have in long term and continuous form (Said *et al*., 2004). When using this index, however, caution should be taken; the measurements should not be performed downstream of a wastewater treatment plant or in areas where large amounts of animal or untreated human waste is deposited into the stream (Said *et al*., 2004).

This index gives results very similar to those calculated using NSFWQI and Watershed Enhancement Program Water Quality index (WEPWQI) methods while using fewer variables. This was indicated when it was used alongside these indices to characterise the water quality of the Big Lost River Watershed in Idaho using water quality data from 1980 to 2000 (Said *et al*., 2004). On another level , when this index was used along side the Oregon Water Quality index it showed to be more sensitive for degraded water quality parameters in which case where the OWQI indicated water of good quality the Idaho WQI had values of less than 2; there by indicating water requiring remediation (Said *et al*., 2004).

$$\text{WQI} = \log\left[\frac{(\text{DO})^{1.65}}{(3.8)^{\text{TP}}(\text{turb})^{0.15}(15)^{\text{fcol}/10000}+0.14(\text{SC})^{0.5}}\right] \qquad \textit{Equation 2.2}$$

Where by:

WQI: IdahoWater Quality Index
DO: dissolved oxygen (% saturation),
turb: turbidity (NTU),
TP: total phosphates (mg/l)
f.coli: fecal coliform bacteria (counts /100 ml),
SC: specific conductivity (µs/cm at 25 ^{o}c)

This index has numerical values ranging from 0 to 3. For the Idaho WQI0 indicates a worse case and 3 indicating best state of the water (Table 2.7). According to said *et al.*, 2004 water quality ranging from 3 to 2 (upper limit), indicates water of good quality suitable for drinking. Water within the same range but within the lower limits of the range indicates water suitable for recreation and not for drinking. Water ranging between 1 and 2 indicates water that cannot be used for certain beneficial uses such and drinking and swimming. The lowest range of the index being 1 – 0 which indicates water that needs remediation in the form of total maximum daily loads and requiring best management strategies. Shown in Table 2.7 are the Idaho WQI ranges expressed with suitability for use and possible management actions for the lower ranges.

Table 2.7: Idaho Water Quality Index and Suitability for use

Idaho WQI ranges	*Interpretation and suitability for use*
3-2 (Upper limits)	Water of good quality suitable for drinking
3-2 lower limits	Water suitable for recreation and not for drinking.
2-1	Water not suitable for certain beneficial used and cannot be used for drinking and swimming.
1-0	Water requiring total maximum daily load and best management strategies.

Adapted: Said et al. (2004)

2.3.3: Aquatic Toxicity Index

The Aquatic Toxicity Index (ATI) was developed to aid as a tool in the operational management of rivers passing through the Kruger National Park, South Africa. A total of six rivers pass through this park. However, considerable attention has been paid on the Olifants River based on its remarkable user demand. This index was developed in 1992 as part of the water quality monitoring programme which initiated towards the end of 1983 by the Department of Water Affairs and Forestry (DWAF). This index came about as an attempt to simplify the interpretation of the water quality data: mainly metal contamination in the biotic and abiotic component of the Olifants and Selati Rivers. Its initial use was in 1992, mainly to condense water quality data collected by the department between 1990 and 1992. In this case the ATI was able to condense large amounts of data collected over this period, giving two index values (the additive index score and the lowest rating score). This index has demonstrated seasonal cycles and trends in water quality and highlighted river reaches which showed a change in water quality when applied to summarise data sets from Hlanganini Dam, Pioneer Dam, the Olifants, Letaba and Selati Rivers in South Africa (Wepener *et al.*,1992).

The index value produced by the ATI gives an indication of the rivers' suitability for a specific beneficial use say for the maintenance of aquatic ecosystem. The lowest rating score on the other hand is selected since the aggregation technique used to derive the final score may hide the most valuable information. This score is meant to identify the determinant which limits the water's suitability for use and the degree to which it occurs. To derive an index score the ATI uses Dissolved Oxygen (DO), pH, Ammonium (NH_4^+), Fluoride (F), orthophosphates (PO_4), potassium (K), total dissolved solids (TDS), turbidity (NTU), manganese (Mn), Nickel (Ni), copper (Cu), Chromium (Cr), lead (Pb), and Zinc (Zn). Previous studies using the Aquatic Toxicity Index to analyse data did not only base their conclusions on the index value. To conclude on the water quality of the Selati River, Wepener *et al*., 1999, considered sodium and sulphates in addition to the index scores.

A final index score is produced by employing a computer based software programme called WATER 2. This software is written in Pascal with turbo Pascal version 6. It incorporates all the equations for the fourteen parameters. The programme is able to compute both the additive and the minimum operator final index values. In addition this programme also provides valuable information on the harmful effects that the different determinants would have on fish should the suitability for use concentration limit be exceeded? The interpretation and classification of the ATI scale has values of water quality ranging from 0 to 100 whereby the higher the index scores the better the quality of the water (Table 2.8).

The ATI was designed specifically for fish in water system with hardness greater than 120 mg/l as $CaCO_3$ and pH > 7.8. The aquatic toxicity index describes water quality with reference to its suitability for fish as health indicators of the aquatic ecosystem. The ATI was developed to aid the interpretation of water quality information in order to facilitate management decisions. This index was developed reflect the effect of water quality on specific water use with specific reference to aquatic environment. The development of this index was directed on the effects of water quality on aquatic organisms, especially fish when taken into account. This index was developed for fish only because of the intensive toxicity data base available on for fish. ATI scores are interpreted using Table 2.8 in Chapter 2.

Table 2.8: Interpretation and classification of the ATI scale

ATI scale	*Interpretation*
60-100	Indicate water of suitable to all fish life
51-59	Indicates quality of water suitable only for hardy fish species e.g. adult *Oreochromis mossambicus* and adult *Clarius gariepinus*
0-50	Indicates water quality which is totally unsuitable for normal fish life.

2.3.4: The SASS 5 Biotic Index

National water quality monitoring in most countries is focused on the measurement of physical and chemical variables. It is, however, increasingly realised that measuring chemical variables on their own cannot provide an accurate account of the general health of an aquatic ecosystem (Roux *et al.*, (1993). It is therefore on such basis that biomonitoring protocols need to be incorporated into monitoring actions in order to allow effective protection of aquatic resources. It is of note, however that biological data have to be integrated with chemical and physical data in order to provide meaningful environmental information (Roux *et al*., 1993). This is also of the fact that the measurement of chemicals in water can give a very accurate measure of the amounts of individual substances present in the water (Day, 2000). To aid in the interpretation of the SASS results it is always coupled with the measurements of a few physicochemical water quality parameters. These are temperature, dissolved oxygen, pH and electrical conductivity. These ancillary analyses can be useful in interpretation of the SASS data. They are, however, only as good as the method and instruments (Dickens and Graham, 2002).

The history of the SASS began from the index that was developed by (Chutter, 1972). This index was never widely used as it was excessively labour intensive. Improvements by Chutter in the 1990s as he set out to develop an index that would be faster and easier basing it in the BMWP method developed earlier in the United Kingdom. This index was referred to as the South African Scoring System (SASS). This index as well had to undergo various improvements, however, not solely by Chutter (1972) but with an involvement of the South African Research Commission. Since then, great improvements have taken place. Such changes have resulted to the SASS4 index and at a later stage the SASS5 index.

The South African scoring system uses riverine invertebrates to explain the state of water quality. Riverine Macro invertebrates are suitable for use because, they are usually available in large numbers, are fairly biodiverse, have relatively short lifespan, and they differ in their tolerances to pollutants and other aspects of water quality (Day, 2000). Secondly because, of their visibility to the naked eye, ease of identification, rapid life cycle often based on the seasons and their largely sedentary habits (Dickens and Grahams, 2002).

There are two principles that govern the SASS. Invertebrates occur in less impacted waters in pristine conditions while other invertebrates occur in more impacted waters in the lower reaches of the river. The second principle is that some invertebrate taxa are much more sensitive to water quality impairment than others. Examples of sensitive groups are Oligoneuride (may flies), Prosopistomatidaes (water specs), Ephemeridae, Hydrosalpingidae and Blephariceridae. Less sensitive groups include, Oligochaeta, Culicidae, Muscidae and Syrphidae. In polluted water there will be fewer sensitive species.

The application of SASS always makes reference to a reference and monitoring site. Reference sites are the pristine conditions of the river, representing the less impacted sites. The reference sites are used as control sites for the invertebrates present in the river. At family level it is allocated a sensitivity or tolerance score ranging from 1 to 15. Where by 1 is for tolerant taxa and 15 for sensitive taxa. SASS scores are interpreted using a guide shown in Table 2.9. This guide was devised by Chutter in 1998 and modified by Dallas in 2002.

The main scoring categories:

- SASS Score: sum of sensitivity or tolerance scores of the SASS - taxa encountered in the sample.
- Number of taxa and Avarage Per Taxon (ASPT): calculated by dividing the SASS Score by the number of taxa found in the sample.

Table 2.9: Interpretation of Results: List of invertebrates pollution indicators

Category	*Total score*	*ASPT*	*Water Quality*
A	>100	>6	Natural water quality , high biotope diversity
B	<100	>6	Natural water quality reduced biotope diversity
C	>100	<6	Border between natural water quality and deterioration
D	50-100	<6	Some deterioration in water quality
E	<50	Variable	Major deterioration in water quality

Source: Dallas (2002)

Various Southern African countries have utilised the SASS as means of assessing the status of certain rivers. In South Africa this index is one of the tools used in the rivers' assessment for the National River Health Programme (Uys *et al*., 1996; Dallas, 2000; Dickens and Graham 2002). In South Africa, this index has since been adopted and used by various institutions, such include, the Metro council, Umgeni Water, Umlaas irrigation board, Mpumalanga Parks board, Department of water affairs and forestry and many others including forestry companies and heavy industries (Dickens and Graham, 2002).

Other countries whereby this index has been used include Zimbabwe (Dallas, 2000). This index has been applied in Zimbabwe as both SASS4 and SASS 5. Thirion (1995) used the SASS4 index in the assessment of the Chivero Basin as a tool for biological characterisation. In this case the presence and pollution tolerance or sensitivity of selected macro-invertebrates' orders and families were used to classify different sites. This tool has been used to assess the status of the Yellow Jacket and Mazowe Rivers among others. In this study (Gratwicke, 1999) found that the water quality of the two rivers was dynamic as the SASS scores changed with seasons. Rather Gratwicke found that SASS scores were highest at polluted sites during rainy seasons and low during dry seasons. This is attributed to dilution effect during rainy season and concentration during the dry season.

The SASS5 biotic index has also been used in Swaziland. It has been used in the biological assessment of the Mbuluzi River. In this study (Muthimkhulu *et al*., 2005) concluded that South African rivers and Swaziland's rivers are similar ecologically, this therefore allows for the application of the index with no modifications. From this study as well it was recommended that a similar study be carried out to capture seasonal variations, as it was carried out during the rainy season.

Namibia is another country that has used the SASS. However, its utilisation has taken another route as it resulted in the development of an improved index to suit the ecological conditions of Namibia. In agreement with (Dallas, 2000) the SASS was developed for South African rivers, but it could be modified and used in other Southern African rivers. In the case of Namibia this led to the Namibian Scoring System (NASS) Version 2. The NASS according to Palmer and Taylor (2004) was developed based on the SASS 5, it was however, modified to account for additional tropical invertebrates, taxa that occur in northern Namibia. The NASS version 2 has been applied to the Zambezi near Katima Mulilo and the results from this index were found to be fluctuating predictably with changes in water level.

This SASS Biotic Index has also been used in Zambia. This is mainly with reference to a study done by Mpande (2007). In this case the index was used alongside the measurement of various physical and chemical parameters. The use of biotic indicators alongside physico chemical parameters gives an integrated assessment of a system (Roux *et al*., 1993). The SASS was applied without any modifications. In the case of Zambia it may have been ideal to have some modifications. Day (2000) states that if this index is to be used further north of South Africa it may be necessary to modify it. Such biomonitoring modifications would most likely include adding or removing certain taxa and/ or modifying the sensitivity/ tolerance scores for particular taxa (Dallas, 2000). This is in light of the NASS version 2 developed in Namibia to cater for tropical invertebrates in Northern Namibia. Given that Zambia is even further north, possible modifications of the SASS are a major prerequisite for Zambian rivers as well.

2.4: Water Quality Studies in Southern Africa

Various approaches have been taken in studying water quality in Southern Africa. Recently, South Africa has taken the National River Health Programme (NRHP) approach to water quality. Such has resulted in water quality studies in South Africa moving more towards an integrated approach. The NRHP put emphasis on the measurement of physical, chemical and biological characteristics of rivers that can give qualitative and quantitative information on rivers (CSIR National Resources and the Environment, 2007). Such an approach has resulted to greater development of biomonitoring protocols (use of macro invertebrates) which are gradually adopted as water quality assessment tools in Southern Africa as a whole; such is the application of the SASS 5 in South Africa, Zimbabwe, Zambia, Swaziland, the NASS2 in Namibia and others.

Beside the use of invertebrates as indicators of water quality fish has been greatly used in various countries in the region. Such include studies by (Dlamini and Hoko, 2004) in the assessment of the Great Usutu River in Swaziland. Others include the fish indexing system referred to as the Fish Assemblage Integrity Index (FAII) developed and applied in the Crocodile River in South Africa (Kleynhans, 1999). This index showed spatial variations in the quality of the system by indicating that certain stretches of the river were impaired.

Other studies have paid attention on specific aspects of water quality. Such include work by Mansuetus *et al.* (2004). Their focus was on the population of bacteria in the waters samples of Usuthu, Usushwana and Komati Rivers in Swaziland. The population of these bacteria showed both spatial and temporal variations. However, such an approach is not complete as water quality is not only a result of the absence of microbes, Hence the move towards an integrated approach to water quality.

Other approaches taken in studying water quality in the region have been through the use of physico chemical water quality indices. Such indices include the Aquatic Toxicity index developed for the assessment of water quality of rivers passing through the Kruger National Park in South Africa (Wepener *et al.*, 1992); the Estuarine Water Quality Index (EWQI) used in various estuaries in South Africa (Cooper., *et al* 1994). Another index that has been used to evaluate water quality in the region is the Fuzzy Water Quality Index in the Odzi River in the Eastern Highlands in Zimbabwe (Jannalagadda, 2000). These indices have been useful tools in the monitoring programmes of these water bodies and they have clearly depicted spatial and temporal variations.

2.5: Water Quality Studies in WREM and IWRM Master's Programmes

Water quality studies within the Integrated Water Resources Management (IWRM) and Water Resources Engineering and Management (WREM) Masters Programmes have taken three major directions. The first group of studies have entirely focused of the measurement of the magnitude of physico chemical water quality parameters in explaining the quality of the water bodies such include (Nkambule, 2001; Nyikuri, 2001; Mbandeka 2002; Mvungi, 2002; Mhlanga 2005; Kuutondokwa, 2008; Nkuli, 2008). Another notable direction has been by those that have measured the magnitude of the concentration of the physico chemical water quality parameters alongside the measurement of biological indicators such as fish survey and biological accumulation in fish tissues, which were, however not expressed in an index form. Such include Dlamini (2004); Biringu (2006). The third route has been by those that have measured the physical and chemical water quality variables alongside biological assessment with results expressed as an index. Such studies include work by Muthimkhulu *et al.*, 2005; Mpande 2007; Dlamini 2009; Ndhlovu 2009.

It is of note that the water quality studies in the IWRM and WREM Master's Programmes have explained water quality in relation to the concentrations of environmental variables, fish surveys, biological accumulation of certain compounds in fish tissues and rapid biological assessment. Indexing of water quality has been entirely through biotic indices like the South African Scoring System, normalised difference vegetation index and the Shannon- Weiner index of diversity indices. It is noted as well that none of the studies in these programmes have used water quality indices that input physical and chemical water quality parameters like the National Sanitation Foundation Water Quality Index, the Idaho Water Quality Index and the Aquatic Toxicity Index alongside a biotic index to explain the quality of a water body. It is partly on the basis of such a point of departure that this study is different and therefore carried out.

2.6: Summary

Various water quality indices have been developed and applied to aid in the evaluation of water quality in various parts of the world. Some of these indices have as well been infused into policies by environmental protection agencies like the CCMEWQI (CCME, 2001). From, literature, however, it seems that the indices of water quality, both physico chemical and biotic indices, do not capture pathogens (disease causing organisms) like viruses. In this way the aquatic biologists seem to be ignoring human health at the expense of the aquatic life. On another level, remarkable work has been done to establish consistency among various physico chemical water quality indices. Such include the consistency between the NSFWQI, OWQI, WEPWQI and the Idaho WQI (Said *et al.*, 2004). Other indices that had been related are the NSFWQI and the Shannon Wiener richness index (Palupi *et al*., 1995). However, it is of interest to explain the relationships between the physico chemical water quality indices and biotic indices like the SASS 5 Biotic Index and what stories can such indices tell in a different geographic region. On the same line as raised by Wepener *et al*. (1992) for example they proposed that the relationships between results generated by the Aquatic Toxicity Index and biotic indices like the SASS be investigated.

3: MATERIALS AND METHODS

3.1: Description of Study Area

3.1.1: Sampling Programme

The Lusushwana River is part of the Great Usuthu Catchment. The river begins from South Africa and enters Swaziland in the north western part of the country. The river flows from its upper reaches, through the Ezulwini Valley towards the middle reaches along Lobamba, pass through the Matsapha industrial area until it joins the Great Usuthu River in Sidvokodvo as shown in Figure 3.1. Located within the Lusushwana Catchment are the Mbabane City and the Matsapha industrial area.

3.1.2: Geography

The Lusushwana sub-catchment cuts across three physiographic regions in Swaziland. These are the Highveld, Upper Middleveld and Lower Middleveld. The Highveld has an average of 1, 300 m above mean sea level it is a continuation of the Drankensburg Escarpment. It is characterised by rugged mountains, deep river valleys and steep rocky slopes and erosion of igneous rocks, mainly granite. This region consists of short grassland covered with bushes and small trees interspersed with rock out crops.

3.1.3: Water and Land Use

The Lusushwana sub catchment upstream is characterised by small pockets of agricultural lands, forestry plantation and scattered settlements. Lusushwana River is dammed at the Luphohlo dam for the generation of hydro power. Further downstream the river is used for industrial production, where it supplies bulk water to the Matsapha and Manzini urban areas. The Lusushwana River is also used as a sink for urban and industrial waste as waste from the industries and urban areas. The water from the Lusushwana River is also abstracted for the generation of hydropower at the Mkinkomo Reservoir and then diverted through the Ferreira canal for hydro power generation at the Maguduza and Dwaleni Power Station.

Beside these uses the Lusushwana environs are also used for fishing, sand mining, tourism and the abstraction of water for irrigation purposes. Irrigation is for both commercial and subsistence purposes. This river is also used as a source of water for domestic purposes both upstream and downs stream of the industries. Communities that utilises the river for domestic purposes include the Beaconkop and Luhlendlweni upstream and downstream are the Ngonini and Nhlambeni communities.

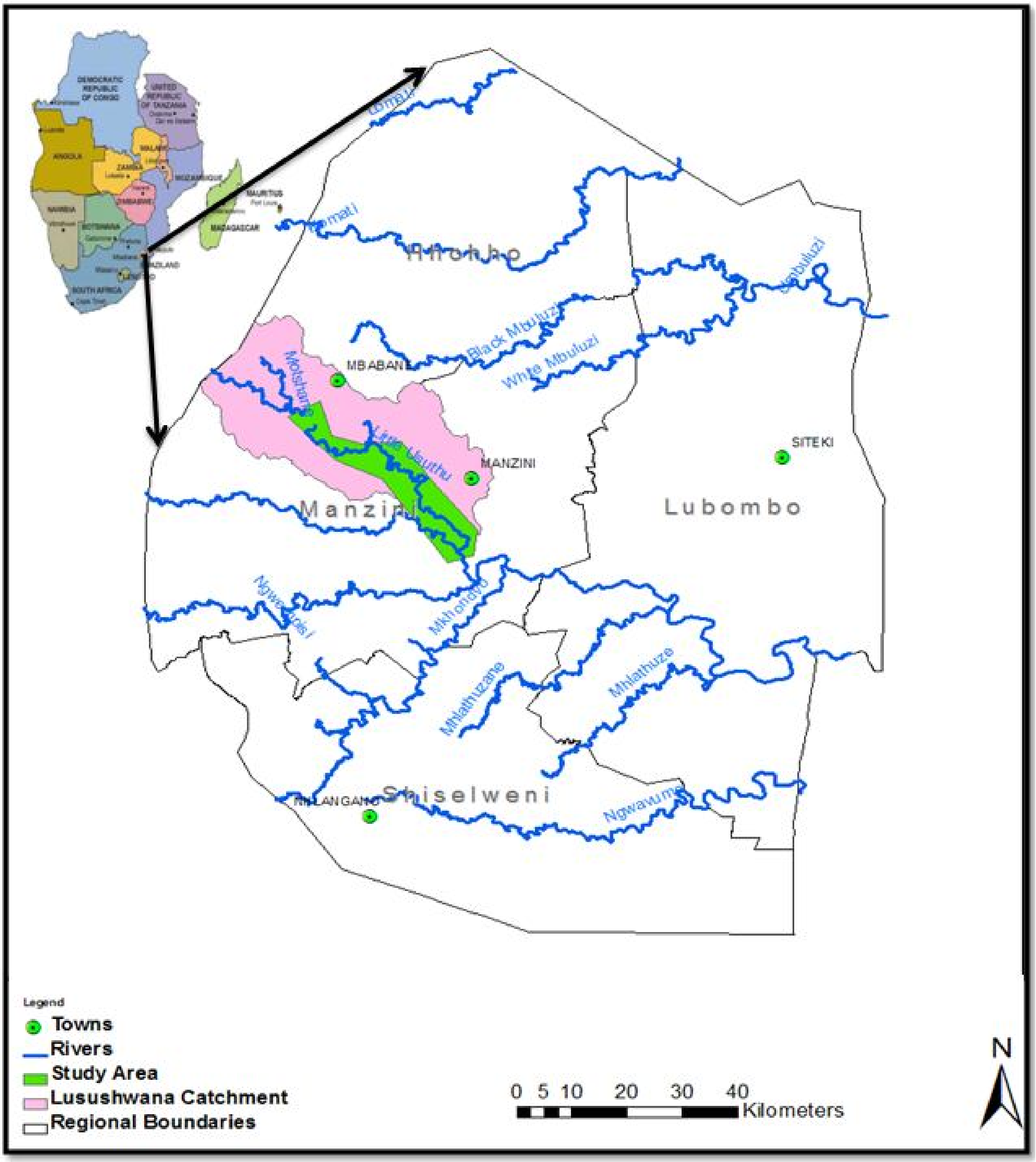

Figure 3.1: Map showing the position of the study area in Swaziland

3.2: Sampling Programme

3.2.1: Location of Sampling Sites

The points were chosen to capture spatial variation in the water quality of the river covering reference point and sites considered to be impacted (Table 3.1). This was from Siphocosini before the Luphohlo dam moving down stream to Nhlambeni before the confluence with the Great Usuthu River (Figure 4.1). Bimonthly samples were collected in February and March 2010. Collected data within this period were the geographic coordinates for the sampling points, water quality variables and aquatic micro invertebrates. A total of 5 sampling sites within the stretch of the river were chosen from upstream to downstream (T1 to T5) as indicated in Figure 3.2. Specific geographic locations of the sites are shown in Appendix A.

Table 3.1: Characteristics and justification of sampling points

Sampling points	*Characteristics of the sampling points*	*Justification*
T1	Siphocosini before Luphohlo reservoir upstream of the weir. Upstream of this point there are pine trees plantations found at about 5km upstream of this point.	Point used as a reference point aimed to capture less impacted conditions of the river.
T2	Zulwini/ Mantenga downstream of the Luphohlo Dam. Point located –13 km from the Luphohlo Dam.	Point meant for capturing the status of the river after the Luphohlo dam.
T3	Lobamba before the bridge. 8 km Upstream of the Matsapha industrial area. The point is located at about 1.5 km downstream of the confluence with the Mbabane River which receives discharges from the Zulwini sewage treatment plant.	Point for capturing the status of the river before the Matsapha industrial area.
T4	Phocweni 12 km downstream of the industrial area.	Point for capturing the conditions of the river after the industries and before receiving effluent from Nhlambeni sewage treatment plant.
T5	Nhlambeni 2 km downstream of the confluence with the Mzimnene River, which receives discharge from the Nhlambeni sewage treatment plant 3 km before joining the Lusushwana River.	The state of the river before it joins another river system to capture self purification capacity of the river.

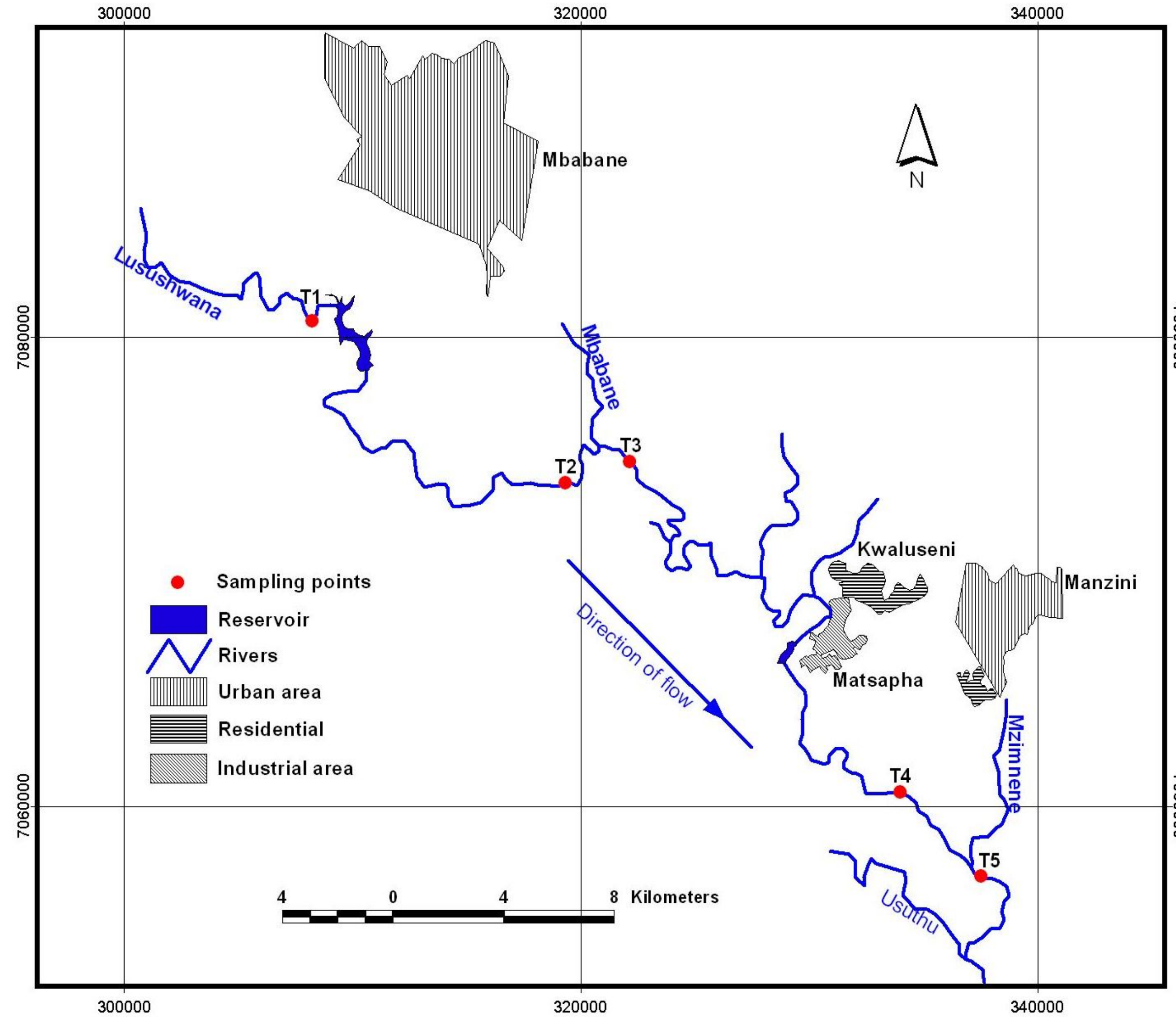

Figure3.2: Map of Lusushwana Sub Catchment showing sampling points

3.2.2: Selection of Parameters

Since this study utilises water quality indices in the assessment of the river, the selected indices were the major determinants in the selection of the parameters that were considered. These indices input different variables. Riparian land uses did not play a major role in the selection. The selected water quality parameters can be divided into three groups and these are water properties, chemicals and metals for the physico chemical water quality indices. The SASS 5 Biotic Index only considered the water properties and aquatic macro invertebrates.

3.2.3: Data Collection: Macro Invertebrates

The SASS5 protocol (Dickens and Graham, 2002) was used for collection and analysis of the macro invertebrates. The invertebrates were identified in the field using identification guides of the South African-National River Health Programme guides by Gerber and Gabriel (2002). The sampling sites were characterised of gravel, sand, mud, marginal vegetation and in stream vegetation. The biotopes were agitated by kicking while holding the hand net opposite the direction of the flow for 2-5 minutes. The vegetation biotope was swept for 1 minute over a distance of 2 metres. The collected invertebrates were tipped into a white sorting tray for identification, enumeration and scoring. Identified taxa were returned into the river and unidentified specimens were collected into labelled jars for further analysis in the laboratory.

3.2.4: Data Collection Physico Chemical Water Quality Parameters

Sub surface water samples (grab), at each site, were collected in triplicate and then mixed to form composite samples. The collection bottles were divided into three. For microbial (fecal coliforms) sterilised glass bottles were used. Metals were collected using 500 ml polythene bottles acidified with nitric acid in order to keep metals in solution. The collection of water samples for the other physico-chemical parameters, 500 ml polythene bottles pre- washed with dilute nitric acid and thoroughly rinsed with deionised water. Temperature, dissolved oxygen and pH were tested in the field. The water samples were then put in a cooler box with ice cubes and transported to the laboratory for further analyses. Laboratory analyses for the water samples were performed within 24 hours after collection. Table 3.2 shows a summary of the standard methods used to analyze the physical and chemical parameters (APHA, 1989).

Table 3.2: Parameters with standard method for analysis

Parameters	*Method*	*Reference*
Faecal coliform density (counts/100ml)	Membrane filtration	APHA 9222 D
DO (mg/l), DO (% sat.), pH (units), Electrical/specific conductivity, Change in temperature from 1mile upstream (^oC), Temperature (^oC	Portable Multi-meter (Model HANNA HI9812)	APHA 2510 B
Potassium (mg/l)	Atomic Absorption spectrophotometer	3500-K B
Ammonium (mg/l)	Nesslerization	4500-NH_3
Orthophosphates (mg/l)	PC: multi-direct: Lovibond photometer	
Total Dissolved solids (mg/l)	Total dissolved solids dried at 180^oC	
Total suspended solids (mg/l)	Gravimetric glass fibre method	APHA 2540 D
Turbidity (NTU)	Nephelometric method	APHA 2130 B
Total Solids (mg/l)	Total solids dried at 103- 105^oC	2540 B
Nitrates (mg/l), Total phosphates (mg/l)	UV Spectrophotometric Method (Model HATCH DR/3000)	APHA 4500-NH_3C
BOD_5 (mg/l)	5 Day-BOD Test	APHA 5210 B
Fluoride (mg/l)	Colorimetry	
Nickel (mg/l), Copper (mg/l), Chromium (mg/l), Iron (mg/l), Lead (mg/l), Zinc (mg/l), Manganese (mg/l)	Inductively Coupled Plasma	
total phosphorus (mg/l)	Colorimetry	
chemical oxygen demand (mg/l)	COD –Closed Reflux Method	APHA5220.C
Nitrogen- ammonia (mg/l)	Colorimetry	

Source: APHA (1989)

3.3: Water Quality Data Processing

The physical and chemical variables of the Lusushwana River collected between February and March 2010 were used as input in calculating the selected water quality indices. The indices input different water quality variables as presented in Chapter 2 (Table 2.3). In calculating the National Sanitation Foundation Water Quality Index the Wilkes University (WU) NSFWQI' online calculator was used. The calculator input nine variables and calculates Q- values (expressing each parameter in a range of 0 to 100) for each of the nine variables. Each of these Q- values was then weighted by multiplying the obtained value with its weighting factor. The weighting factor for each parameter used in this index is shown in Chapter 2 (Table 2.5) from Wills and Irvine (1996). The values obtained are then aggregated for obtaining the final index score based on the nine variables. The Wilkes University calculator for the NSFWQI has been utilised by various scholars, such include Sharma *et al.* (2008), in the assessment of Yamuna River in India. The index scores were interpreted using Table 2.6 in Chapter 2 from Samantray (2009). The NSFWQI calculator used to derive the index scores is a convenient tool for reducing the burden of manually calculating the index (Wilkes University, 2008). The mathematical expression for the NSFWQI is shown in Chapter 2 (Equation 2.1). This expression runs at the background of the (WU) calculator or any other calculator used for deriving the NSFWQI.

The Aquatic Toxicity index was calculated using the Rand Afrikaans University WATER 2 Software (RAUWATER2). This software was developed specifically for the ATI. According to Wepener *et al.* (1992), this software was written in Pascal with turbo version 6. The RAUWATER2 software was developed for the operational management of surface river water. With the aid of this software the number of determinants can be interpreted immediately with resultant value to enable game rangers and researchers to pinpoint deteriorating water quality and possible sources of pollution identified, Weperner *et al.* (1992). In this study, the RAUWATER 2 Software was used in the calculation of the ATI scores and in the production of the reports in Appendix B to F. The Final index score appears as Solway aggregate (an aggregation of all the variables the software input for deriving the index score), the software also indicate the minimum operator or the variable with worst value. The index scores for the ATI were interpreted using Table 2.8 (Chapter 2) by Wepener *et al.* (1992). The procedure in calculating ATI is as shown:

1. Identification of the 13 variables considered by the ATI.
2. Rating of the values of each parameter using the rating curves produced as shown in Table 3.3.
3. The rated values which range between 0 and 100 are the sub indices. From these sub indices the least sub index is referred to as the minimum operator, this helps in explaining the variable that hinders the state of the river water with reference to suitability for fish. The minimum operator is obtained by using the minimum operator function (Equation 3.2)
4. The sub indices are then aggregated using Equation 3.1 to produce the index score. The type of aggregation used is referred to as the Solway aggregation.

$$I = \frac{1}{100}\left(\frac{1}{n}\sum_{i=1}^{n} q_i\right)^2$$ *Equation 3.1*

Where by :

I is the final index score

qi is the equation of the ith parameter (as value between 0 and 100)

n is the number of determinants in the indexing system

MO = minimum (Q_1,Q_2,...Q_i) *Equation 3.2*

Where by:

MO is the minimum operator

Q_i is the quality of the i^{th} parameter.

Table 3.3 shows the various equations used to arrive at the rating curves for each of the thirteen variables considered in calculating the ATI score. The parameters are shown alongside the equations for deriving their rating curves for the ATI. The equations shown in this table are used for plotting the Y-axis and the determined value of the parameter plotted along the X- axis.

Table 3.3: Equations for the determination of Aquatic Toxicity rating curves

Parameter	*Index Rationg Curve*
Dissolved oxygen (mg/l)	$0 \le DO \le 5$:Y = 10 (DO) 5< DO ≤ 6 : Y= (DO)50
	6 < DO ≤ 9: =10(DO) +10 DO > 9 : Y = 10
pH (units)	Y = 98exp[-(pH-8.16)^2(0.4)b +17 exp[-(pH-5.2)^2 (0.5)
	+15 exp[-pH-11)^2 10.72)]+ 2
Manganese (µg/l)	Y= a exp^{-c} exp$^{(Mn)b}$+d a= 0.115: b= 0.00013: c= 0.05 d= 5
Fluoride (m/l)	Y= c ln(a(Cr+b))+d a= 0.001: b=2.5 : c=7.1
Nickel (µg/l)	Y= -c ln (a(Ni+ b)) +d a=1 :b =10 : c =28 :d= 211
Chromium (µg/l)	Y= c ln (a(Cr+b))+ d a = 0.1 : b= 150: c = 40 : d = 210
Lead (µg/l)	Y= -c ln (a(pb+b))+d a =0.1: b= -30: c= 27: d= 148
Ammonium (mg/l)	0.02 ≤ NH^+_4: Y = 100
	0.02< NH^+_4 ≤0.062 : Y= 500(NH^+_4)+10
	0.062< NH^+_4≤ 0.5 : Y = 40/ NH^+_4 + 0.65
Copper (µg/l)	Y=-c ln (a(Cu+b))+d a= 1 : b=-18 ;c= 26 : 180
Zinc (µg/l)	Y = -c ln (a (zn+b)+d a =o.oo1: b= -20: c=22 :d = 16
Orthophosphate (mg/l)	Y= a exp(P)b a= 100: b= -20: c= 22: d=16
Potasium (mg/l)	Y= a exp-b(k)+c a= 150: b= -0.02 : c= -8
Turbidity (NTU)	Y= -c ln (a ln(NTU)+b)+ d a= 0.001: b= 30 : c= 220: d= 689
Total Dissolved Salts (mg/l)	Y= a exp $^{-b(TDS)}$+d a= 117 : b= 0.00068 : d= 7

Source: Wepener et al. (1992)

The Idaho Water Quality Index considers only five water quality parameters as discussed in Chapter 2. The five water quality parameters are aggregated using a logarithmic equation (Equation 2.2). For the final index value there is no weighting of the parameters and calculation of sub indices Said *et al*. (2004).

In the South African Scoring System version 5, calculated were the three SASS principal indices (SASS Score, number of taxa and average score per taxon). On the basis of the SASS the quality of the ecosystem has been interpreted with the aid of the guide provided by Dallas, 2002 in Chapter 2 (Table 2.8).

3.4: Statistical Analysis

The correlation between the water quality indices in this study were calculated using the Spearmans rank correlation coefficient. The spearmans rank is a non parametric measure of the relationship between two sets of ordinal or ranked data. It can be applied to data that is ordinal or interval data converted to interval form (Ebdon, 1985). This test was chosen because it is a non parametric test and non parametric tests do not make assumptions on the nature of the data. Secondly because the indices have different ranges, with the ATI and NSFWQI ranging from 0 to 100, the Idaho WQI ranging from 0 to 3 and the SASS 5 Biotic Indices (SASS Score and the SPT) not having a specific range this test was utilised as ranking of the indices was most appropriate since ranks were developed for each index and independent of the other. The correlation coefficient (r) ranges between +1 and -1 as shown in Table 3.4. Shown against the coefficient ranges are the interpretations of the strength of the correlation for each range from +1 to -1.

Table 3.4: Coefficient ranges and correlation description

Coefficient ranges	*Correlation description*
0.0	No correlation at all
+1 and -1	Perfect positive and perfect negative correlation respectively
0.0 to 0.2	Very weak , negligible correlation
0.2 to 0.4	Weak ,low correlation
0.4 to 0.7	moderate correlation
0.7 to 0.9	Strong , high marked correlation
0.9 to 1.0	Very strong , very high correlation

Adopted: Derek (1981)

4: RESULTS AND DISCUSSIONS

4.1: Water Quality Assessment using the Criteria and Water Quality Indices

The analytical results obtained from the water samples of the Lusushwana River collected between February and March 2010 are shown in Table 4.1.

Table 4.1: Analytical results for water quality samples of Lusushwana River collected between February and March 2010

Parameters	*T1*	*T2*	*T3*	*T4*	*T5*	*SWQO*	*SAAEWQG*
F.coli. (counts /100ml)	100 ±45	124 ±101	453 ±1667	355 ± 159	156±137	1-10	-
DO (mg/l)	7.8 ±1.8	7.5 ±1.7	4.9 ±1.8	4.9 ± 1.6	5.1±0.1	> 4	-
DO (% sat.)	87.6 ±31.3	86.2 ±36.5	62.4 ±31.7	55.7 ±27.6	58±21.7		80- 100
BOD_5 (mg/l)	2.2 ±0.2	2.1 ±0.1	4.3 ±1.5	4.5 ±1	3.5 ±1	< 5	-
pH (units)	7.3 ±0.3	7 ± 0.1	7.2 ±0.5	7.1 ±0.1	6.8±0.3	6.5-8.5	-
Electrical Conductivity (µS/cm)	108.7 ±38.5	96.7 ±33	118.5 ±57.6	246.9±169.2	287.2 ± 175.1	< 1800	-
Turbidity (NTU)	45.1 ± 30.3	28.5 ± 12.3	80.5 ± 80.6	89.0 ± 94.9	67.5 ± 56.5	<5	-
Nitrates (mg/l)	0.4 ± 0.4	0.6 ± 0.4	0.7 ± 0.5	0.8 ± 0.9	0.4 ±0.3	< 10	-
Ammonia (mg/l)	0.04 ± 0.02	0.04 ± 0.01	0.07 ± 0.02	0.07 ± 0.01	0.06 ± 0.01	< 0.6	-
Iron (mg/l)	0.4 ± 0.3	0.5 ± 0.1	0.8 ± 0.3	0.9 ± 0.2	1.1 ± 0.7	< 1	-
Manganese (mg/l)	0.0007 ±0.0009	0.0010±0.0012	0.0016±0.0023	0.0044±0.0043	0.0051±0.0055	< 0.5	-
Chromium (mg/l)	0.0010±0.0010	0.0010±0.0014	0.0020±0.0027	0.0024±0.0031	0.0008±0.0023	-	0.007 mg/l
Zinc (mg/l)	0.0017 ± 0.0015	0.0005 ± 0.0004	0.0019 ± 0.0018	0.0076±0.0089	0.0026±0.003	-	0.0002 (mg/l)

SWQO: Swaziland Water Quality Objectives   SAAEWQG: South African Aquatic Ecosystem Water Quality Guidelines

The results are presented in mean ± standard deviation for average values of each variable obtained from the five sampling sites; T1 (Siphocosini), T2 (Zulwini/ Mantenga), T3 (Lobamba), T4 (Phocweni), T5 (Nhlambeni) over four sampling sessions. The results obtained were compared with the Swaziland Water Quality Objectives (SWQO) and the South African Ecosystem Water Quality Guidelines (SAAEWQG). The comparison was between values for faecal coliforms (counts/ 100ml), Dissolved oxygen (mg/l, % saturation), biochemical oxygen demand (mg/l), pH (units), electrical conductivity (μS/cm), turbidity (NTU), nitrates (mg/l), ammonia NH_3-N (mg/l), iron (mg/l), manganese (mg/l), Chromium (mg/l) and Zinc (mg/l).

4.1.1: Faecal coliforms

The acceptable range for faecal coliforms in surface water according to the Swaziland Water Quality Objectives (SWQO) is between 1 and 10 counts per 100 ml. The faecal coliform counts for the five sampling sites along the Lusushwana River varied from point to point. For all five sampling sites (T1 to T5) the average faecal coliform (counts/ 100 ml) were all above the SWQO, as shown in Table 4.1. Faecal contamination of surface water in developing countries is a major challenge. The major sources of fecal colifoms are inadequate treatment of human waste from densely populated areas. Past study of the water quality of the Lusushwana River by Mansuetus *et al*. (2004) indicated a high average number of Coliform Forming Units (CFU) of bacteria between February and March. A similar trend between Mansuetus *et al*. (2004) and this study has been observed as the highest counts for this study of bacteria were found along the Lobamba- Lozitha (within Site T3) stretch of the Lusushwana River. The highest counts of faecal coliforms along this stretch could be attributed to the grazing domestic animals and from people bathing in the Lobamba Hot Springs (located adjacent to site T3).

4.1.2: Dissolved Oxygen

Average Dissolved Oxygen (DO) levels assessed in all sites for the Lusushwana River for February and March 2010, were between 4.9 mg/l to 7.8 mg/l in sites (T3 and T4) and T1 respectively as shown in Table 4.1. For all the sampling sites DO was within acceptable levels as stipulated in the Swaziland Water Quality Objective (SWQO) for surface water. As indicated by this guideline water that is suitable for aquatic ecosystem must have DO (mg/l) that is above 4 mg/l. Previous study of the water quality of the Lusushwana River by Mtetwa (1996) (for data collected between 1991- 1992) found that the average DO for the river was 5.7 mg/l this finding did conform to the SWQO. For aquatic ecosystems, as stipulated in the South African Aquatic Ecosystem Water Quality Guidelines (SAAEWQG) DO (% saturation) must be between 80-100% (Table 4.1). For DO (% Saturation), only sites T1 and T2 were within the acceptable range for aquatic ecosystems as stipulated in the SAAEWQG. Sites T3, T4 and T5 had DO (% saturation) below the acceptable levels. However, on the suitability for aquatic ecosystems it is worth noting that whatever DO range stated stands to be contested as the tolerance concentrations of DO varies from species to species and even within genus.

4.1.3: Biochemical Oxygen Demand

The average results for Biochemical Oxygen Demand (BOD_5) were low for all the sampling sites. The BOD average values for the sites ranged from 2.1 to 4.5 mg/l for sites T2 and T4 respectively. The average BOD values when compared with the SWQO were all within the acceptable maximum level of 5 mg/l as stipulated in the SWQO. BOD values in the study were relatively high for Sites T3 and T4. In as much as these values may have been within the permissible levels for surface water as stipulated in the SWQO, the water was polluted. Chapman (1996) states that Unpolluted waters typically have BOD values of 2 mg/l or less. As opposed to findings by Mtetwa 1996, the average values were above the SWQO stipulated levels of BOD for surface water in Swaziland. The variations between the findings by Mtetwa (1996) and the findings in this study could be attributed to the fact that the data for this study was collected during the rainy season whilst Mtetwa's findings captured both rainy and dry seasons. Increase in river flows for the rainy season could have diluted the water and thereby lowering the BOD values.

4.1.4: pH

The Swaziland Water Quality Objective (SWQO) range for pH is 6.5 -8.5 and the South African standards for Aquatic Ecosystem has a maximum variation of less than 5. For all the sampling sites for this study all the pH levels were within the acceptable levels. There was, however, a drop in pH levels at Site T5 with an average pH level of 6.8. Previous studies on the Lusushwana also present a similar picture with Mtetwa (1996) having observed an average pH value of 7.4 and Mensuetus *et al*. (2004) recoding an average value of 6.8 for the rainy season, which was slightly lower than the other values obtained from the other studies. On the basis of these studies, the pH values for the river are within the required ranges, and the water quality with respect to pH does meet the SWQO for surface water and is also suitable for aquatic ecosystems as stated in the South African Standard for Aquatic Ecosystem.

4.1.5: Electrical conductivity

According to the SWQO surface water must have a value of Electrical Conductivity (EC) not exceeding 1800 µS/cm. The observed average values for the water quality of the Lusushwana River in this study were all within allowable levels as stipulated in the SWQO. The average EC levels for the five sampling sites ranged from 108.7 to 287.2 µS/cm (Table 4.1). Past water quality studies in Swaziland have shown that EC levels in Swaziland rivers have generally low EC levels. Such include Nkambule, 2001 observed a maximum EC value of 440.9 µS/cm for the Mbabane River; a tributary of the Lusushwana River. Dlamini and Hoko (2005) observed Maximum EC value of 36.69 µS/cm for water quality of the Great Usuthu River.

4.1.6: Turbidity

The average results for turbidity indicated high turbidity values on all sites. The turbidity values for the five sampling sites ranged between 28.5 NTU for site T2 to 89.0 NTU. For all the five sampling sites the turbidity values were far above the permissible amount of turbidity in surface water as stipulated by the SWQO. The high amount of turbidity can be attributed to the fact that the study was carried out during the rainy season (between February and March). Studies by Dlamini and Hoko (2005) of the water quality of the Great Usuthu River concluded that turbidity was relatively higher during the rainy season than the dry seasons. Turbidity is normally high during the rainy season due to increased erosion within watersheds (Palupi *et al*., 1995).

4.1.7: Nitrates

Nitrates concentration in the water of the Lusushwana River for the five sampling sites (T1- T5) in this study ranged from 0.4 to 0.8 mg/l as indicated in Table 4.1. The nitrates concentrations in this case were within the acceptable levels of nitrates in surface water as stipulated in the

SWQO. According to the SWQO nitrates concentrations in surface water must not exceed 10 mg/l. Previous study of the water quality of the Lusushwana River for water quality data collected between 1991 and 1992, by Mtewa 1996 indicated lower levels of nitrates in the water. According to observations by Mtetwa (1996) the average concentrations of nitrates ranged between 1.68 and 4.52 mg/l. The highest concentration of nitrates in both this study and Mtetwa 1996, were observed downstream of the Matsapha Industrial Complex. Fadiran and Mamba (2005) on the other hand, observed that the nitrates levels in the Lusushwana River had increased by seven to sixteen times within a period of ten years (between 1995 and 2005). Findings by these three studies are in agreement that there is elevated amount of nitrates in the Lusushwana River downstream of the Matsapha Industrial Complex. The elevated nitrates concentration in the water of the Lusushwana River after the Matsapha Industrial Complex could be attributed to the leachates and runoff from domestic activities and industrial effluent being discharged into the river (Fediran and Mamba, 2005).

4.1.8: Ammonia (NH_3-N)

The concentrations of nitrogen ammonia for the five sampling sites in the study ranged from 0.04 mg/l for sites T1 and T2 to 0.07 for site T4. The SWQO for surface water in Swaziland states that ammonia concentration must not exceed 0.6 mg/l. For all the sites the concentrations of ammonia were within the maximum permissible value of ammonia as nitrogen in surface water. High concentrations of ammonia in water could be an indication of organic pollution such as from domestic sewage, industrial waste and fertilizer run-off (Chapman, 1996).

4.1.9: Iron

The concentration of iron in the water of the Lusushwana River for the fiver sampling sites ranged between 0.4 and 1.1 mg/l. The SWQO allows a maximum of 1 mg/l of iron in surface water. Sites T1, T2, T3 and T4 had average concentration of iron that was within the acceptable concentration as stipulated in the SWQO. It is only site T5 that had iron concentration above the maximum permissible levels for surface water according to the SWQO. Mtetwa (1996) obtained an average of an average of 2.79 mg/l of iron from the Lusushwana River for data collected between 1991 and 1992. In both studies the elevated concentrations of iron were observed downstream of the Matsapha Industrial Complex. In light of such observation therefore the high iron concentrations could be pollution from the industrial area.

4.1.10: Manganese

The average concentrations of Manganese in the water of Lusushwana River for February and March 2010 ranged between 0.0007 and 0.0051 mg/l. For all the sites the concentrations of manganese were within the acceptable levels for surface water in Swaziland as stipulated in the SWQO. According to the SWQO, manganese concentrations in surface water must not exceed 0.5 mg/l. In this study all the observed values for manganese were within the permissible concentrations of manganese for surface water in Swaziland. Mtetwa (1996) obtained an average of 0.12 mg/l manganese from the Lusushwana River, between 1991 and 1992. The data from both studies shows that manganese was within acceptable levels for surface water in Swaziland.

4.1.11: Chromium

The average concentration of Chromium in the Lusushwana River ranged from 0.0008 mg/l (Site T5) to 0.0024 mg/l for site T4. The South African Aquatic Ecosystem Water Quality Guidelines (SAAEWQG), states that water for aquatic ecosystems must not exceed a maximum of 0.007 mg/l. For all the five sampling sites in this study the water quality of the Lusushwana River, had average chromium concentrations within the SAAEWQG stipulated levels. Mtetwa (1996) obtained an average of 0.07 mg/l chromium concentration from the Lusushwana River between 1991 and 1992. In both studies high levels of chromium were obtained downstream of the Matsapha Industrial Complex. The increase in chromium concentrations in both cases could be attributed to the industrial effluent from the Matsapha Industrial Complex. As stated in the Water UK (2001) the largest contribution of chromium in water is industrial discharge and can account up 87 % such industrial discharges include textile printing works. In this study as well there was an increase in chromium level from sites located upstream of the Matsapha Industrial Complex to sites located immediately after the Industrial Complex (from 0.0020 to 0.0024 mg/l). The difference in the chromium values was, however, very small to safely pin point the industries as a major source of chromium in this case.

4.1.12: Zinc

The average concentration of Zinc in the Lusushwana River for the five sampling sites was all above those required by the South African Ecosystem Water Quality Guidelines (SAAEWQG). The SAAEWQG stipulates that water suitable for aquatic ecosystems must have zinc concentrations not exceeding 0.0002 mg/l. The Zinc concentration in the water ranged from 0.0005 mg/l to 0.0076 mg/l. Such concentrations of zinc in the water indicated that the water was not fit for aquatic ecosystems as stipulated in the SAAEWQG. The zinc concentrations observed from this study were relatively higher than finding by Mtetwa (1996).

The evaluation of the water quality of the Lusushwana River based of the Swaziland Water Quality Objectives (SWQO) for surface water and the South African Aquatic Ecosystem Water Quality Guidelines (SAAEWQG) has indicated that some parameters were not within the stipulated ranges or limits. For the SWQO, faecal coliforms and turbidity were both above the stipulated limits for all the sampling sites (T1 to T5). DO, BOD_5, pH, electrical conductivity, nitrates, nitrogen and ammonia were all within the acceptable levels as stipulated in the SWQO. With respect to iron, however, it was within the stipulated levels for sites T1, T2, T3 and T4, for site T5 iron was above 1mg/l the maximum stipulated concentrations for surface water in Swaziland. For the SAAEWQG, the water quality of the river was meeting the acceptable levels of zinc and chromium. For the DO (% saturation), the average values were only compliant with sites T1 and T2, for sites T3, T4 and T5 the DO values were below the acceptable levels as stipulated by the guidelines.

4.2: Water Quality on the Basis of the Four Indices

4.2.1: Water Quality On The Basis of the Aquatic Toxicity Index

The average index scores per site (T1 toT5) with the minimum operator are shown in Table 4.2. The mean ATI scores were interpreted using Table 2.8 in Chapter 2. The procedures for deriving the ATI and the minimum operator are shown in chapter 3 (Equation 3.1, 3.2 and Table 3. 3). In this case the minimum operator was due to Zinc indicating a minimum score for the index.

Table 4.2: Aquatic Toxicity Index Scores with minimum operator of the water quality of the Lusushwana River water samples for collected between February and March 2010

Site	*Mean ATI Scores*	*Minimum operator*
T1	68.1	16 due to zinc
T2	69.5	16 due to zinc
T3	63.1	16 due to zinc
T4	61.1	16 due to zinc
T5	59.1	15 due to zinc

The average Aquatic Toxicity Index value, for the Lusushwana River was 64.2. Such an index value as shown in Chapter 2 (Table 2.8) indicates water of good quality, water that is suitable for all fish life. This score is with a minimum operator of 16 which in most of the sites is due to zinc. Zinc according to the ATI index' reports produced by the RAUWATER 2 software is not very toxic due to the ionic form [ZnOH+], however, increases in water hardness causes decreased zinc toxicity (Appendix C to G). According to the Aquatic Toxicity Index site T1, T2, T3 and T4 indicate water that is suitable for all fish types. These sites have index values of 68.125, 69.5.63.1 and 61.125 respectively (Table 4.2). An index score ranging from 60 to 100 indicates water that is suitable for all fish types (Table 2.8). The water quality for T5 has an index score of 59.1 indicating water that is suitable only for hardy fish species for example adult *Orechromis mossambicus* and adult *Clarius gariepinus* (Wepener *et al*., 2004).

4.2.2: Water Quality on the Basis of National Sanitation Foundation Water Quality Index.

The average values for each water quality parameter used in deriving the NSFWQI' score are shown alongside the calculated Q- values (Table 4.3). Shown as well in this table are the index categories and descriptor words for each sampling site. A complete interpretation of the various scores of the NSFWQI are shown in Chapter 2 (Table 2.6) by Samantray (2009). The procedures for calculating NSFWQI are shown in Chapter 3, the index' aggregation equation that runs at the background of the Wilkes University's NSFWQI calculator used in this study is shown in Chapter 2 (Equation 2.1).

Table 4.3: NSFWQI Parameters with Q-values for variables, site' category and description for water of the Lusushwana River collected between February and March 2010

Parameters and Q-Values	*Site T1*	*Site T2*	*Site T3*	*Site T4*	*Site T5*
Faecal coliform (col. /100ml)	100	124	453	355	149
Q –values	45.8	44.8	30.3	32.5	37.8
Temp. Change (^{0}C)	0.2	0.3	0.8	1.3	1.1
Q –values	92.3	92	90	87.8	88.8
DO (% sat.)	87.8	86.2	62.4	55.7	58
Q –values	78.8	75.8	57.5	51.3	55.3
pH (Units)	7.3	7	7.2	7.1	6.8
Q –values	91	88	85.8	83.8	81.78
Total phosphate (mg/l)	0.6	0.4	0.6	0.7	0.8
Q –values	57.3	70	59	55	49.8
Total solids (mg/l)	41.5	31.8	75.8	101.8	109
Q –values	85.5	63.3	84.3	83.5	82.5
Nitrates (mg/l)	0.4	0.6	0.7	0.8	0.4
Q –values	96.5	96.3	96.3	96.3	96.3
BOD (mg/l)	2	2	4.25	4.5	3.5
Q –values	80	80	60.3	58.8	65.8
Turbidity (NTU)	45.1	28.5	39.5	89	67.5
Q –values	45.3	54.5	37	34.8	36
***NSFWQI**	**74**	**74**	**64.3**	**62**	**64**
Category	B	B	C	C	C
Description	Good	Good	Medium	Medium	Medium

** (bold): Average NSFWQI Scores*

The average NSFWQI score for the Lusushwana River was found to be 67.7. An index score within this range indicates water falling within Category C. Water classified in this category is described as water of medium or average quality (Table 2.6). Sites T1 and T2 both have an index value of 74. Water with this score is classified under Category B. Water within this range is described as water of good quality. Site T3, T4 and T5 fall under Category C, this category indicates water that is of medium quality. According to this index no site falls under the lowest categories of D and E; categories described as having water of bad to very bad quality respectively. On the basis of this index it can be concluded that the water quality of the Lusushwana River is on Class C as indicated by the average score.

4.2.3: Water Quality On the Basis Of the Idaho Water Quality Index

The sampling sites alongside the five water quality variables used in deriving the Idaho Water Quality Index Scores, the index value and the individual water quality parameter expressed per sampling site (T1 to T5) with the index scores at the last column are shown in Table 4.4. The Idaho Water Quality Index is calculated following procedure shown in Chapter 3 adopted form Said *et al.* (2004). The aggregation Equation used in calculating the Idaho WQI is shown in Chapter 2 (Equation 2.2). The variables used for deriving the index scores were, dissolved oxygen, turbidity, faecal coliforms, total phosphates and specific conductivity.

Table 4.4: Idaho Water Quality Index scores and average water quality variables of the Lusushwana River measured In February and March 2010

site	*DO (% sat.)*	*Turb. (NTU)*	*f.col. (f.col./100ml)*	*TP (mg/l)*	*SC (μs/cm)*	*WQI*
T1	87.8	45.1	100	0.60	193.5	2.13
T2	86.2	28.5	124	0.40	96.7	2.24
T3	62.4	80.5	453	0.60	88.7	1.85
T4	55.7	89	355	0.70	246.9	1.7
T5	58	67.5	2234	0.80	287.2	1.75

DO, dissolved oxygen; F.col, faecal coliform bacteria; TP, total phosphates; SC, specific conductivity

The obtained average Idaho Water Quality Index score for the Lusushwana River was 1.9. This score indicate that the water quality of the Lusushwana River was degraded and could not be used for drinking and recreation. Based on the index scores for T1 and site T2 the water was of good quality with index values 2.13 and 2.24 respectively. Water within this range is in the lower limit of the range 2 -3. As indicated in Table 2.7 adopted from Said *et al*. (2004) water within this category is suitable for recreation and not for drinking. Site T3, T4 and T5 indicates water that cannot be used for certain beneficial uses such as drinking water and swimming.

On the basis of this index it can be concluded that the water of the Lusushwana River based on both the average score and on site by site evaluation, is not falling within the lowest range. Said *et al*. (2004) states that water with an index value of 1.9 needs remediation in the form of Total Maximum Daily Loads (TMDL) and a change in management strategies.

4.2.4: Water Quality On the Basis of the SASS 5 Biotic Index

The interpretation of the SASS results was based on the SASS scores and ASPT. Indicated in Figure 4.1 is the SASS5 Biotic Index shown per site and the index class with sites ranging from Category A to E.

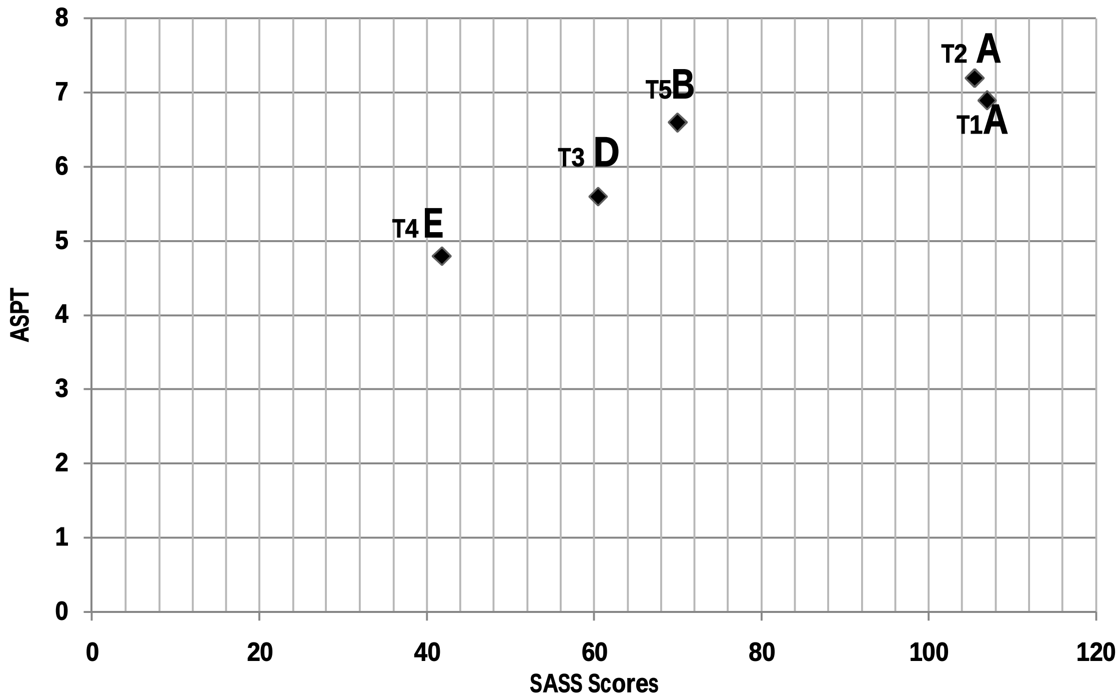

Figure 4.1: SASS Index based on the SASS Scores and ASPT shown per sampling site for invertebrates' data collected between February and March 2010

The sites records from the 5 sites indicate that site T1 and T2 fell under Category A. This category is defined with a SASS score > 100 with an ASPT > 6. Water within this class is classified as natural and therefore of good water quality. Site T5 fell under Category B having a SASS score between 50 and 100 with an ASPT > 6. Site T3 having a SASS score between 50 and 100 and an ASPT less than 6 fell under category D. Class D indicates some deterioration in water quality. Site T4 with a SASS score less than 50 was classified under E. Water in this category is indicative of major deterioration in water quality.

The general statistics of the data of the aquatic macro invertebrates obtained between February and March 2010 over four sampling campaigns is given in Table 4.5. The table shows that the mean SASS Scores for the four campaigns were 77.0, with the SASS Score ranging between 32 and 116. The ASPT had a mean of 12 with values ranging from 7- 17. The number of taxa had a mean of 6 and a range of 4.4 to 8.

Table 4.5: Descriptive Statistics for Macro Invertebrates Data of the Lusushwana River collected between February and March 2010

SASS Index	*mean*	*standard deviation*	*standard error*
SASS Score	77.0	29.7	13.0
ASPT	6.0	3.4	1 .5
No. of taxa	12	1.2	0.5

The average values of each SASS 5 principal indices calculated per sampling site over four sampling sessions are shown in Figure 4.2. The water quality of this river based on the SASS scores and ASPT shows some variations. According to Dickens and Graham (2002), habitat quality and diversity results in reduced biotic diversity and consequently lowering SASS scores. The three SASS indices indicate some variations with three of them having the highest scored in site T2 and the lowest scores in site T4.

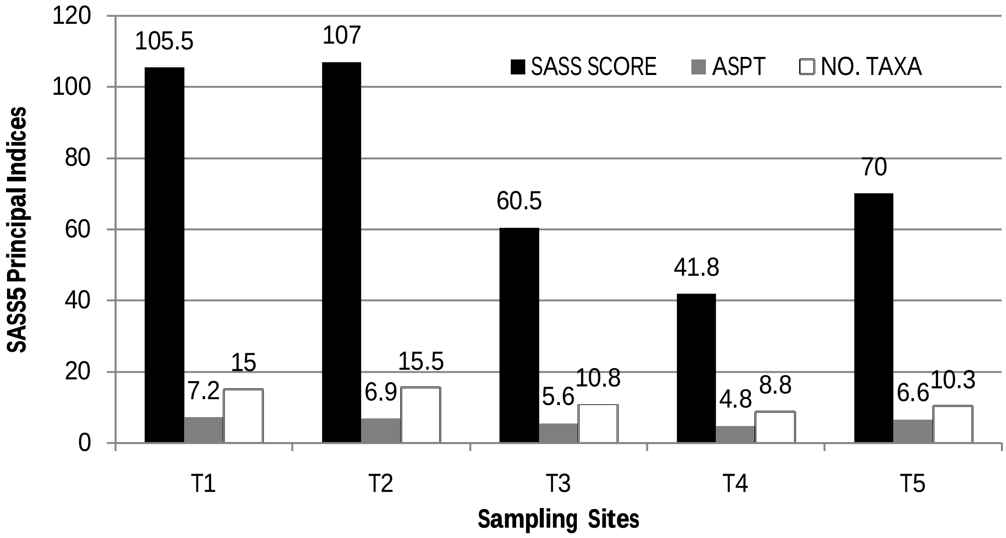

Figure 3.2: SASS 5 principal indices for invertebrates data collected between February and March 2010

The SASS 5 Biotic Index for site T1 and T2 falls under category A and the water quality dropped from site T3 (Category D) to site T4 (Category E) and picks up again in site T5 (Category B). From the data it was observed that the SASS principal indices (SASS scores, number of taxa, ASPT) observed in the study were higher upstream and reducing in the middle and lower stretches of the Lusushwana River. The decline in the indices was mainly associated with the sites located in the urban parts of the catchment, where human activities such as sewage disposal, sanitary landfills and urban and industrial effluent greatly affected the water quality of the river.

It is, however, of note that the Aquatic invertebrates are used as an indirect measure of water quality. The general principle is that poor habitat quality and diversity results in reduced biotic diversity and consequently lowering SASS Indices (Dickens and Graham, 2002). This is the case because the availability of invertebrates in a sample is affected not only by the pollutants in the water but by other factors as well (Gaufin, 1973). Such factors include riverine perturbations and sedimentation.

4.3: Relationship between the Water Quality Indices

One of the objectives of this study was to establish the extent of correlation between the four indices under consideration in this study (ATI, NSFWQI, Idaho WQI, and SASS 5 Biotic Index). Indicated in Table 4.6 is the water quality status if the five sampling points (T1 to T5), presented as averages for the four sampling campaigns (for data collected between February and March 2010).

Table 4.6: Comparison of the Indices' values of water quality data collected between February and March 2010

Site	*ATI*	*NSFWQI*	*Idaho WQI*	*SASS 5 Biotic Index*
T1 (Siphocosini)	Water suitable for all fish life (*68.1)	**B**: Water of good quality (*74)	Water suitable for recreation and not for drinking (*2.13)	**A**: Natural water with high biotope diversity
T2 (Zulwini/ Mantenga)	Water suitable for all fish life (*69.5)	**B**: Water of good quality (*74)	Water suitable for recreation and not for drinking (*2.24)	**A**: Natural water with high biotope diversity
T3 (Lobamba)	Water suitable for all fish life (*63.1)	**C**: Water of medium quality (*64.3)	Water not suitable for beneficial use - drinking and recreation (* 1.85)	**D**: Some deterioration in water quality
T4 (Phocweni)	Water suitable for all fish life (*61.1)	**C**: Water of medium quality (*62)	Water not suitable for beneficial use - drinking and recreation (*1.70)	**E**: Major deterioration in water quality
T5 (Nhlambeni)	Water suitable for hardy fish only (*59.1)	**C**: Water of medium quality (*64)	Water not suitable for beneficial use - drinking and recreation (*1.75)	**B**: Natural water quality with reduced biotope diversity
Overall status	Water suitable for all fish life (* 64.2)	**C**: Medium water quality (*67.7)	Water not suitable for beneficial use – drinking and recreation (*1.93)	**B**: Natural water quality with reduced biotope diversity

(*) Average index scores (ATI, NSFWQI and Idaho WQI) per site

4.3.1: Water Quality for Site T1 (Siphocosini)

Site T1 was used as a reference point; a site meant to capture less impacted water quality conditions of the Lusushwana River. Based on the four indices calculated in this study (ATI, NSFWQI, Idaho WQI and the SASS 5 Biotic Index), there was a general decline in water quality from Site T1 (upstream) to Site T5 (downstream). Site T1 was generally a site with good water quality. According to the ATI Site T1 had an average index value of 68.1, indicating water of good quality. Water with such an index value is suitable for all fish life. With respect to the NFWQI, the water quality of Site T1 had an average index value of 74, indicating water falling under Category B. According to the Idaho WQI, Site T1 had an index value of 2.13. Water with this index value is suitable for recreation and cannot be used for drinking. With respect to the SASS5 Biotic Index the water of Site T1fell under Category A. A site falling within this category indicates water with high biotope diversity.

The water quality of Site T1 was of good quality according to the four indices used in the study. Such an assertion is in line with the initial assumption made in this study, in which case Site T1 was used for capturing less impacted conditions of the Lusushwana River. The status of the water of Site T1 could partly be attributed to the fact that upstream of the point there are scattered settlements with some pockets of agricultural lands. There are no land uses that could highly impact the quality of the water.

4.3.2: Water Quality for Site T2 (Zulwini/ Mantenga)

According to the four indices used in this study the water quality of site T2 had the same index values as those of Site T1, the only differences were with the particular index scores. The ATI score for the water quality of T2 was 69.5; this value indicates water suitable for all fish life. In comparison with Site T1, the average index value for Site T2 (69.5) indicates an improvement in water quality from 68.1 for T1.With respect to the NSFWQI the water quality of Site T2 was categorised under Class B, water within this class is described as water of good quality. According to NSFWQI the average index values indicates no change in water quality from Site T1 to Site T2 as they both have the same average index values (74) Site T2 according to the Idaho WQI had water that was suitable for recreation and not for drinking. With respect to the average scores there was a slight improvement in water quality from 2.13 (average index value for T1) to 2.24 (average index value for Site T2). In both sites (T1 and T2) the SASS 5 Biotic Index indicated water within category A, this indicated no change in water quality for both sites.

Similar to Site T1, Site T2 had water of good quality. The good quality water at Site T2 could be attributed to the fact that, there are no discharges (industrial and Urban) into the river at the upstream of the point. With the Luphohlo Dam upstream, however, the index values could have been expected to be having been lower for Site T2. This is in light of arguments made by Chapman (1996), whereby it is stated that damming has effects on both the physico chemical and ecological conditions of a river.

4.3.3: Water Quality for Site T3 (Lobamba)

The index values for Site T3 changes from Site T2 to Site T3. However, with the ATI, Site T3 had the same category as Site T2. In both Sites T1 and T2 the water was suitable for all fish life. With respect to the index values there is a decline from T2 with an average index value of 69.5 to Site T3 with an average index value of 63.1. The NSFWQI showed a decline in water quality from the Site T2 with an average index value of 74 to T3 with an average index value of 64.3. With respect to the Idaho WQI, a decline in water quality from T2 with water suitable for recreation to T3 with water not suitable for any beneficial use (drinking and recreation) was observed. With respect to the average index values for the Idaho WQI the index values dropped from 2.24 for T2 to 1.85 for T3. According to the SASS 5 Biotic Index a major decline in water quality was also observed. The SASS index class dropped from Category A for Site T2 to D for Site T3.

The decline in water quality from Site T2 to Site T3 could be attributed to the increase in land use intensity between Sites T2 and T3. Particular land uses that could be responsible for the decline in water quality at Site T3 could include discharges from Zulwini Town, the Mbabane River which drains the Mbabane City and the clustered settlements of Lobamba area.

4.3.4: Water Quality for Site T4 (Phocweni)

Site T4 was mainly chosen to capture the conditions of the Lusushwana River after the Matsapha Industrial Complex. This site according to most of the indices used in the study had the lowest index scores foe the water. For Site T4, the ATI average values dropped from 63.1 for Site T3 to

61.1 for Site T4. With suitability for fish life, however, there was no change, as the water even in site T4 was suitable for all fish life. According to the NSFWQI the water for both Sites T3 and T4 fell under Category C. With respect to the average index values, there was a decline from Site T3 with an index value of 64.3 to an index value of 62 for Site T4. Site T4 according to the NSFWQI recorded the lowest average index value. The Idaho WQI indicated that the water for Site T4 was not suitable for beneficial use (drinking and recreation). On the basis of the average index values there was a decline in water quality from Site T3 with an index value1.85 to Site T4 with an index value of 1.70. The SASS 5 Biotic Index also had the lowest class for Site T4. According to the SASS 5 Biotic Index Site T4 fell under Category E, indicating major deterioration in water quality.

There was a further decline in water quality from Site T3 to Site T4. With reference to the NSFWQI, Idaho WQI and the SASS 5 Biotic Index, Site T4 was the most polluted point; this is the case because Site 4 had the lowest average index values. It is only the ATI that did not classify this site as most polluted. The decline in water quality at Site T4 could be attributed to the pollutants discharged by the Matsapha Industrial Area, urban and domestic waste from the Matsapha Residential Area and from waste from Manzini City, which enters the Lusushwana River through the Mzimnene River. Past studies by Mtetwa (1996); Mansuetus *et al*. (2004); Fadiran and Mamba (2005) indicate major decline in water quality at the Matsapha Industrial Area and downstream. The decline in water quality in this case therefore confirms the findings by the three past studies.

4.3.5: Water Quality for Site T5 (Nhlambeni)

Site T5 was located further downstream of Site T4 at this site it was expected that the quality of the water would have improved from the pollutants from the Matsapha Industrial Area. Some indices showed improvements in water quality yet others did not. With respect to the ATI the average index values dropped from Site T4 with an index value of 61.1 to an average index value of 59.1 for T5. At Site T4 the water was suitable for all fish life, according to the ATI and at Site T5 the Water was only suitable for hardy fish. According to the ATI Site T5 had the lowest average index score, on the contrary the other indices (NSFWQI, Idaho WQI and SASS 5 Biotic Index) classified Site T4 as the worst site. According to the NSFWQI Site T5 fell under Category C, this category indicates water of medium quality. The NSFWQI showed some improvements in water quality from average index value of 62 for site T4 to and average index value of 64 for site T5. The water quality status of Site T5, according to the Idaho WQI showed improvements, with site T4 having recorded an index value of 1.70 to Site T5 with an index value of 1.75. However, in both Sites T4 and T5 the water was not suitable for beneficial use (drinking and recreation). The SASS 5 Biotic Index had a category B for site T5; this indicated an improvement in water quality from Category E for site T4.

4.4: Relationship between ATI, Idaho, NSFWQI and the Indices of the SASS 5 Biotic Index

Table 4.7 shows the correlations (R^2) and p values for the indices used in the study; Idaho WQI, NSFWQI, ATI and the indices of the SASS 5 Biotic Index (SASS Score and ASPT). The correlations between these indices were established using the Spearmans rank correlation coefficient. The correlations between the indices were preformed on the Statistical Package for

Social Scientists (SPSS) Version 17. Correlation coefficients range from -1 to +1. The value of +1 indicates a perfect positive correlation while -1 indicating a perfect negative correlation. The closer the value is to 1 the stronger the correlation and the closer the value to 0 the weaker the correlation. The results produced by the indices are correlated (in pairs) as shown in Table 4.7. A detailed interpretation of the correlation coefficients with the coefficient ranges are shown in Chapter 3 (Table 3.4).

Table 4.7: Correlations of the results of the indices for water quality data of the Lusushwana River collected between February and March 2010

WQI	*Idaho WQI*	*NSFWQI*	*ATI*	*SASS Score*
NSF WQI	*0.914 (0.000)			
ATI	*0.736 (0.000)	*0.675 (0.001)		
SASS Score	*0.486 (0.300)	*0.672 (0.001)	*0.356 (0.124)	
ASPT	*0.233 (0.032)	*0.371 (0.107)	*0.273 (0.244)	*0.799 (0.000)

** (asterisk): correlation coefficients,(R^2) (In brackets): p-value ($p < 0.05$), sample size: 20*

The correlation between the Idaho Water Quality Index and the National Sanitation Foundation Water Quality Index (NSFWQI) was 0.914; this indicated a strong positive correlation between the two water quality indices. The correlation between these indices was significant ($p < 0.05$). This finding also agrees with a study by (Said *et al*., 2004), the two indices produced almost similar classifications when used in the evaluation of the water quality of the rivers of the Big Lost River Watershed in Idaho. Two reasons can be offered for the strong positive correlation between the two indices. Firstly, the Idaho WQI was developed or modeled from the NSFWQI (Said *et al*., 2004). Secondly, the Idaho WQI is derived from five water quality parameters, in which case four of them are also used in deriving the NSFWQI (shown in Table 2.3). On the basis of the two reasons, the correlations between the Idaho WQI and the NSFWQI are bound to be very strong.

The correlation between the between the Idaho WQI and the Aquatic Toxicity Index (ATI) was 0.736. This indicated a strong positive correlation between the two indices. The correlation between the Idaho WQI and the ATI was significant ($p < 0.05$). There are only two common parameters between the two indices. In this case the common parameters are too few to justify the strong correlation between the two indices. The correlation between the NSFWQI and ATI was 0.675; such a correlation indicates a moderate correlation. The correlation between the two indices was significant ($p < 0.05$).

The physico chemical water quality indices were also correlated with the indices of the SASS 5 Biotic Index (SASS score and ASPT). The correlation between the ATI and the SASS score was 0.356; such a correlation indicates weak or low correlation between the ATI and the SASS Score. The correlation between the ATI and ASPT was 0.273, indicating a weak or low correlation between the two indices. In both situations (ATI with the SASS score and ASPT), the correlations were low and not significant ($p < 0.05$).

The correlation between the Idaho WQI and the SASS score was 0.486, indicating a moderate correlation. However, the correlation between the two indices was not significant ($p < 0.05$). When the Idaho WQI was correlated with the ASPT the correlation was 0.233, indicating a weak or low correlation between the two indices. In this case however the correlation between the Idaho WQI and the ASPT was significant ($p < 0.05$).

The correlation between the NSFWQI and the ASPT was 0.37, indicating a weak or low correlation. The correlation between the two indices was not significant ($p < 0.05$). When correlating the NSFWQI with the SASS score the correlation was 0.672, indicating a moderate correlation. The correlation between the NSFWQI and the ASPT was significant ($p < 0.05$).

The indices used in the study were all positively correlated, that applies to both physico chemical water quality indices (Idaho WQI, NSFWQI and ATI) when correlated with each other and when correlated with the indices of the SASS 5 Biotic Index (SASS score and ASPT). Moreover, the correlations among all the three physico chemical water quality indices were significant ($p < 0.05$). With respect to correlations between the physico chemical water quality indices and the indices of the SASS 5 Biotic Index, the correlations were, however, only significant for relationships between NSFWQI with the SASS score and between the Idaho WQI and the ASPT. The other correlations (between the NSFWQI and the ASPT, the ATI and the ASPT, ATI and SASS score, Idaho WQI and SASS score) were not significant ($p < 0.05$). The correlations between the physico chemical water quality indices and the indices of the SASS 5 Biotic Index were not significant for most of the correlations. Such could be partly attributed to the fact that, the physico chemical water quality indices are direct measures of water quality whilst the SASS utilises aquatic macro invertebrates to explain water quality and thus an indirect measure of water quality. The availability of invertebrates in a sample is affected not only by the pollutants in the water but by other factors as well, such as riverine perturbations and sedimentation (Gaufin, 1973; Isham, 2005).

5: CONCLUSIONS AND RECOMMENDATIONS

5.1: Conclusions

The general objective of the study was to assess the status of the water quality of the Lusushwana River in Swaziland using biological and physico chemical water quality indices. From the study with limitations discussed, conclusions drawn are presented in Table 5 alongside their corresponding objectives.

Table 5: Conclusions with objectives

No.	*Objectives*	*Conclusions*
1.	To assess the water quality of the Lusushwana River based on physico chemical criteria and three selected water quality indices.	The quality of the water of the Lusushwana River was polluted with respect to faecal coliform, turbidity and dissolved oxygen levels based on evaluations using standards for surface water as prescribed by the Swaziland Water Quality Objectives and the South African Aquatic ecosystem water quality guidelines. With respect to the water quality indices the water quality declined from site T3 to sites located downstream of the Matsapha Industrial Complex.
2.	To assess the water quality of the Lusushwana River based on the SASS 5 Biotic Index	The SASS 5 Biotic Index showed some variation in the water quality of the Lusushwana River. Site T1, T2 and T5 were sites with water of good quality whilst site T3 and T5 were impacted sites.
3.	To investigate the extent of correlation between the water quality indices	The indices used in the study were all positively correlated. This applies to physico chemical water quality indices (ATI, NSFWQI and Idaho WQI) when correlated among each other and when correlated with the SASS 5 Biotic Index. The correlations were only significant for the relationships between the physico chemical water quality indices ($p < 0.05$). For relationships with the indices of the SASS 5 Biotic Index the correlations were only significant between the NSFWQI and the SASS score and between the Idaho WQI and the ASPT. The other correlations (between the NSFWQI and the ASPT, the ATI and the ASPT, ATI and SASS score, Idaho WQI and SASS score) were not significant ($p < 0.05$).

5.2: Recommendations

Based on the results and discussions from this study the following can be recommended:

1. It is recommended that the study be carried out covering more sampling campaigns, more sampling points and both the rainy and dry seasons. The bases for this suggestion are that the drawn conclusion are from data collected only during the rainy season and covering only four sampling campaigns with five sampling points.

2. The preliminary results show downstream deterioration of the water quality of the Lusushwana River. It is important to monitor effluent and waste water effluent downstream of the Matsapha Industrial Complex.

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APPENDICES

Appendix A: GPS Locations of the Sampling Points

Sampling points	*Coordinates*	
	Latitude	longitude
T1	-26^{o}.38.084	31^{o}.07.782
T2	-26^{o}.44.476	31^{o}.18.787
T3	-26^{o}.43.673	31^{o}.21.641
T4	-26^{o}.56.546	31^{o}.33.319
T5	-26^{o}.59.813	31^{o}.36.835

Appendix B. RAUWATER2 Reports for ATI

Water Site: T1: Date: average

Solway Aggregate: 69.4445447   Minimum Operator: 16

Environmental pH: Value: 7.25   ATI Index: 74.4469760936584

=================

pH has reached the recommended guideline value, and any sudden change in pH within recommended levels may alter the toxicity of heavy metals.

Dissolved Oxygen Content: Value: 7.8   ATI Index: 88

=========================

The recommended guideline value is reached. Should Oxygen levels decrease rapidly, it can adversely affect all aquatic organisms. Decreases in water Oxygen content causes increases in haematocrit as a result of swelling of red blood cells and/or fluid loss to the tissue with a subsequent decrease in plasma volume

Turbidity: Value: 1.6   ATI Index: 46

==========

No effects but turbudity increase should not be greater than 5 - 25 NTU`s above the natural. In South Africa 1 mg/l is roughly equivalent to 1 NTU.

Fluoride: Value: .035   ATI Index: 99.4068810209951

========

Potassium: Value: 2.9   ATI Index: 100

==========

Water hardness has an effect on availability of free ions.

Total Dissolved Solids: Value: 17.9   ATI Index: 100

=======================

Water hardness has an effect on the availability of free ions.

Ammonium: Value: .09   ATI Index: 73.0460189919649

=========

Orthophosphates: Value: .15   ATI Index: 69.7676326071031

================

Chromium: Value: .8   ATI Index: 100

=========

Copper: Value: .5   ATI Index: 100

=======

Manganese: Value: .7   ATI Index: 100

==========

Appendix C: RAU WATER2 Reports for ATI

Water Site: T2

Date: average

Solway Aggregate: 62.2662942 Minimum Operator: 16

Environmental pH: Value: 7 ATI Index: 62.5743564810489

=================

pH has reached the recommended guideline value, and any sudden change in pH within recommended levels may alter the toxicity of heavy metals.

Dissolved Oxygen Content: Value: 7.5 ATI Index: 85

=========================

The recommended guideline value is reached. Should Oxygen levels decrease rapidly, it can adversely affect all aquatic organisms. Decreases in water Oxygen content causes increases in haematocrit as a result of swelling of red blood cells and/or fluid loss to the tissue with a subsequent decrease in plasma volume

Turbidity: Value: 1.5 ATI Index: 48

==========

No effects but turbudity increase should not be greater than 5 - 25 NTU`s above the natural. In South Africa 1 mg/l is roughly equivalent to 1 NTU.

Fluoride: Value: .135 ATI Index: 96.6599233007731

========

Potassium: Value: 2.8 ATI Index: 100

==========

Water hardness has an effect on availability of free ions.

Total Dissolved Solids: Value: 13.7   ATI Index: 100

=======================

Water hardness has an effect on the availability of free ions.

Ammonium: Value: .425   ATI Index: 34.6133044889129

=========

Lethal to most species but reduced growth rate for catfish.

Orthophosphates: Value: .2   ATI Index: 61.8783391806141

================

Chromium: Value: .95   ATI Index: 100

=========

Copper: Value: .775   ATI Index: 100

=======

Manganese: Value: .95   ATI Index: 100

==========

Nickel: Value: 1.43   ATI Index: 100

=======

Lead: Value: .6   ATI Index: 100

Appendix D: RAUWATER 2 Reports For ATI

Water Site: T3

Date: avarage

Solway Aggregate: 63.5685135   Minimum Operator: 16

Environmental pH: Value: 7.2   ATI Index: 72.0852458693322

=================

pH has reached the recommended guideline value, and any sudden

change in pH within recommended levels may alter the toxicity

of heavy metals.

Dissolved Oxygen Content: Value: 5.4   ATI Index: 58

=========================

Reduced survival, fecudity an behaviour. Dissolved Oxygen

should not be lower than 4.0 mg/l for more than 8 hours

out of any 24 hour period.

Turbidity: Value: 1.6   ATI Index: 46

==========

No effects but turbudity increase should not be greater than

5 - 25 NTU`s above the natural. In South Africa 1 mg/l is

Roughly equivalent to 1 NTU.

Fluoride: Value: .18   ATI Index: 95.4576367985956

========

Potassium: Value: 8   ATI Index: 100

==========

Water hardness has an effect on availability of free ions.

Total Dissolved Solids: Value: 17.6   ATI Index: 100

======================

Water hardness has an effect on the availability of free ions.

Ammonium: Value: .06   ATI Index: 80

=========

Orthophosphates: Value: .3   ATI Index: 48.6752255959972

================

Organic enrichment of the water may be found due to untreated sewage effluent entering the river, phosphates may be due to high quantities of organophosphorous compound.

Chromium: Value: 1.95   ATI Index: 100

=========

Copper: Value: 1.4   ATI Index: 100

=======

Manganese: Value: 2.025   ATI Index: 100

==========

Nickel: Value: 2   ATI Index: 100

=======

Lead: Value: 1.325   ATI Index: 100

=====

Zinc: Value: 1.025   ATI Index: 16

=====

Zinc is not very toxic due to the ionic form [ZnOH+], however increases in water hardness causes decreased zinc toxicity.

Appendix E: RAUWATER 2Reports for ATI

Water Site: T4

Date: avarage

Solway Aggregate: 59.2513992 Minimum Operator: 16

Environmental pH: Value: 7.1 ATI Index: 67.3188905079596

=================

pH has reached the recommended guideline value, and any sudden change in pH within recommended levels may alter the toxicity of heavy metals.

Dissolved Oxygen Content: Value: 4.9 ATI Index: 49

=========================

Reduced survival, fecudity an behaviour. Dissolved Oxygen should not be lower than 4.0 mg/l for more than 8 hours out of any 24 hour period.

Turbidity: Value: 1.9 ATI Index: 38

==========

No effects but turbudity increase should not be greater than 5 - 25 NTU`s above the natural. In South Africa 1 mg/l is roughly equivalent to 1 NTU.

Fluoride: Value: .0925 ATI Index: 97.8144202947566

========

Potassium: Value: 13.7 ATI Index: 100

==========

Water hardness has an effect on availability of free ions.

Total Dissolved Solids: Value: 43.35 ATI Index: 100

=======================

Water hardness has an effect on the availability of free ions.

Ammonium: Value: .1225 ATI Index: 67.0290424272892

=========

Orthophosphates: Value: .3525 ATI Index: 42.9128015559633

================

Organic enrichment of the water may be found due to untreated sewage

effluent entering the river, phosphates may be due to high quantities

of organophosphorous compound.

Chromium: Value: 2.4 ATI Index: 100

=========

Copper: Value: 4.05 ATI Index: 99.5738715087646

=======

Manganese: Value: 4.1 ATI Index: 100

==========

Nickel: Value: 1.45 ATI Index: 100

=======

Lead: Value: 2.85 ATI Index: 100

=====

Zinc: Value: 7.55 ATI Index: 16

=====

Zinc is not very toxic due to the ionic form [ZnOH+], however increases in water hardness causes decreased zinc toxicity.

Appendix F.: RAUWATER 2 Reports For ATI

Water Site: T5 Date: avarage

Solway Aggregate: 57.1005492 Minimum Operator: 16

Environmental pH: Value: 6.8 ATI Index: 53.4913253037692

=================

Dissolved Oxygen Content: Value: 5.1 ATI Index: 52

=========================

Reduced survival, fecudity an behaviour. Dissolved Oxygen

should not be lower than 4.0 mg/l for more than 8 hours

out of any 24 hour period.

Turbidity: Value: 1.8 ATI Index: 40

==========

No effects but turbudity increase should not be greater than

5 - 25 NTU`s above the natural. In South Africa 1 mg/l is

roughly equivalent to 1 NTU.

Fluoride: Value: .035 ATI Index: 99.4068810209951

========

Potassium: Value: 11.875 ATI Index: 100

==========

Water hardness has an effect on availability of free ions.

Total Dissolved Solids: Value: 50.05 ATI Index: 100

=======================

With pH less than 6.9, the toxicity of the free ions may increase.

Water hardness has an effect on the availability of free ions.

Ammonium: Value: .1675 ATI Index: 59.8527995211776

=========

There may be a reduced growth rate and adverse physiological and histopathological effects.

Orthophosphates: Value: .4125 ATI Index: 37.1576691022046

================

Organic enrichment of the water may be found due to untreated sewage effluent entering the river, phosphates may be due to high quantities of organophosphorous compound.

Chromium: Value: 2.3 ATI Index: 100

=========

The toxicity of chromium increases when pH<6.9 due to the increased amount of toxic monovalent oxo-anions.

Copper: Value: 3.5 ATI Index: 100

=======

The toxicity of copper increases four fold when pH<6.9, where as a decrease in water hardness leads to an increase in toxicity.

Manganese: Value: 4.825 ATI Index: 100

==========

Nickel: Value: .9 ATI Index: 100

=======

Lead: Value: 2.55 ATI Index: 100

=====

There is a threefold increase in Lead [Pb] uptake, whereas if water hardness decreases, lead toxicity increases

Zinc: Value: 2.6 ATI Index: 16

=====

Zinc is not very toxic due to the ionic form [ZnOH+], however increases in water hardness causes decreased zinc toxicity.

Appendix G: Macro invertebrates composition and abundance (08/02/2010)

Site	*T1*	*T2*	*T3*	*T4*	*T5*
ANNELIDA					
Oligochaeta	0	A	A	A	1
CRUSTACEA					
Amphipoda	1	1	A	1	0
Potamonautidae*	B	0	1	A	1
Atyidae	0	0	0	0	0
HYDRACARINA					
PLECOPTERA					
Notonemouridae	0	0	0	0	0
Perlidae	0	0	1	0	0
EPHEMEROPTERA					
Baetidae 1sp	1	1	0	0	0
Leptophlebiidae	0	0	0	0	0
Oligoneuridae	A	1	0	0	0
Teloganodidae SWC	A	1	0	0	A
Tricorythidae	0	B	0	0	0
ODONATA					
Calopterygidae ST,T	0	0	0	0	0
Chlorocyphidae	0	1	B	0	0
Coenagrionidae	0	0	0	0	0
Lestidae	0	0	1	0	0
Platycnemidae	0	A	1	0	0
Zygoptera juvs.	A	0	0	0	0
Aeshnidae		0	1	0	0
Corduliidae	0	0	1	1	0
Gomphidae	B	0	B	A	A
Libellulidae	0	1	0	A	A
LEPIDOPTERA					
Pyralidae	1	1	0	1	0
HEMIPTERA					
Belostomatidae*	0	1	0	B	A
Gerridae*	0	0	0	0	0
Hydrometridae*	0	0	0	0	0
Naucoridae*	A	A	0	A	0
Nepidae*	0	A	0	0	0
Pleidae*	0	0	0	0	0
MEGALOPTERA					

Hydropsychidae 1 sp	0	1	0	0	0
Leptoceridae	0	1	0	0	0
COLEOPTERA					
Dytiscidae*	0	1	0	0	0
Elmidae/Dryopidae*	0	1	0	0	0
Gyrinidae*	A	A	A	0	0
Helodidae	A	0	0	0	0
Hydraenidae*		0	0	0	0
DIPTERA					
Chironomidae	0	0	0	0	0
Culicidae*	0	0	0	0	0
Empididae	0	1	1	0	0
Ephydridae	0	0	0	0	0
Psychodidae	0	0	1	0	0
Syrphidae*	0	A	0	0	0
Tabanidae	0	0	1	0	0
GASTROPODA					
Hydrobiidae*	0	0	1	0	0
Lymnaeidae*	0	1	1	0	0
Planorbinae*	0	1	1	0	0
Thiaridae*	A	A	1	A	A
PELECYPODA					
Corbiculidae	0	0	0	0	0

*0= absent 1=1 A=2-10 B 10-100 C =100- 100 * air breathers*

Appendix H: Macro invertebrates composition and abundance (21/02/2010)

Site	*T1*	*T2*	*T3*	*T4*	*T5*
ANNELIDA					
Oligochaeta	B	1	1	1	B
CRUSTACEA					
Amphipoda	B	0	B	0	B
Potamonautidae*	B	B	0	B	A
Atyidae	1	1	0	0	0
HYDRACARINA					
PLECOPTERA					
Notonemouridae	1	1	0	0	0
Perlidae	0	0	0	0	0
EPHEMEROPTERA					
Baetidae 1sp	0	0	0	0	0
Leptophlebiidae	0	0	0	0	0
Oligoneuridae	A	1	0	0	0
Teloganodidae SWC	0	0	0	0	0
Tricorythidae	0	1	0	0	0
ODONATA					
Calopterygidae ST,T	0	A	0	0	0
Chlorocyphidae	0	B	1	0	0
Coenagrionidae	0	A	A	0	0
Lestidae	0	1	0	0	0
Platycnemidae	B	A	0	0	0
Zygoptera juvs.	0	0	0	0	0
Aeshnidae	0	0	0	0	0
Corduliidae	0	0	0	0	0
Gomphidae	0	0	0	B	B
Libellulidae	B	B	0	0	1
LEPIDOPTERA					
Pyralidae	A	0	1	1	1
HEMIPTERA					
Belostomatidae*	0	0	0	0	0
Gerridae*	1	1	1	1	0
Hydrometridae*	1	0	0	0	0
Naucoridae*	B	0	1	B	B
Nepidae*	0	0	0	0	0
Pleidae*	0	0	0	0	0
MEGALOPTERA					
TRICHOPTERA					
Hydropsychidae 1 sp	0	0	0	0	0

CASED CADIDS					
Leptoceridae	0	1	0	0	0
COLEOPTERA					
Dytiscidae*	0	A	0	0	0
Elmidae/Dryopidae*	0	0	0	0	0
Gyrinidae*	0	0	0	0	0
Helodidae	0	0	0	0	0
Hydraenidae*	0	0	0	0	0
DIPTERA					
Chironomidae	0	0	0	0	0
Culicidae*	0	0	0	0	0
Empididae	0	A	0	0	0
Ephydridae	0	0	0	0	0
Psychodidae	0	0	1	0	0
Syrphidae*	0	1	0	1	0
Tabanidae	0	0	0	0	0
GASTROPODA					
Hydrobiidae*	0	0	0	0	0
Lymnaeidae*	0	0	0	0	0
Planorbinae*	0	0	0	0	0
Thiaridae*	A	A	0	1	B
PELECYPODA					
Corbiculidae	0	0	0	0	0

*0= absent 1=1 A=2-10 B 10-100 C =100- 100 * air breathers*

Appendix I: Macro invertebrates composition and abundance (09/03/2010)

Site	*T1*	*T2*	*T3*	*T4*	*T5*
ANNELIDA					
Oligochaeta	A	B	B	A	1
CRUSTACEA					
Amphipoda	B	0	B	0	1
Potamonautidae*	A	1	1	0	A
Atyidae	0	1	0	0	0
HYDRACARINA					
PLECOPTERA					
Notonemouridae	0	0	0	0	0
Perlidae	0	0	0	0	0
EPHEMEROPTERA					
Baetidae 1sp	0	0	0	0	0
Leptophlebiidae	0	1	0	0	0
Oligoneuridae	1	1	0	0	0
Teloganodidae SWC	1	1	0	0	0
Tricorythidae	A	A	A	0	A
ODONATA					
Calopterygidae ST,T	0	0	0	0	0
Chlorocyphidae	0	0	0	0	0
Coenagrionidae	0	0	0	0	0
Lestidae	0	0	0	0	0
Platycnemidae	A	0	A	0	0
Zygoptera juvs.	0	0	0	0	0
Aeshnidae	0	0	0	1	1
Corduliidae	0	0	0	0	0
Gomphidae	0	0	0	B	B
Libellulidae	0	1	0	0	1
LEPIDOPTERA					
Pyralidae	A	A	A	A	1
HEMIPTERA					
Belostomatidae*	0	A	0	0	0
Gerridae*	0	0	0	0	0
Hydrometridae*	0	0	0	0	0
Naucoridae*	0	0	B	B	B
Nepidae*	0	0	0	0	0
Pleidae*	0	0	0	0	0
MEGALOPTERA					

TRICHOPTERA					
Hydropsychidae 1 sp	0	0	0	0	0
CASED CADIDS					
Leptoceridae	0	0	0	0	0
COLEOPTERA					
Dytiscidae*	A	0	0	0	0
Elmidae/Dryopidae*	0	0	0	0	0
Gyrinidae*	B	1	A	0	1
Helodidae	0	0	0	0	0
Hydraenidae*	0	0	0	0	0
DIPTERA					
Chironomidae	A	0	0	0	0
Culicidae*	0	0		1	0
Empididae	0	1	0	0	0
Ephydridae	0	0	0	0	0
Psychodidae	0	0	0	0	0
Syrphidae*	0	0	0	B	0
Tabanidae	A	0	1	0	0
GASTROPODA					
Hydrobiidae*	0	0	1	0	0
Lymnaeidae*	1	A	0	0	0
Planorbinae*	B	0	1	0	0
Thiaridae*	1	0	1	1	B
PELECYPODA					
Corbiculidae	1	1		0	0

*0= absent 1=1 A=2-10 B 10-100 C =100- 100 * air breathers*

Appendix J: Macro invertebrates composition and abundance (21/03/2010)

Site	*T1*	*T2*	*T3*	*T4*	*T5*
ANNELIDA					
Oligochaeta	1	1	1	1	1
CRUSTACEA					
Amphipoda	0	0	1	0	1
Potamonautidae*	1	A	1	B	0
Atyidae	B	0	0	0	0
HYDRACARINA					
PLECOPTERA					
Notonemouridae	0	A	0	0	0
Perlidae	0	B	1	1	B
EPHEMEROPTERA					
Baetidae 1sp	0	0	0	0	0
Leptophlebiidae	0	0	0	0	0
Oligoneuridae	A	B	0	0	0
Teloganodidae SWC	0	0	0	0	0
Tricorythidae	0	0	0	0	0
ODONATA					
Calopterygidae ST,T	0	A	1	0	0
Chlorocyphidae	1	0	1	0	1
Coenagrionidae	0	0	1	0	0
Lestidae	0	A	1	A	0
Platycnemidae	0	0	1	0	0
Zygoptera juvs.	0	0	0	0	0
Aeshnidae	0	0	1	1	1
Corduliidae	0	0	1	0	0
Gomphidae	1	0	1	1	0
Libellulidae	1	0	1	A	1
LEPIDOPTERA					
Pyralidae	1	A	1	0	0
HEMIPTERA		1			
Belostomatidae*	0	0	1	0	0
Gerridae*	0	0	1	A	B
Hydrometridae*	A	1	1	A	0
Naucoridae*	B	0	1	1	0
Nepidae*	0	0	0	0	0
Pleidae*	0	0	0	0	0
MEGALOPTERA					

TRICHOPTERA					
Hydropsychidae 1 sp	0	0	1	0	1
CASED CADIDS					
Leptoceridae	0	1	0	0	0
COLEOPTERA					
Dytiscidae*	1	A	1	0	
Elmidae/Dryopidae*	B	1	0	0	A
Gyrinidae*	B	B	1	B	A
Helodidae	0	0	0	0	0
Hydraenidae*	0	0	0	0	B
DIPTERA					
Chironomidae	0	0	0	0	0
Culicidae*	0	0	0	0	0
Empididae	0	1	1	1	0
Ephydridae	1	0	0	A	B
Psychodidae	0	0	1	0	0
Syrphidae*	0	1	0	0	0
Tabanidae	1	0	1	1	0
GASTROPODA					
Hydrobiidae*	0	0	1	0	0
Lymnaeidae*	0	1	1	1	0
Planorbinae*	1	1	1	0	0
Thiaridae*	B	1	1	0	1
PELECYPODA					
Corbiculidae	1	0	0	0	0

*0=absent 1=1 A=2-10 B 10-100 C =100- 100 * air breathers*