An Investigation into the Spatial and Temporal Variations in Water Quality of Selected Rivers in the Durban Metropolitan Area

by
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Submitted as the dissertation component (which counts for 50 % of the degree) in partial fulfillment of the academic requirements for the degree of Master of Science in the School of Environment and Development

University of Natal - Pietermaritzburg

2002

Abstract

The spatial and temporal variations in water quality of selected rivers in the Durban Metropolitan Area were investigated using a Geographical Information System. Dissolved oxygen (DO), turbidity, pH, phosphorus and *Escherichia coli* (*E.coli*) were selected as water quality parameters for the study.

The study reflects a pattern of water quality deterioration due to the numerous landuse practices that have had an adverse impact on the receiving waters. In addition, the communities that use this water for various purposes have been impacted on. Spatially, an impoverishment of water quality conditions were observed by the increase of phosphorus, turbidity, DO and *E. coli*. The parameter of *E. coli* represented the worst water quality status in all the catchments of the study area. These were attributable to landuse factors such as informal settlements and urban formal settlements. For the parameter of pH, no adverse water quality was present. Temporal evaluation of the data indicated that although there were no distinct trends that could be directly related to rainfall, some of the parameters showed some influence by rainfall, through runoff.

Selected rivers of the Durban Metropolitan Area reflect poor water quality. There is an urgent need for the implementation of a strategy for improvement. The evaluation of water quality forms the basis for integrated catchment management (ICM), which has been advocated as the only holistic way to manage water resources. Due cognisance must be taken of the various landuse practices, which have a great impact on water quality. There should be concerted efforts to reduce the input of pollutants that may have adverse effects on water quality, e.g., by provisions of sanitation facilities in informal settlements. It is hence recommended that for any improvement of water quality to occur, there needs to be an implementation of ICM for all the catchments.

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List of Abbreviations

BOD	Biochemical Oxygen Demand
DO	Dissolved Oxygen
DEAT	Department of Environmental Affairs and Tourism
DMA	Durban Metropolitan Area
DWAF	Department of Water Affairs and Forestry
DWWM	Department of Wastewater Management
ICM	Integrated Catchment Management
GIS	Geographical Information System
NTU	Nepholetric Turbidity Unit

List of Definitions

A catchment: is defined as the drainage basin of a river, the boundaries of which are demarcated by the points of highest altitude of the surrounding landscape

GIS: a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world

Urban formal: all areas of formal housing including townships. Certain areas within town centers have major blocks of residential accommodation, which have also been placed into this category

Urban informal: Areas of predominantly informal housing stock. Where this housing occurs in distinct pockets on 'infill' land between formal housing, it is categorised separately from the surrounding formal development

Declaration

I hereby declare that the work submitted in this dissertation is entirely my own unaided research unless otherwise stated, and that this document has not been submitted for any other degree than a Master of Science, nor to any other university than the University of Natal - Pietermaritzburg.

25/03/2003

Date

Signature

31/03/2003

Date

Supervisor's Signature

Acknowledgments

I would like to extend my sincere gratitude to the following people and institutions, without whom this study would not have been possible:

- The National Research Foundation (NRF, South Africa) for their financial assistance,
- The Department of Wastewater management for allowing me the use of their data,
- My supervisor, Dr. F. Ahmed for his guidance,
- Mr. A. Simpson from the University of Natal (Pietermaritzburg) for his technical expertise,
- Experts from the Department of Wastewater Management, water quality and GIS divisions for their input
- Mr Deon Marais of the Department of Environmental Affairs & Tourism
- My family and friends for their encouragement and support.

"South Africa's Constitution places an obligation on the State to ensure an environment that supports the health and well being of all South Africans. It also makes the Department of Water Affairs and Forestry responsible for managing the nation's water resources. As such, my department must not only ensure fair access to water, but must also protect water from becoming polluted. After all, without clean water we simply cannot survive."

Prof Kader Asmal, Minister of Water Affairs and Forestry (1998)

Chapter 1. Introduction

1.1. Introduction

The fixed amount of water available on earth sets an absolute limit on water use (Jordaan *et al*, 1993). South Africa, a semi-arid country has its water resources geographically unevenly distributed (DWAF, 1993b). South Africa's average annual rainfall of 500mm, which is only 60 percent of the world average, makes water a scarce and valuable resource in the region (DWAF, 1994).

At present South Africa is using approximately 50 % of its available freshwater supply, and it is projected that by the year 2026, all conventional water resources will be fully utilized (DEAT, 1996). The Durban Metropolitan Area (DMA), located in the province of Kwa-Zulu Natal (South Africa) has a high water demand. The capacity of the DMA's major water supply, the Mgeni River, has been almost fully harnessed for urban use. Distributed throughout the DMA, is a multitude of landuse activities, which impacts on water quality (Hindson *et al*, 1996).

The DMA's population, manufacturing, tourist and recreational industries all depend heavily on natural freshwater systems, both as inputs into production and consumption and as a recreational resource. As a result, sections of many of the DMA's rivers and streams have become severely polluted by industrial and human effluents, to a point where their ecological functioning is threatened (Hindson *et al*, 1996). Poor water quality and unhygienic conditions prevail in streams draining informal settlements, which rely to some degree on these water sources for domestic and recreational use (Hindson *et al*, 1996).

One of the most common objectives of a water quality study is the characterization of the water quality of a water body or a river basin. This is usually accomplished by the determination of the temporal and spatial distribution of physical, chemical or biological variables (Demayo, 1992).

The introduction, by man of foreign substances into the aquatic environment has resulted in pollution, which ultimately impairs water quality. Water quality is generally defined by a set of concentrations of organic and inorganic parameters or by the state of biota found in the water body (Meybeck and Helmer, 1992). These parameters include amongst others, phosphorus, *Escherichia coli*, turbidity, pH and dissolved oxygen, all of which, are indicative of the water quality within a given water body. Water quality indices have also been developed as weighted combinations of these parameters to allow for the quantification of water quality.

In addition to the above, invertebrates and fish are also used as indicators of water quality. Invertebrates and fish taxa are sensitive to altered flow regimes, deterioration in water quality, and habitat alteration and therefore certain stresses can result in a decrease in species richness, or a predominance of certain species. The composition of invertebrate or fish communities at a site can thus provide information about the condition of the aquatic ecosystem at a site (Uys *et al*, 1996).

The Department of Wastewater Management (DWWM) is responsible for the treatment of wastewater within the DMA. Part of their responsibility is to ensure that waters released after treatment, do not impact further by degradation of water quality in rivers. Poor water quality is indicative of pollution, and the DWWM uses numerous sets of guidelines, predominantly those for recreational use, aquatic life and those known as the compliance criteria set by the Department of Water Affairs and Forestry (Jackson, 1998). This study is based on the data obtained from these sampling exercises conducted by the DWWM. Water quality studies undertaken within the DMA, have seldom focused on that of catchment units. In addition, many have failed to provide an overview of water quality and its associated problems within the DMA. It is the purpose of this project to use the tools of Geographic Information System (GIS) to display and interpret water quality in the DMA and thus provide a framework for better management of water resources in the study area.

1.2. Aim and Objectives of the Study

The overall aim of this study is to examine at a broad level the spatial and temporal variations in water quality of selected rivers in the DMA. The study will highlight problematic areas reflecting poor water quality. The determination of water quality will be achieved primarily by the use of specific water quality variables for aquatic and recreational waters (DWAF, 1996b & 1996c), to determine water classes ranging from acceptable to poor. Due to the number of variables that require investigation for the determination of water quality for potable use, this study does not focus on potable water use. However, cognizance has been taken of the impacts that water quality may have on potable use and this is discussed briefly.

The determination of water quality will facilitate the identification of points along the various rivers (within catchments), which reflect poor water quality. Points will reflect water quality ranging from acceptable to poor. Points within the study region that reflect the poorest water quality for each of the parameters will be further investigated and related to landuse (spatial) and seasonal (temporal) variations within a GIS. This will provide an overview of the areas that reflect poor water quality and possible reasons relating to the landuse type practiced in and around a point.

The specific objectives of this study are:

1. To determine water quality in relation to recreational use and aquatic ecosystems using the water quality parameters developed by DWAF (DWAF, 1996b & 1996c).
2. To determine different levels of water quality ranging from acceptable to poor for different points in the study area.
3. To determine spatial variation of water quality through land use patterns (such as industry, farming, formal and informal settlements) using GIS.
4. To analyze data and highlight seasonal variations in water quality, which will provide a temporal perspective.
5. To provide recommendations for improved water resource management in the study area.

1.3. Role of the Department of Wastewater Management

Durban Waste and Water provides an essential service to all the people who live in the DMA. This essential service is concerned with the provision of water (from Umgeni Water) and the removal and treatment of wastewater (Durban Metro Wastewater Management, 1996).

The passing of the 1995/1996 year marked the end of existence for Durban Water and Waste as a primarily Durban-focused organization and has led to it having to meet the challenges of dealing with the DMA as a whole. This has meant an almost doubling of the sewage reticulation and the department is now responsible for a larger number of treatments works in its area of operation (Durban Transitional Metropolitan Council, 1996).

The economic and environmentally friendly disposal of liquid wastes from the urban environment is essential in maintaining the health of the community. A whole range of technologies are necessary to give the users a good service, from maintaining pit latrines to computer based GIS and specialized waste treatment processes (Durban Metro Wastewater Management, 1996).

The southern treatment works on the banks of the Umlaas canal currently treats approximately 190 megalitres of waste per day, while the central treatment works on the tip of the Bluff treats approximately 55 to 60 megalitres. Both of these discharge effluent to the sea via sea outfalls. North of the Mgeni river, the northern treatment works treats about 40 megalitres a day, whilst the KwaMashu and Phoenix treatment works treats approximately 50 to 12 megalitres respectively. These discharge into river systems. All secondary treatment effluent from Kwamashu, Northern works and Phoenix is continually tested by the laboratory division. Effluents may only be discharged into the river systems in terms of permits issued by the Department of Water Affairs and Forestry (Durban Metro Wastewater Management, 1996).

The Department of Water Affairs and Forestry policy requires that all effluent is treated and returned to natural water-courses in order to obtain maximum utilization of scarce water resources. However doing this lowers the quality of water available further downstream, as pollutants contained in effluents are returned to the receiving waters (DWAF, 1996b). The water quality division collects water samples for river systems throughout the DMA and analyses these to ensure that they meet the standards set by the Department of Water Affairs and Forestry (Jackson, 1998). The predominant concern is reflective of whether the disposed effluents into river systems are suitable to be used by recreational users.

1.4. Structure of Dissertation

This dissertation is structured as follows:

- The introductory chapter sets out the background and objectives of the study.
- A detailed literature review includes the examination of geographical information systems (GIS) and integrated catchment management (ICM) as tools for the examination and improvement of water quality respectively. Landuse and rainfall are also analysed as being the source of variation of water quality spatially and temporally. In addition, this section seeks to examine both national and international literature with similar studies undertaken.
- A methods section describes the study area and sets out the methodologies that were undertaken in the study.
- A results section provides detailed results, which are depicted through a series of maps and graphs. This is divided into a section relating to the spatial investigation and is followed by the results of the temporal investigation.
- A discussion section provides the analysis of the results obtained in the study. The focus is on landuse patterns that may impact on the spatial distribution of water quality and the use of rainfall as the source of temporal variations in water quality. Throughout the discussion reference is made to integrated catchment management (ICM) as a tool for improving water quality in the various catchments.

- The conclusions section of this study makes recommendations for improved water quality management. It also draws on some of the short-comings of the investigation.

Chapter 2. Literature Review

2.1. Integrated Catchment Management

DWAF (1996a) has recognized that naturally occurring water can only be managed effectively and efficiently, within a river basin or catchment area. A catchment area is defined as the drainage basin of a river, the boundaries of which are demarcated by the points of highest altitude of the surrounding landscape. It is adjoined by other catchments and its geographical area covers all of the land, which drains into one river system, from its source to its estuary (DWAF, 1996a).

In integrated catchment management, the entire catchment is viewed as a fundamental environmental unit and a common geographical definition of land and water use. Past practices of separate management of catchment elements have resulted in the emphasis and development of certain elements, with neglect and exploitation of others and in some cases has led to irreparable damage (DWAF and Umgeni Water, 1996).

Water quality management within a catchment is a central component of ICM as it provides an important link between the socio-political-economic and physical environments. Catchment management must address all the elements (e.g. water quality, landuse, terrain, etc) of the physical catchment, focusing on the causes associated with the sources of pollution (i.e. catchment perspective), as well as the impacts on the receiving water bodies and their users (i.e. riverine perspective) (Pegram *et al*, 1997).

There are four components in a catchment, which represent the major processes in the hydrological and water quality cycles. These are the production of water, contamination at a source in the catchment, delivery into and transport through the receiving water bodies (rivers and impoundments), and finally use. Management of water resources may occur at the source, during delivery and transport, or before use. The holistic and integrated management of these components underlies catchment management (DWAF and Umgeni Water, 1996).

With an ICM approach, comes the implication that "water and associated land resources will be managed in harmony so as to gain the full benefits of multipurpose use and to co-ordinate the activities of various agencies and other bodies involved in water resource utilization and protection" (DWAF, 1996a, page 53).

A number of countries have accepted and adopted ICM as the most practical approach to water resource management. Countries such as Australia, North America, the United Kingdom, France and others in Africa have adopted a management system similar to ICM. The implementation of the watershed approach in the USA is equivalent to the adoption of ICM in countries such as Australia and the United Kingdom. This approach, as in other countries, has focused on the protection and management of the quality of natural resources in a river basin (DWAF, 1996a).

Although ICM is still at its very early stages in South Africa, considerable progress has been made towards its implementation. The Department of Water Affairs and Forestry together with Umgeni Water have put forward a framework for the ICM of the Mgeni River. The Mgeni Catchment Management Plan embodies the principles of ICM, as they might be applied in order to achieve sustainable water resource management. "In the context of water resources, the concept of sustainable resource use is one where, with effective management, the rate of resource withdrawal, use, consumption or depletion should always be balanced (or preferably exceeded) by the rate of resource replenishment. In the process, the selected and agreed characteristics of the resource (e.g. water quality, biological diversity, degree of resilience to external disturbance or change) should also be maintained" (DWAF and Umgeni Water, 1996, page 9). The Ntshongweni Catchment Program recognized the fact that current conditions of deterioration and pollution within the Mlazi catchment will not change significantly, unless there is a change in the management of the entire catchment (Farmer Support Group and Umgeni Water, 1995).

It has been mentioned by many practitioners that the full analysis of the many problems faced by those attempting ICM requires an extensive set of capabilities

(Pillay and Howard, 1998). Computer based information systems in which many tools providing these capabilities are integrated to provide decision support information to managers and stakeholders play an increasingly important role in catchment management initiatives both internationally and locally (Pillay and Howard, 1998). It has been accepted that in order to adequately provide information about a catchment and its water resources, these systems must include tools that aid in the visualization of both spatial and temporal variation of the components of the catchment. These capabilities are increasingly provided for by computer tools such as time-series display, analysis software, metadata query and GIS (Pillay and Howard, 1998). The most important parameter for metadata query is the quality of the data. This is important when dealing with a study of this nature, examining water quality as the integrity of the data will impact on the results obtained.

Increasingly the use of ICM, in combination with a GIS, is used to identify problems within a catchment. The capability of a GIS in combining large volumes of data from a variety of sources makes it an invaluable tool for the various aspects of water quality investigations. The data sources are diverse, measured in varying units and at different spatial and temporal scales. As a result the spatial analysis of these parameters becomes difficult to perform manually. Using a GIS it becomes possible to identify and determine the spatial extent and causes of water quality problems, such as the effects of land use practices on adjacent bodies of water (Demayo, 1992). GIS has thus become a useful tool for management decisions pertaining to water quality due to its capabilities.

2.2. Geographical Information Systems

"The history of GIS is in many (but not all) ways the history of using digital computers to handle and analyse mapped data. A second and quite distinct history of GIS stems from the benefits of automating the map production process. Once information of any kind is in digital form, it is much easier to manipulate, copy, edit and transmit. " (Longley *et al*, 1999, page 2).

Geographical information systems (GIS) have emerged as crucial technology tools for addressing many of the World's most pressing problems, from infrastructure development to environmental and resource management (Sweeney, 1997). Rising concern over environmental degradation has resulted in an increase in research on the identification and study of environmental problems. In parallel to this rapid rise in the volume and quantity of data collected, massive changes in the technical capability have facilitated the development of GIS to handle the diversity of information involved. Environmental planning and management is inherently cross-disciplinary, and therefore the use of GIS technology to build databases from disparate sources of information to study problems of some commonality is highly appropriate (Mounsey,1991).

Burrough (1986), defines GIS as "a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world". However, the term GIS has continued to be defined more by its applications and technology than by any clear principles. Several alternative ways of defining the term, have emerged, by its capabilities, applications, or contents of its databases. Each of the many disciplines involved in the field brings a somewhat different perspective (Goodchild *et al*, 1991).

The three main concepts evident in a GIS are, namely, the map, the database and spatial analysis. The key feature, which differentiates GIS from other information systems is the general focus on spatial entities and relationships, together with specific attention to spatial analytical and modelling operations (Maguire, 1991).

It was therefore seen as appropriate that GIS serve as the platform for the collection and analysis of the data for this study. The ability to condense enormous amounts of data into clear visual maps through analysis, has made the selection of GIS as a valuable tool for this water quality study.

The component of spatial referencing of information, is the crucial difference between a GIS and other databases. The ability to manipulate and provide information, rather than just data, is another key component in the definition of a GIS. A useful GIS should be able to assist in management decisions by providing spatially referenced insight into a wide range of processes and activities (Cinderby, 1995). With regard to the provision of various data sources in combination and the ability to manipulate this has added tremendous value in determining water quality throughout the DMA.

The demand in recent years, for the storage, analysis and display of complex and voluminous environmental data has led to the use of computers for data handling and the creation of sophisticated information. Effective use of large spatial data volumes is dependent upon the existence of efficient systems that can transform this data into usable information (Belward and Valenzuela, 1991).

GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps. These abilities distinguish GIS from other information systems and makes it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes, and planning strategies (Environmental Systems Research Institute, 1998).

'"Today's GIS is in the process of being reinvented. There is much less emphasis on 'system', with all that is implied in that term – a clearly demarcated, monolithic, probably proprietary solution. The 'open GIS consortium (but by no means restricted to it), is driven by a vision of GIS as a collective of interoperable modules, under common standards. The growth of electronic communications networks and associated applications means that it is no longer necessary for the data, the software, and the user to be in the same place at the same time" (Longley *et al*, 1999, page 4).

"Over the years the vision of a GIS has shifted significantly, but has always included the notion of processing geographical information within an integrated environment. It has been argued that the environment need not be digital, and that the principles of GIS can certainly be taught outside the digital environment, but today's world is increasingly digital and GIS is now almost always associated with digital computing in one form or another. It has also been argued that the definition of GIS should include much more than the digital environment – in this conception the people who interact with it are also part of the system. Finally, GIS has been defined by its objectives. Today, the term GIS tends to be applied whenever geographical information in digital form is manipulated, whatever the purpose of that manipulation" (Longley *et al*, 1999, page 5).

GIS has been used to assist in the decision making process by indicating various alternatives in development and conservation, planning and modeling the potential outcomes of a series of scenarios. It provides planners with a readily accessible source of objective earth science related facts and, an inexpensive, rapid, and flexible tool for combining these facts with various products to create decision alternatives (Cinderby, 1995). In the context of this study, the provision of information with regard to water quality will be able to provide managers with a source that at a glance will be able to locate points on the river systems with poor water quality. In terms of management, GIS will provide an effective tool for decision making.

Many disciplines have benefited from the application of GIS techniques. The use of GIS to manage and analyze large volumes of data allows for the better understanding of terrestrial processes and the better management of human activities to maintain world economic vitality and environmental quality (United States Geological Survey, 1997).

One such discipline is that which focuses on the study of water quality. GIS is proving to be a very powerful tool, not only for graphically presenting water quality data, but also for relating this data to other information, e.g. demography and land use, thus contributing to water quality interpretation, and highlighting facets previously not possible (Demayo, 1992).

In water quality studies GIS can be used to:

- determine location, spatial distribution and area affected by point-source and non-point source pollution,

- be used to correlate land cover and topographical data with a variety of environmental variables including surface run-off, drainage, and basin size, and
- be used for assessing the combined effects of various anthropogenic (e.g. land use) and natural (e.g. drainage) factors on water quality (Demayo, 1992).

The GIS capability of combining large volumes of data from various sources, lends itself as a useful tool for the many aspects of water quality investigations. GIS can be used to identify and determine the spatial extent and causes of water quality problems, such as the effects of landuse practices on adjacent water bodies Demayo, 1992).

2.3. Water Quality

The term water quality describes the properties of water that determine how fit it is to be used (DWAF, 1998). Effective management of land and water resources requires an understanding of spatial and temporal effects of human activities on these resources (Peters and Meybeck, 2000).

2.3.1. Water Quality and Landuse

The quality of freshwater at any point on the landscape is reflective of the combined effects of many processes along water pathways. Human activities on all spatial scales affect both water quality and quantity. Alteration of the landscape and associated vegetation changes not only affects the water balance, but also alters processes that control water quality (Peters and Meybeck, 2000).

Interference of man with the water cycle is inevitable; the changes of landuse and the use of water for irrigation, industry and human consumption affect the processes of the water cycle and consequently the quality of water (Jordaan *et al*, 1993). Land-use activities can modify ecosystems. First of all, many landuse activities depend on water. Consequently, water management is crucial for the support of proper or sustainable land management. Landuse also affects physical determinants of water flow, and can alter hydrochemical behaviour, for example, by introducing pollutants along water pathways (Falkenmark,1999).

Disturbances that have an impact on water have their origin in many aspects of society. Water flowing through a landscape system is influenced by human activities in that landscape, and also by polluting activities upstream, e.g. industry, urbanization, agriculture or tourism (Falkenmark, 1999). Water quality problems tend to be worse near large underserviced communities that use water directly from rivers and streams (DWAF, 1998).

A study undertaken in the Lilongwe watershed in Malawi, showed that landuse practices had a negative impact on surface water quality. The main categories of landuse consisting of commercial farming, livestock, subsistence farming, timber plantation, forest reserves, cultivation of vegetables and sugar cane and peri-urban and rural settlements all contributed to the problems of phosphorus, turbidity, nitrate, *E. Coli*, pesticide residues and total dissolved solids in the river (Ghambi and Mzumara, 1998).

Human influences have direct effects on the hydrological cycle by altering the land in ways that change its physical, chemical and biological characteristics. Water quality characteristics maybe modified by physical alterations such as urbanisation, transportation, farming (irrigation), deforestation and forestation, land drainage, channelization and damming (Peters and Meybeck, 2000).

In addition, these human activities alter water quality not only by changing hydrologic pathways, but also by the addition of substances and wastes to the landscapes. The chemical alteration associated with human activity occurs mainly through the addition of wastes (gases, liquids, solids) and other substances. These additions include waste disposal on the land or in water-ways and the application of substances to control the environment, such as fertilizers for crop production, herbicides for weed control and pesticides for disease control (Peters and Meybeck, 2000).

Water-flow characteristics are influenced by several physical factors, which in turn, are influenced by human activities. The landscape relief (depressions and elevations), for example, is influenced by industrial activities and agricultural farming systems. Preparation of land for economic development adds man-made structures such as buildings and parking lots. These changes alter water pathways, increase surface runoff from impervious areas, such as roofs and asphalted parking lots and streets, and decrease groundwater recharge (Falkenmark,1999).

Poor water quality is a direct effect of the presence of contaminants and pollutants that are present in the water body. Pollution as described by Schmitz (1996) is the introduction into the environment, ecosystem or biosphere of any physical phenomena, biological agent or chemical substance (in any quantity) that has an adverse impact on the receiving (aquatic) system.

Pollution can be categorized into point and non-point source pollution. Point source pollution is that which originates from discrete measurable sources such as discharges from wastewater works and industry (Schmitz, 1996). Point source pollution can be directly traced to a source and is therefore easier to control than non-point source pollution. Non-point source pollution (diffuse source pollution), occurs when pollution enters rivers and streams either from the atmosphere or from water draining the land in the catchment, and is thus difficult to identify and control (Greenbeat, 1998).

2.3.2. Water Quality and Rainfall

Curran and Robertson, 1991, emphasize that a comparison of water quality data either by region or for a period should allow for climatic variability.

Water quality studies have revealed that the variability in the mean annual concentrations of some constituents (e.g. turbidity), are strongly influenced by climatic conditions (amount of rainfall) and runoff during large storms. Due to this variation, pollutants are highly variable and therefore due cognizance needs to be taken of the rainfall experienced during an investigation before data is assessed (Simpson, 1992).

There has been widespread increase in awareness in many countries of a deterioration of water quality due to runoff from non-point sources. Urban run-off threatens water resources in numerous ways, from being harmful to aquatic life through to recreation via the transmission of diseases from pathogenic bacteria (Simpson, 1992).

Storm-water runoff is an important non-point source of municipal pollution. Storm water discharges are a result of runoff from sewered environments, including drainage from streets, parking lots and lawns and may contain chemicals and organic wastes. The more developed an area, the more significant these non-point source discharges are as a pollution source (Kupella and Hyland, 1998). Runoff from agriculture often releases pesticides and nutrients that pollute both surface and groundwater. During development of land for use in farming, the resultant erosion, may be an important source of sediments that can foul surface waters as a non-point source of pollution (Schmitz, 1996). Runoff can contain, in both soluble and particulate forms, a wide variety of pollutants (Simpson, 1992).

However, in certain instances an increase in rainfall may have a positive impact on water quality as illustrated by a study undertaken in the catchment of the upper Clyde estuary, Glascow. The results showed that the area which had received a steady increase of rainfall over a twenty-year period, showed a corresponding increase of runoff resulting in a positive impact on the water quality of both the individual rivers as well as the estuary. The observed improvements have been attributable to the additional dilution of the system through the rainfall. Although rainfall trends for the study area have been beneficial for alleviating pollution, it is emphasized that opposite trends may equally well become established either in other regions or during other periods (Curran and Robertson, 1991).

2.3.3. Adverse Effects of Poor Water Quality

A polluted watercourse is a serious threat to the natural environment, endangering human and aquatic life. Far-reaching economic, social and demographic changes throughout South Africa have resulted in a steady decline in the quality of water countrywide. The most serious forms of surface water pollution result in eutrophication as a result of nutrient enrichment of water sources, toxic substances (for example, heavy metals, agricultural agents such as pesticide residues and carcinogens) and pathogens (viruses, bacteria and parasites) originating from water contaminated by faecal matter (Umgeni Water, 1998).

Water quality is fundamental to the health, efficiency and well-being of individuals and societies all over the world. It is however, threatened by almost all modern interactions of man with nature. Chemical and biological pollutants from diffuse sources, such as fertilizers and pesticides from agricultural areas, or storm-water runoff from urban catchments, appear with increasing frequency and concentrations in many surface and ground water sources. For many lakes they are the major cause of eutrophication. Some of the substances introduced by human actions (Table 2.1.), are non-biodegradable and many accumulate in their passage through the food chain, some are highly toxic and contaminate aquatic and terrestrial ecosystems (Jordaan *et al*, 1993).

Table 2.1. Typical sources of water pollution (with impacts on both human health and ecosystem function)

Pollutant	**Example**	**Source**
Infectious agents	Bacteria, viruses, parasites	Human and animal wastes
Organic chemicals	Pesticides, petrol, oil, plastics, detergents	Industrial, farm and domestic use
Inorganic chemicals	Acids, caustics, salts, heavy metals	Mining and industrial effluents, household cleaners, surface runoff
Plant nutrients	Nitrates and phosphates	Agricultural and urban fertilizers, sewage, effluent discharges
Oxygen demanding wastes	Human and animal wastes and plant residues	Sewage, agricultural runoff, paper mills

(Adapted from DEAT, 1996).

2.3.3.1. Waterborne Diseases

A wide range of pathogenic viruses and bacteria may be transmitted via watercourses. Associated with polluted water, are a variety of diseases causing micro-organisms. Infections of diseases such as gastroenteritis, giardiasis, hepatitis, typhoid fever, cholera and *Salmonellosis* are generally contracted by drinking contaminated water or through recreational exposure to contaminated water (DWAF, 1996c).

The greatest health threat that people face is from gastro-intestinal infections like diarrhoea, dysentery and cholera. These are the leading causes of death world wide and major causes of death, particularly for children, in South Africa's poor communities. These diseases are related to malnutrition and poor living conditions, especially poor sanitation and dirty water. In South Africa these problems mainly face people living in rural areas and informal settlements (DEAT, 1996).

The presence of disease-causing micro-organisms and parasites in polluted water is a major cause of ill health and death, especially amongst children in communities without access to adequate sanitation and clean drinking water. Contamination of water by raw or partially treated sewage carries an associated threat of disease, some of which are life threatening to humans. Water-borne disease causing pollutants that have been isolated in rivers of the Mgeni catchment are directly related to diseases such as cholera, typhoid, dysentery, and infectious hepatitis. This places the informal sectors of the community at risk of contracting these diseases, since a large proportion of them rely, to some extent on this water for their daily use, which also includes potable use (Umgeni Water,1998).

Human settlements are the major source of these pollutants. Micro-organisms and parasites may enter the water in the form of partially treated or untreated sewage, seepage from pit latrines and run off from settlements with inadequate sanitation and waste disposal facilities. Sewage is a choice environment for micro-organisms and is thus a carrier of disease-causing agents. The provision of adequate sanitation and adequate supplies of clean drinking water supported by education in hygiene will help to address these problems, especially with regard to the rural communities where such facilities are lacking (Umgeni Water, 1998).

2.3.3.2. Species Diversity

Poor sewage treatment complicates the problem of species diversity, as chemicals left over after treatment can kill vegetation, especially in lakes, cause excessive algal growth, and leave the water with little oxygen.

High levels of suspended solids reduce light penetration in water, plants cannot carry out photosynthesis and oxygen levels decline affecting aquatic life. Sources of suspended solids include agriculture, forestry, construction activities, open cast mining and other disturbances of vegetation, particularly along river banks (DEAT, 1996).

2.3.3.3. Human Safety

Poor visibility in polluted waters, due to suspended solids or algal growths can create hazards for swimmers and divers. In terms of human safety, accidents arising from diving into submerged objects can be dangerous and may lead to injuries. In addition, recreational activities may be hampered by prolific macrophytic growth, which could result in entanglement (DWAF, 1996c).

2.3.3.4. Aesthetics

Waters contaminated by sewage and other industrial effluents may cause unpleasant odours and may discolour water bodies, producing aesthetically unpleasant conditions. This detracts from the aesthetic enjoyment of watercourses (DWAF, 1996c).

2.4. Water Quality Parameters

Rivers have to support a wide variety of activities including water supply for various uses (potable water, irrigation of agricultural land, industrial use and recreation). Progressive urbanization and industrial development has also led to the increased use of rivers for waste disposal activities. The pollution arising from these sources has led to the increased need for rigorous assessment of river water quality. The complexity and components of such assessment programmes are defined by the water uses and their water quality requirements, as well as a need to protect the aquatic environment from further degradation (Meybeck *et al*, 1992).

The quality of an aquatic environment can be defined by a set of concentrations, specifications, and physical partitions of inorganic or organic substances. The selection of parameters for any water quality assessment programme depends upon the objectives of the programme (Meybeck *et al*, 1992). The objective of this study is focused predominantly on the water quality of recreational water bodies. As such, the selection of parameters pertinent to that of recreational waters differs from that of other water uses such as potable, irrigation of agricultural land or industrial use.

Recreational use of water bodies (which is the sector of water quality being examined in this study), is widely practiced in South Africa, particularly during the summer season, and can therefore be expected to be impacted by changes in water quality. Recreational water use, as referred to in the South African Water Quality Guidelines applies to freshwater bodies only (DWAF, 1993b).

Water quality for recreation depends largely on ambient water quality, since no water treatment or maintenance is practiced. Since contact with water is generally seasonal or of limited duration, this use has less stringent quality requirements than other water use (example domestic use). However, certain broad limits are necessary to protect the well-being and enjoyment of recreational water users. A body of water may be considered fit for recreational use if it is aesthetically pleasant, does not give rise to adverse health effects and does not pose a safety hazard to recreational users. This implicitly includes the requirements for a healthy aquatic ecosystem (DWAF, 1993b).

Although aquatic ecosystems are not considered users of water, in competition with other users, (implying that unlike the other sectors, which have certain quotas of water for use, e.g. industrial, aquatic organisms don't fall into this category), water within certain quality ranges, is required to protect and maintain their health. The different components of aquatic ecosystems may be utilized by people in several ways, such as recreation, irrigation and as a source of potable water. Such utilization of South Africa's water resources will inevitably result in some impact on, and modification of, aquatic ecosystems. However, utilization has to be managed and regulated in such a way that these impacts do not affect the functioning of the ecosystems (DWAF, 1996b).

In order to set water quality objectives, an assessment of what constitutes acceptable and unacceptable water quality is required. Water quality guidelines are generally expressed as a range of values, where each range is associated with a description of the fitness for use. The total range extends from the most ideal to the point of unacceptability. Guidelines classify water quality into a number of ranges. Upper and lower limits of each range are defined on the basis of health and /or aesthetic effects experienced by the water user. Guideline ranges are presented as consecutive concentration ranges (DWAF, 1993). The first range is generally associated with no or very limited adverse effects on the user and is regarded as being acceptable. Subsequent ranges are associated with increasing user effects, and generally with increasing concentrations of the constituent and are seen as being dangerous or very dangerous (DWAF, 1993b).

A number of factors may affect the aesthetic acceptability of recreational waters, and the healthy functioning of aquatic ecosystems, ranging from odour to nuisance plants. Some of the water quality parameters include dissolved oxygen, turbidity, pH, phosphorus, and *E. coli* (DWAF, 1993b). Each of the water quality parameters are discussed in the sections to follow.

2.4.1. Dissolved Oxygen

Dissolved oxygen (DO) is an essential requirement to maintain healthy river systems. The presence of oxygen in water indicates a healthy system and is thus a positive sign, whereas the absence of oxygen is an indication of severe pollution. Most aquatic plants and animals require a certain level of DO to survive (Mitchell and Stapp, 1990). Therefore, the determination of dissolved oxygen concentration is a fundamental part of a water quality assessment since oxygen is involved in, or influences, nearly all chemical and biological processes within water bodies.

Adequate levels of DO are critical for the survival and functioning of aquatic biota because it is required for the respiration of all aerobic organisms. Therefore, the DO concentrations provide a useful measure of the health of an aquatic ecosystem (DWAF, 1996b).

One of the greatest contributing factor that results in changes of DO levels is the build-up of organic wastes, wastes from once living organisms and from animal faeces. Organic wastes occur in the form of sewage, urban and agricultural run-off and industrial discharges. Fertilizers contribute largely to agricultural runoff and stimulate the growth of algae and other aquatic plants. Bacteria are involved in the decomposition of sewage and other organic matter and consume oxygen in the process (Mitchell and Stapp, 1990).

A sudden shift in the oxygen levels in river systems can have many adverse effects, which include the preclusion of those species that are oxygen intolerant to pollution tolerant species. Nuisance algae and anaerobic organisms will become more abundant in waters with low levels of DO (Mitchell and Stapp, 1990).

Oxygen is essential to all forms of aquatic life. Water discharges high in organic matter and nutrient content can cause decreases in DO concentrations due to increased microbial activity (respiration), during the degradation of the organic matter. Concentrations below $5mgl^{-1}$ may adversely affect the functioning and survival of biological communities and below $2mgl^{-1}$ may lead to the death of most fish. The measurement of DO can be used to indicate the degree of pollution by organic matter, the destruction of organic substances and the level of self-purification of the water (Chapman and Kimstach, 1992). Table 2.2. indicates the acceptable ranges of water quality for DO.

Table 2.2. Water Quality Classes for DO

Water Quality Range (mg/l)	Effects
Target 6.4 – 9	Protects most all life stages of SA aquatic biota
Sub-lethal 4.9 - 6.3	Adverse effects on biota
Lethal 0 - 4.8	Acute toxic effects on biota

(Adapted from DWAF, 1996b; Hodgeson pers comm, 1998)

2.4.2. Turbidity

Lack of water clarity is frequently associated with turbidity. Turbidity is a measure of the suspended material, such as clay, sand, silt, finely divided organic and inorganic matter, plankton and other micro-organisms. Lack of clarity and turbidity together pose a danger for swimming since potentially hazardous objects and shallow bottoms may be obscured, and it may be difficult to locate swimmers who are experiencing difficulties. Turbidity is considered important for recreational water use as it addresses both turbidity and suspended solids. It includes the aspect of water clarity, ensuring that water is sufficiently clear that swimmers, waders, boaters, etc can see to some depth (DWAF, 1993b).

Turbidity results from the suspension of solids in the water, which reduce the transmission of light. Sources of turbidity may include soil erosion, waste discharge, urban runoff or the presence of excess nutrients, which may result in algal growth. At high levels of turbidity, the ability of the system to support a diversity of aquatic life is lost. The presence of the suspended particles results in a decrease in photosynthesis and levels of oxygen. Particles of silt and clay may also settle at the river bottoms in slow moving stretches and smother the eggs and larvae of aquatic organisms (Mitchell and Stapp, 1990). Turbidity ranges are expressed in Table 2.3.

Table 2. 3. Water Quality Classes for turbidity

Range (Nepholetric Turbidity Unit - NTU)	Effects
Excellent 0 - 5	Suitable for swimming. Depth can be judged. No adverse effects on aesthetic appreciation.
Good 6 - 12	Water suitable for swimming. No adverse effects on aesthetic appreciation.
Average 13 - 20	Water suitable for swimming.
Poor 21 - 30	Unsuitable for swimming. Aesthetic effects expected
Bad > 31	Unsuitable for swimming. Aesthetic effects expected. Risk of disease transmission by organisms associated with particulate matter.

(Adapted from DWAF, 1996c; Hodgeson pers comm, 1998)

2.4.3. pH

Variations in pH of recreational waters is important as, extreme deviations from the target guideline range can cause irritation of eyes of swimmers and other users. Although the pH of recreational waters has no direct effect on aesthetics, it may have an indirect effect such as triggering of changes in the color or odor of chemicals, which may be present in the water. Both the physical-chemical and biological processes in the aquatic environment may be influenced by changes in pH. In addition the balance of natural communities is also closely linked to pH. The target water quality range for recreational use is set at between 6.5 to 8.5 pH units as indicated by table 2.4. Skin and eye irritation can be expected at extreme pH values (Department of Water Affairs and Forestry, 1993b). The maintenance of pH ranges of water is critical to aquatic organisms. Most species have adapted to life in water at specific pH levels and may die if changes occur, as extremely high or low values result in unsuitable conditions for survival (Mitchell and Stapp, 1990).

Table 2.4. Water Quality Classes for pH

pH Range (pH units)	Effects
Poor 0 - 5.0	Severe eye irritation occurs. Skin, ear and mucous membrane irritation likely. Adverse aesthetic effects.
Acceptable 5.1 - 6.5	Swimming in this water is generally acceptable. Some eye irritation occurs. Skin, ear and mucous membrane irritation unlikely.
Target 6.6 - 8.5	Minimal eye irritation occurs. The pH of water is well within the buffering capacity of the human eye. Skin, ear and mucous membrane irritation absent.
Acceptable 8.6 - 9.0	Swimming is acceptable. Some eye irritation expected. Skin, ear and mucous membrane irritation may occur. No adverse aesthetic effects.
Poor > 9.1	Eye irritation becomes increasingly severe as pH

	values become more extreme. Skin, ear and mucous membrane irritation occurs. No adverse aesthetic effects.

(DWAF, 1996c).

2.4.4. Phosphorus

Phosphorus is an essential nutrient for living organisms and exists in water bodies as both dissolved and particulate species. It is generally the limiting nutrient for algal growth and, therefore, controls the primary productivity of a water body. Artificial increases in concentrations due to human activities are the principal cause of eutrophication. High concentrations of phosphorus can indicate the presence of pollution and are largely responsible for eutrophic conditions (Chapman and Kimstach, 1992).

Agricultural activities are cited as one of the major drivers of increased nutrient levels such as phosphorus and nitrogen to both aquatic and terrestrial ecosystems. Runoff and erosion are considered to be the main attributing factors for the loss of phosphates from agricultural land. Elevated nutrient concentrations are associated with degraded water quality that can result in potential impacts for human health and the environment (Kampas *et al*, 2002).

Some of the essential nutrients required for algal growth include nitrogen and phosphorus. It has been found that these are the most frequent growth-limiting nutrients and are therefore the most important in stimulating nuisance conditions in water systems (Walmsley and Butty, 1980). Phosphorus ranges are indicated by table 2.5.

Table 2.5. Water Quality Classes for phosphorus

Average Phosphorus (ug/l)	Effects
Oligotrophic < 5	Usually moderate levels of species diversity, usually low productivity systems with rapid nutrient cycling, no nuisance growth of aquatic plants or blue-green algae.
Mesotrophic 5 - 25	Usually high levels of species diversity, usually productive systems, nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms seldom toxic.
Eutrophic 26 - 250	Usually low levels of species diversity, usually highly productive systems, with nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms may include species, which are toxic to man, livestock and wildlife.
Hypertrophic > 251	Usually very low levels of species diversity, usually very highly productive systems, nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms may include species which are toxic to man, livestock and wildlife.

(DWAF, 1996b, page 109)

2.4.5. *Escherichia coli* (*E. coli*)

Faecal contamination is still the primary water quality issue in rivers, especially in many developing countries where human and animal wastes are not yet adequately collected and treated. Although this applies to both rural and urban areas, the situation is probably more critical in fast growing cities where the population growth rate still far exceeds the rate of development of wastewater collection and treatment facilities (Meybeck *et al*, 1992).

The presence of *E. coli* is used to confirm the presence of faecal pollution by warm-blooded animals (often interpreted as human faecal pollution). This indicator group is used to evaluate the quality of wastewater effluents, river water, seawater at bathing beaches, raw water for drinking water supply and recreational waters. Epidemiological studies conducted by the US environmental protection agency indicated levels of *E. coli* to show a far greater correlation with the occurrence of swimming-related gastric illness in freshwater than faecal coliform levels (DWAF, 1993b).

The domestic sewage effluents contribute large numbers of certain species of bacteria which arise from the human intestine. These bacteria, in particular *E. coli* is used as an indicator of the presence of human faecal contamination. Since this poses significant health risks when utilized for recreation and drinking, it is the most basic and important reason for its inclusion in water quality assessments (Friedrich *et al*, 1992). *E. coli* ranges for recreational waters are as in table 2.6. (DWAF, 1996c).

Table 2.6. Water Quality Classes for *E.coli*

E. coli range (counts/100ml)	Effects
Target 0 - 130	A low risk of gastrointestinal illness is indicated for contact recreational use
Acceptable 131 - 200	A slight risk of gastrointestinal effects among swimmers and bathers may be expected
Satisfactory 201 - 400	Some risk of gastrointestinal effects exists if geometric mean or median *E. coli* levels are in this range.
Poor > 401	Risks of health effects associated with contact recreational water use increase as *E.coli* levels increase.

(Adapted from DWAF, 1996c; Hodgeson pers comm, 1998).

2.5. Parallel Studies

The recognition that water quality of rivers is influenced by both spatial and temporal factors, has resulted in its inclusion as a vital component in several studies highlighted below. These studies have been selected specifically for their South African location and similar trends which link to the present study.

2.5.1. A Spatial and Temporal Assessment of Water Quality in Major River and Dam Systems in the Umgeni Water Area from 1990 to 1997 (Pillay and Howard, 1998)

Umgeni Water is a large water supply authority in KwaZulu Natal, which has to ensure that water quality remains fit for drinking and other domestic purposes. A growing increase in demand coupled with an increase in pollutants has made it crucial for water quality to be assessed to identify areas of stress and refer these for remedial action.

The study was restricted in catchments within the Umgeni Water area of operation. The catchments were the Mgeni, Mkomazi, Mooi, Mvoti, Inanda dam and the Mdloti. Water quality data were analysed for both spatial and temporal trends. Parameters that were used for water quality analysis included, *E. coli*, total and soluble phosphorus, algal count, iron, manganese, nitrate, ammonia, suspended solids, conductivity, and major ions.

Analysis of the water samples revealed the following problems:

- phosphorus concentrations were elevated in the Inanda dam catchment
- high *E. coli* counts were present in the Mdloti, Mvoti and Inanda dam catchments
- the Mvoti and Mdloti catchment areas had an elevated turbidity
- the Mdloti and Mvoti catchments revealed high concentrations of manganese.

The other parameters that were analysed revealed their presence in concentrations that would not indicate a significant problem within the catchments for potable water use. This was followed by an investigation into the identification of the sources that contributed to the water quality problem and their impacts, and plans for action (Pillay and Howard, 1998).

The high phosphorus concentration in the Inanda dam catchment was attributed to the Pietermaritzburg's wastewater effluent discharge. The high *E. coli* concentrations were attributed to wastewater discharges, raw sewage from broken and blocked sewers and runoff from informal settlements. These were predominantly informal settlements without proper sanitation facilities. The turbidity levels were a direct result of poor land practises. A strong temporal correlation was established between rainfall and manganese. The high manganese concentrations were attributed to the consequence of soil erosion from degraded catchment areas, and were carried to rivers during heavy rainfall periods.

The study concluded that water quality was seriously threatened in three catchment areas, predominantly, the Inanda, Mvoti and Mdloti. Plans proposed included collaboration with stakeholders for a possible decrease in phosphorus loads and the working together of Umgeni Water with the health authorities towards an acceptable level of sanitation for all catchment residents. Catchment interventions focussing on community involvement and networking to combat problems of poor land practices were also put forward (Pillay and Howard, 1998).

2.5.2. Water Quality and Faunal Studies in the Umzimvubu Catchment (Madikizela *et al*, 2001).

The primary aim of the study was to establish a water quality database and an inventory of aquatic fauna for the Umzimvubu River and its four main tributaries. The results of the survey on water quality and fauna revealed that the Umzimvubu River system is one of the very few systems in South Africa, which are slightly degraded.

The high concentrations of ammonium in the Umzimvubu river may have been a result of wastes washed from commercial farming (afforestation, crop and stock farming) land. There was a high phosphorus concentration around the commercial farming areas. In addition, the high phosphorus concentrations may be attributed to the animal and laundry wastes of the rural settlements.

However, increase in population size is expected to increase the pressure on the land (e.g. crop and stock farming) leading to increased soil erosion and sedimentation (Madikizela *et al*, 2001).

2.5.3. A Situation Analysis of Water Quality in the Catchment of the Buffalo River (Ashton *et al*, 1996).

The main aims of this project undertaken were to carry out a situation analysis of water quality in the Buffalo River using existing data; to define water quality guidelines for different users; to design a water quality monitoring system; and to make management recommendations to reduce the impacts of pollution in the river. A second set of aims was to assess the effects of diffuse runoff from different types of townships in the catchment on the water quality of the river, and to derive a phosphate budget for the catchment, in order to identify the major sources of input.

Water quality studies of the catchment revealed that the main variables of concern were that of salinization, nutrient enrichment and faecal coliforms. Salinization is a problem due to the natural background levels which oringinate from wash-off from the marine shales, which dominate the geology of the catchment. Phosphate concentrations increase in the middle reaches of the catchment mainly because of the urban effluents from the sewage treatment works and diffuse runoff from the urban catchments. The study revealed that the major effluent producers were waste water from the sewerage works, waste water from several of the irrigation schemes as well as industrial effluent. The presence of raw sewage present appears to have originated from broken pipes and these render parts of the dam unfit for recreational purposes.

The water quality problems in the Buffalo River have been ultimately attributed to a consequence of over-population and over-development in a relatively small catchment with inadequate water resources (Ashton *et al*, 1996).

2.5.4. Seasonal Variation of Water Quality of the Nile River at Helwan Area (Zayed *et al*, 1995)

The objective of the undertaken study was to assess the water quality of the river Nile at the Helwan area. Parameters that were used to assess the water quality included DO, pH, conductivity, turbidity, total phosphorus and nitrogen.

The study revealed both spatial and temporal changes in water quality in the area. An analysis of DO, a key test in water pollution and waste treatment process control revealed seasonal as well as spatial fluctuations for the river with influences from industrial and human activities.

Turbidity values also showed spatial and temporal variations. Turbidity values showed a spatial change across the breadth of the river, which is usually dependant on weather conditions, industrial activity, human activity, the variation of the Nile velocity and total suspended solids. These turbidity values ranged from 12 to 55 NTU over the sites and the seasons. Phosphorus analysis indicated higher levels in summer than in winter. The results for nitrogen in the river indicate the highest values for summer and the lowest values for winter. However, at certain sites the high nitrogen values during all the seasons were indicative of sewage pollution.

Some of the key findings of the study reflected that both spatial and temporal variations of water quality generally occur in a given water body and that spatial variations are generally attributable to landcover patterns, whilst rainfall influences the temporal variations in water quality patterns (Zayed *et al*, 1995).

2.5.5. Spatial and Temporal Water Quality Variability in the Piracicaba River Basin, Brazil (Krusche *et al*, 1997)

A water quality monitoring program was established in the State of San Paulo, Brazil, as early as 1978. The monitoring network containing years of monthly data offered a unique opportunity to address the water quality issue. The study evaluated the temporal and spatial variability of key parameters of water quality at nine sampling stations in the Piracicaba River Basin.

Four key parameters chosen to evaluate water quality were DO, biochemical oxygen demand (BOD), nitrate concentration and total coliform. The temporal evaluation of the data over the 18 year period, showed a decrease in the DO for the majority of the sampling stations, while BOD, nitrate and total coliform increased. The results of the study revealed spatially, that the water quality downstream was poor, as indicated by the decrease of DO concentration and an increase of BOD, nitrate and total coliform concentrations. Factors that were cited as contributing to the situation were that of an accumulation of domestic and industrial sewage downstream (Krusche *et al*, 1997).

2.5.6. Water Quality Management for Lilongwe Watershed (Ghambi and Mzumara, 1998)

Initial studies in the Lilongwe catchment, which lies in the central region of Malawi revealed the predominant landuse to be commercial farming, livestock, subsistence farming, timber plantation, forest reserves, cultivation of vegetables and sugar cane and peri-urban and rural settlements.

Regular water quality monitoring exercise involved water sampling for biological, chemical and physical analysis. Analysis was chosen for major pollutants that were related to landuse activities including phosphorus, turbidity, total dissolved solids, nitrates, *E. Coli*, pesticide residues and suspended solids. In addition, rainfall patterns in the catchment were monitored to determine runoff/water quality relationship and to quantify the total load entering the river system. For the study, a GIS was employed to relate the landuse activities to water quality problems.

Faecal pollution trends indicated that most of the populace do not use or have pit latrines and therefore defecate in open areas contributing to high faecal pollution. In addition, livestock production effluent, sewage ponds and point source domestic waste in informal and rural settlements contribute as a source of faecal contamination.

The results also indicated a significant spatial and temporal variation of suspended solids and turbidity. The high turbidity levels during the wet months have been attributed to the runoffs from agricultural fields, grazing and burrow areas as well as domestic sewage discharges. Widespread deforestation and farming have contributed to the high levels of turbidity. The study points out that a partial catchment improvement has been implemented and suggests a more holistic approach (Ghambi and Mzumara, 1998).

Chapter 3. Materials and Methods

3.1. Study Area

3.1.1. Selection of Study Area

The selection of the Durban Metropolitan Area (DMA) as the study area, was based on the availability of relevant data from the Department of Wastewater Management (DWWM). In collaboration with the DWWM staff, it was decided that the DMA was an ideal study site, as it met with the objectives of the proposed study in terms of the presence of various river systems, land use classes, and regular sampling of rivers.

3.1.2. Description of Study Area

The Durban Metropolitan Area (DMA) lies on the eastern seaboard of South Africa located, between latitudes 29^0 31' 30" and 30^0 10' 33" south and between longitudes 30^0 33' 28" and 31^0 11' 33" east (King *et al*, 1995), (Figure 3.1.). The DMA boundary borders the Indian Ocean on the east and goes as far west as Cato Ridge (Figure 3.2.). It occupies a total area of 1366 square kilometers and has a population of just over 2,3 million Durban Metro, 1998). The region consists of 6 local council areas (North Central, South Central, South, North, Inner-West and Outer-West), and a Metropolitan Council with responsibilities that extend across the entire area (Durban Metro, 1998).

The climate of the DMA is often described as humid subtropical with a warm summer and mild winter. The mist belt region, which extends over the western area, makes it more temperate. It is influenced by both tropical and temperate weather patterns, largely due to its latitudinal position. The DMA exhibits a strong seasonal rainfall pattern (Archibald, 1995). The region has a summer rainfall regime, experiencing most of its rainfall during the months of October to March (Swart, 1998).

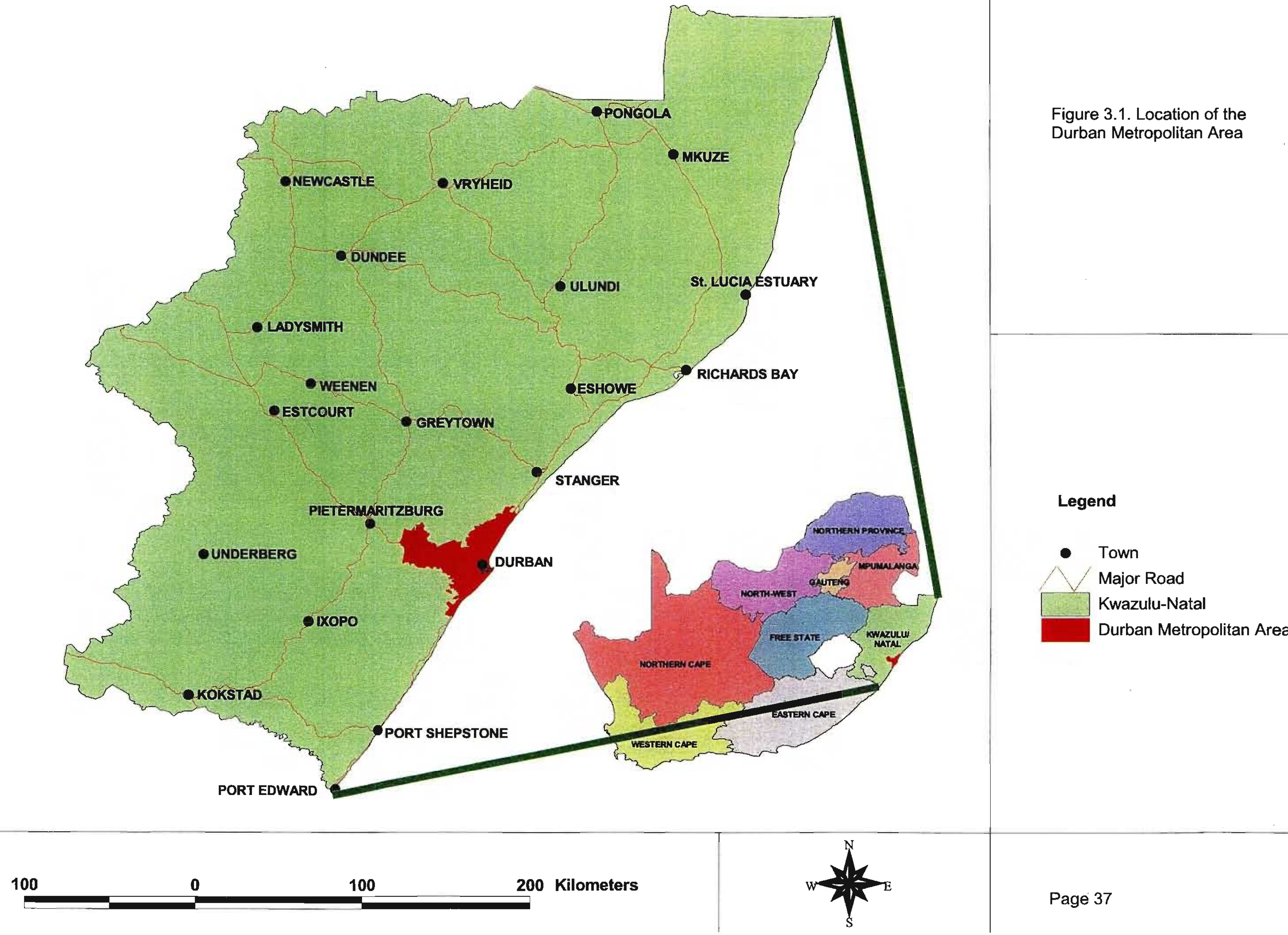


Figure 3.1. Location of the Durban Metropolitan Area

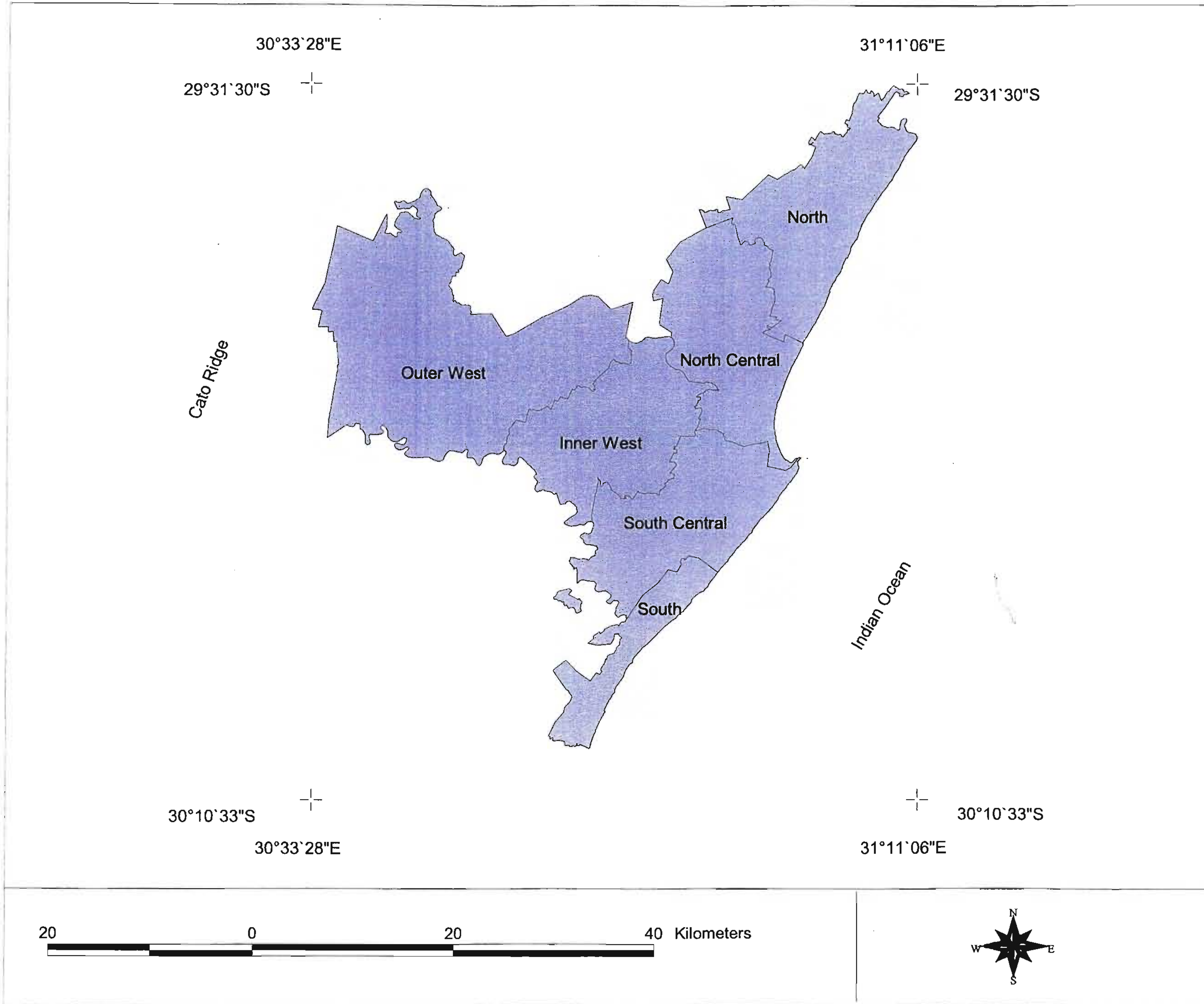


Figure 3.2. The DMA Boundary

Legend

Durban Metropolitan Area

3.1.2.1. Human population

The DMA with a population of about 2,5 million is in many ways negatively impacting on the natural environment. The population growth rate for the DMA was estimated at approximately 2 % per annum (1996) as a result of natural growth, in migration and urbanisation.

The DMA is culturally diverse with a majority of black residents, a large Indian community and a white and coloured minority. The growing population and increasing standards of living has created increased demands for goods and services (including housing, water and electricity), increased production of waste, increased use of the environment for economic and recreational activities and increased transportation needs to enable people to move around the city (Durban Metro, 1999).

3.1.2.2. Economy

The DMA with its large and diversified economy has strong manufacturing, tourism, transportation, finance and government sectors. In addition, the DMA also has a dynamic and growing small and micro business sector. There has, however, been little growth in the jobs provided by the formal sector over the past 20 years. As a result, the DMA has very high rates of unemployment and unequal access to economic opportunities throughout the metropolitan area. A rapidly increasing population as a result of high birth rates and urbanisation is placing strain on the economy of the DMA (Durban Metro, 1999).

3.1.2.3. Terrestrial Resources

The DMA has a high biodiversity ranging from unique plant, bird, mammal and reptile species. This valuable and irreplaceable resource base is, however, increasingly under threat as the city grows. This loss of biodiversity is already impacting on residents through effects such as increased flooding, a reduction in recreational and cultural opportunities and a shortage of traditional medicinal plant species.

Population growth and associated urban development are the prime causes of degradation of biodiversity in the DMA. Other significant causes include invasion by alien plant species, housing and servicing needs, which exceed delivery, urban agriculture, plant harvesting, illegal dumping, quarrying and sand mining.

Durban once contained the largest wetland area on the east coast but now there are only small remnants left. On the positive side, over a quarter of the land area in the DMA is still vegetated, although not undisturbed, open space. The proposed Metropolitan Open Space System links important conservation and recreation areas. Durban still hosts a wide range of plant and animal species (Durban Metro, 1999).

3.1.2.4. Freshwater Resources

Freshwater supplies in the DMA are not assured due to the poor distribution of rainfall and the relatively high evaporation losses across the catchments (Hindson *et al*, 1996). The Durban Metropolitan Area's (DMA) freshwater resources are under pressure from growing needs for potable water and waste disposal. There are 14 rivers traversing the DMA, most of which have been heavily modified through dams and canalisation. The modification of river functioning, where this has occurred, has resulted in loss of biodiversity, natural river purification functions and recreational and tourism opportunities. Increases in water consumption could result in water shortages within the next 15 to 20 years.

This is exacerbated by the fact that many of the DMA's freshwater sources are polluted by the myriad of land-use activities in the region. They are continuously exposed to runoff from industry, return flows from sewage works, agricultural activities, and contaminated storm-water from high-density housing and informal settlements (Hindson *et al*, 1996).

The DMA economy is also a large user of water, as are individual industries, especially in the pulp, paper and textile sectors. Industrialization and industrial pollution are contributing increasingly to the degradation of natural systems (Hindson *et al*, 1996). The area is of high economic significance with a large commercial and industrial sector, an international airport and a major port at Durban (King *et al*, 1995).

3.2. Data

The key sources of data that were used in the study were obtained in the form of digital coverages from the database within the DWWM. This included data such as rivers, sampling points, land use patterns and community locations. These were opened in ArcView (ArcView vers. 3.0 1997), which together with ArcInfo (ARC/INFO vers. 7.2.1. 1997), formed the tools used in the GIS investigation.

3.2.1. DMA Boundary

The DMA boundary was digitized off a 1:50 000 government printer map at a weed tolerance of 5 and a nodesnap distance of 25.

3.2.2. River Systems

Traversing the DMA are numerous river systems. The Mgeni river is one of the largest river basins of KwaZulu-Natal, which exceeds 230km in length and 4000km^2 in area, although it is only the lower reaches, which lie within the DMA (King *et al*, 1995). Many of the DMA's natural systems have been transformed by urban, commercial and industrial development. Throughout the region are numerous land-uses ranging from agriculture to industry.

Rivers were captured by both BKS *(Pty) Limited* and Stewart Scott at a scale of 1:10 000. Coverages of both the major and minor river systems for the DMA were obtained from the DWWM. Traversing the DMA, are a number of river systems. These include the Tongati, Umdloti, Ohlanga, Seekoei, Umgeni, Mbongokazi, Palmiet, Umbilo, Mhlatuzana , Mlazi, Mbokodweni, Manzimtoti, Little Manzimtoti, Lovu and Msimbazi rivers as illustrated by Figure 3.3.

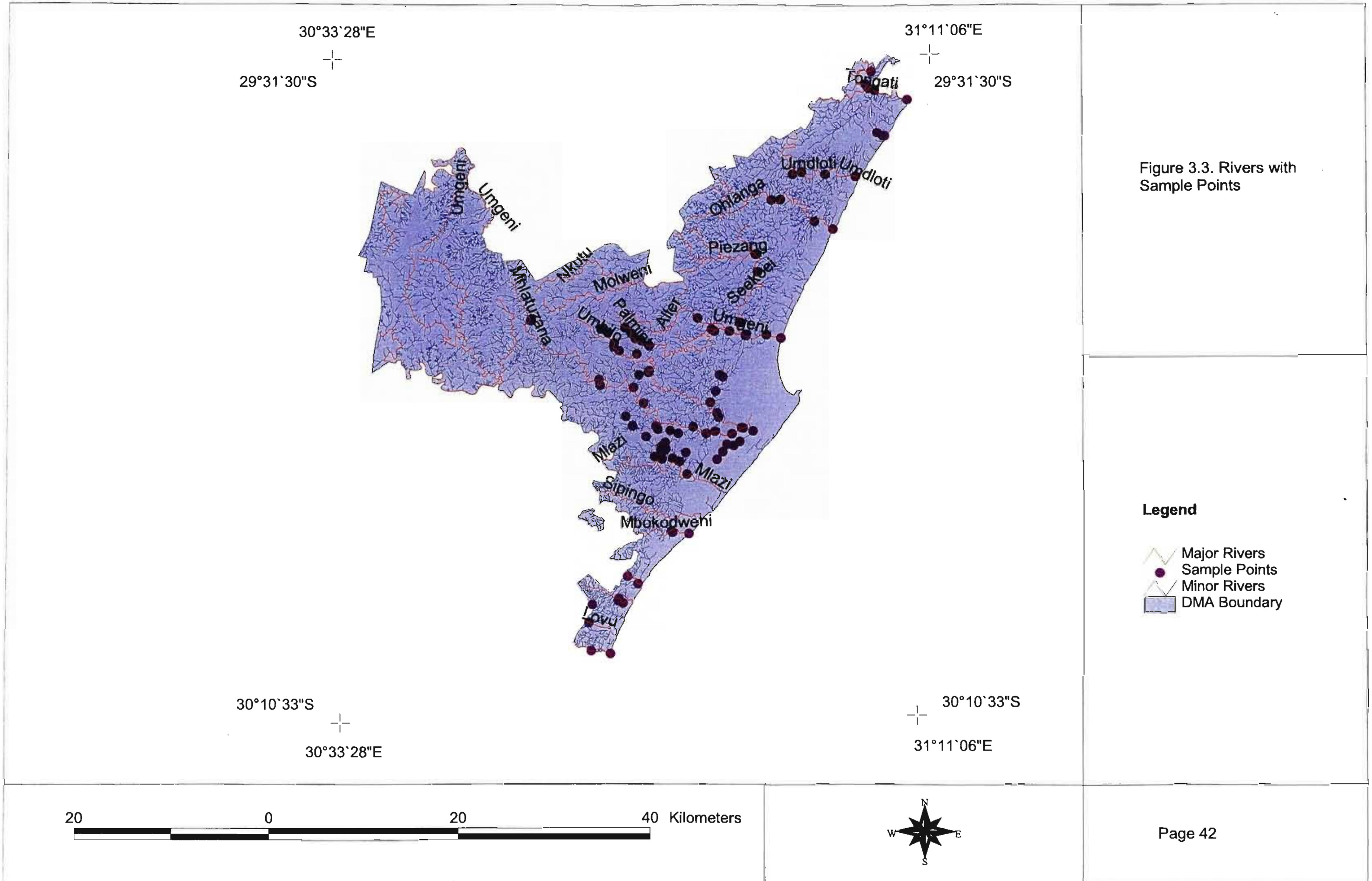


Figure 3.3. Rivers with Sample Points

3.2.3. Catchments

Catchments for the entire country were captured by the Department of Water Affairs and Forestry at a 1:250 000 scale. The clip command in ArcInfo was used to clip the catchment coverage to the boundaries of the DMA. Major catchments of the DMA include Tongaat, Mhlanga, Mgeni, Durban Bay, Mlazi, Mbokodweni, Little Toti, and uMgababa (Figure 3.4.).

3.2.4. Water Quality

For rivers of the DMA, water was collected at the various sample points and tested bi-monthly. Sample points for the DMA were captured by Durban Metro Water Service at a scale of 1:10 000. A digital file of all the sampling points for the DMA was obtained from the DWWM. The sample point file included points that were regularly tested by the department for rivers, pools, the beach and outfalls from the treatment sites. Since this project focused on water quality of rivers, only the river sample points (Figure 3.3.), were selected (98 points) and converted to a shape file for further investigation.

The sample points varied in number for the lengths of the different rivers. Sample points for the catchments are presented in Appendix 1. Regular sampling of the rivers at specific sample points was conducted by the DWWM, and brought back to the laboratory for analysis. These samples were analyzed for various water quality determinants including turbidity, *E.coli*, pH, DO and phosphorus.

A database containing the water quality readings for the sample points of the DMA was obtained from the DWWM. A time frame of one year, (due to the nature of this project), from January to December 1998 was selected. A year frame was chosen to show both spatial and temporal variations in the water quality. The selection of 1998 as the year for this study was largely determined by the unavailability of consistent data for previous years for the DMA from the DWWM. This was largely due to the conversion of the Durban Municipal area to the DMA, which resulted in a relatively large area of operation for DWWM, which resulted in the availability of disjointed data. In addition, the selection of sample points have been inherited from the Durban

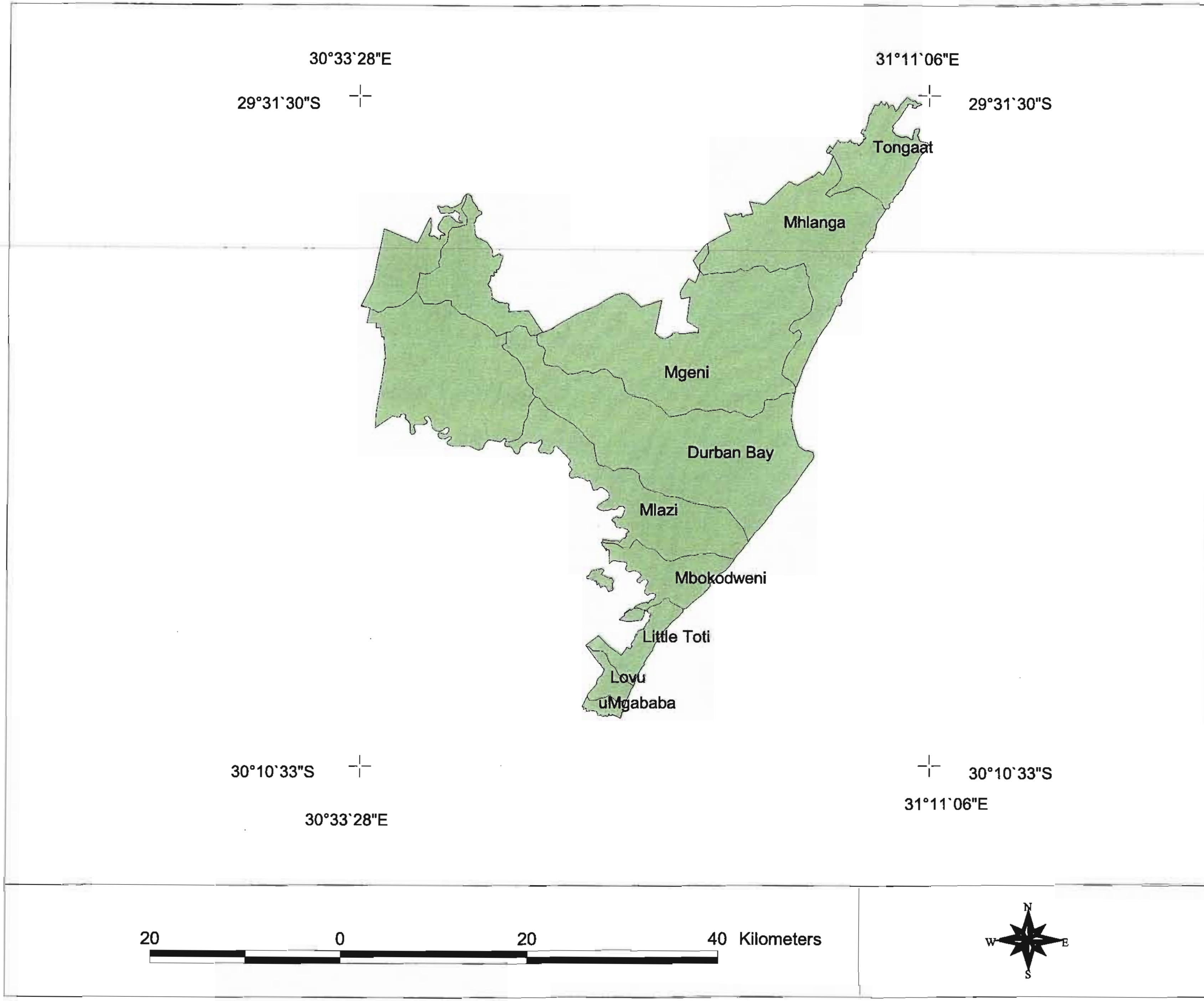


Figure 3.4. Catchments of the DMA

Legend

Catchment Units

Municipality, and the DWWM is still attempting to introduce new sample points further inland and some of the older ones have been dropped. This explains the lack of sample points inland (Jackson, 1998).

The actual water quality readings for the various parameters for the different sample points, often showed missing data. Reasons for these were bad weather conditions and also the recent spate of increased criminal activities, which resulted in certain areas not being sampled as regularly as others (Jackson, 1998). This is shown by Appendix 1 for the parameter DO, which has gaps in data for certain points.

3.2.5. Landuse

The landuse coverage was captured at a scale of 1:10 000 by GeoMap for the Urban Strategy Department within the Durban Metropolitan. This was obtained from DWWM (Figure 3.5.). Landuse classes for the DMA include airport, commercial retail, forestry, industrial, market gardening, other farming, recreation, rural, small holding, state institutional, sugarcane plantations, undeveloped land, unused land, urban formal, urban informal and urban mixed.

3.2.6. Population

A coverage of formal and informal settlements together with population and areas were obtained from the DWWM.

3.2.7. Rainfall

Rainfall data was obtained from the South African Weather Bureau for stations in the DMA. These included the Blackburn, Virginia, (Mhlanga catchment) Mount Edgecombe, Kloof, Durban Heights, (Mgeni catchment), Botanical gardens, Kenneth Steinbank (Durban Bay catchment) and the Durban weather office (Mlazi catchment) (Figure 3.6.). There were no stations for the Tongaat, Little Toti and uMgababa catchments.

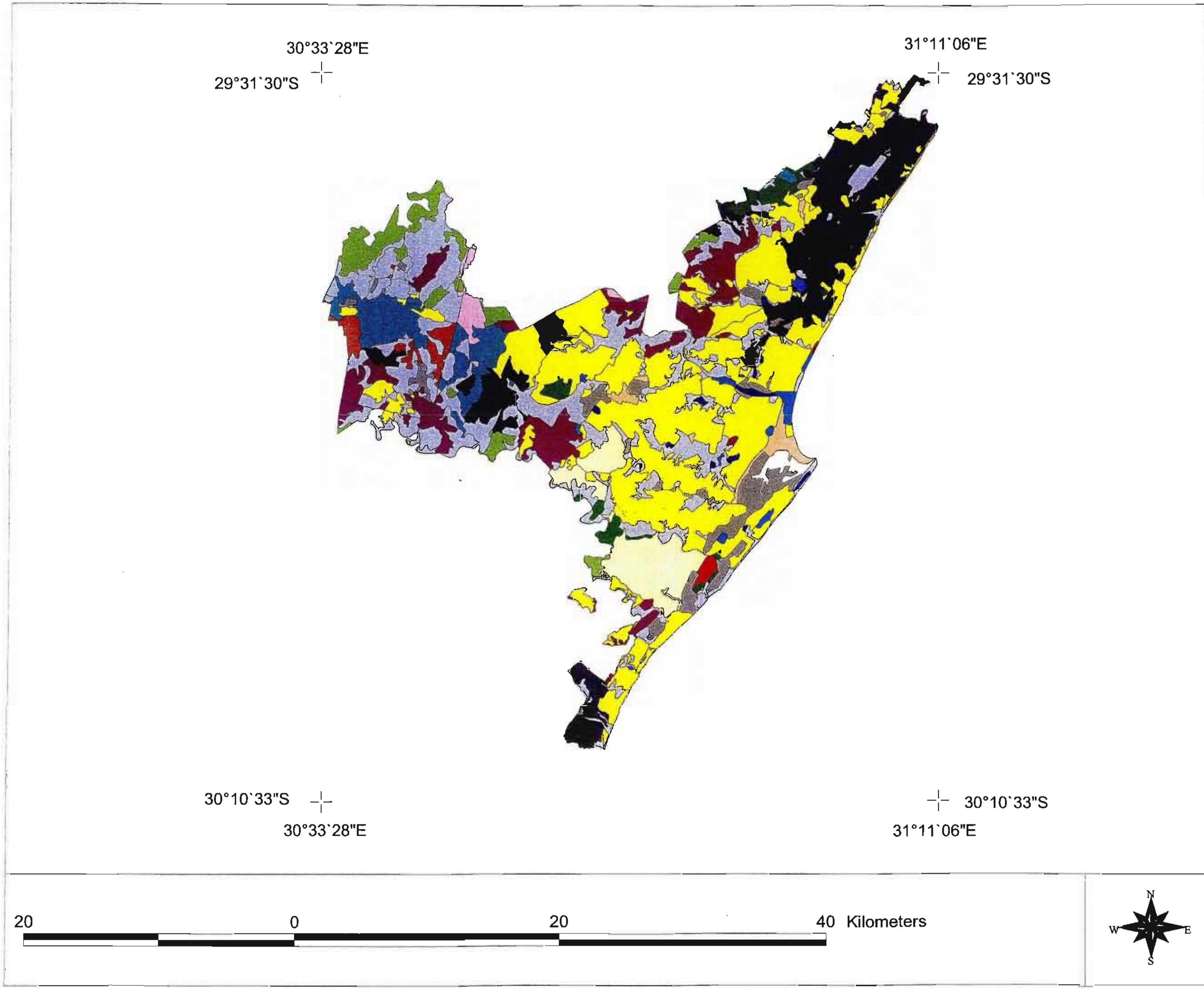
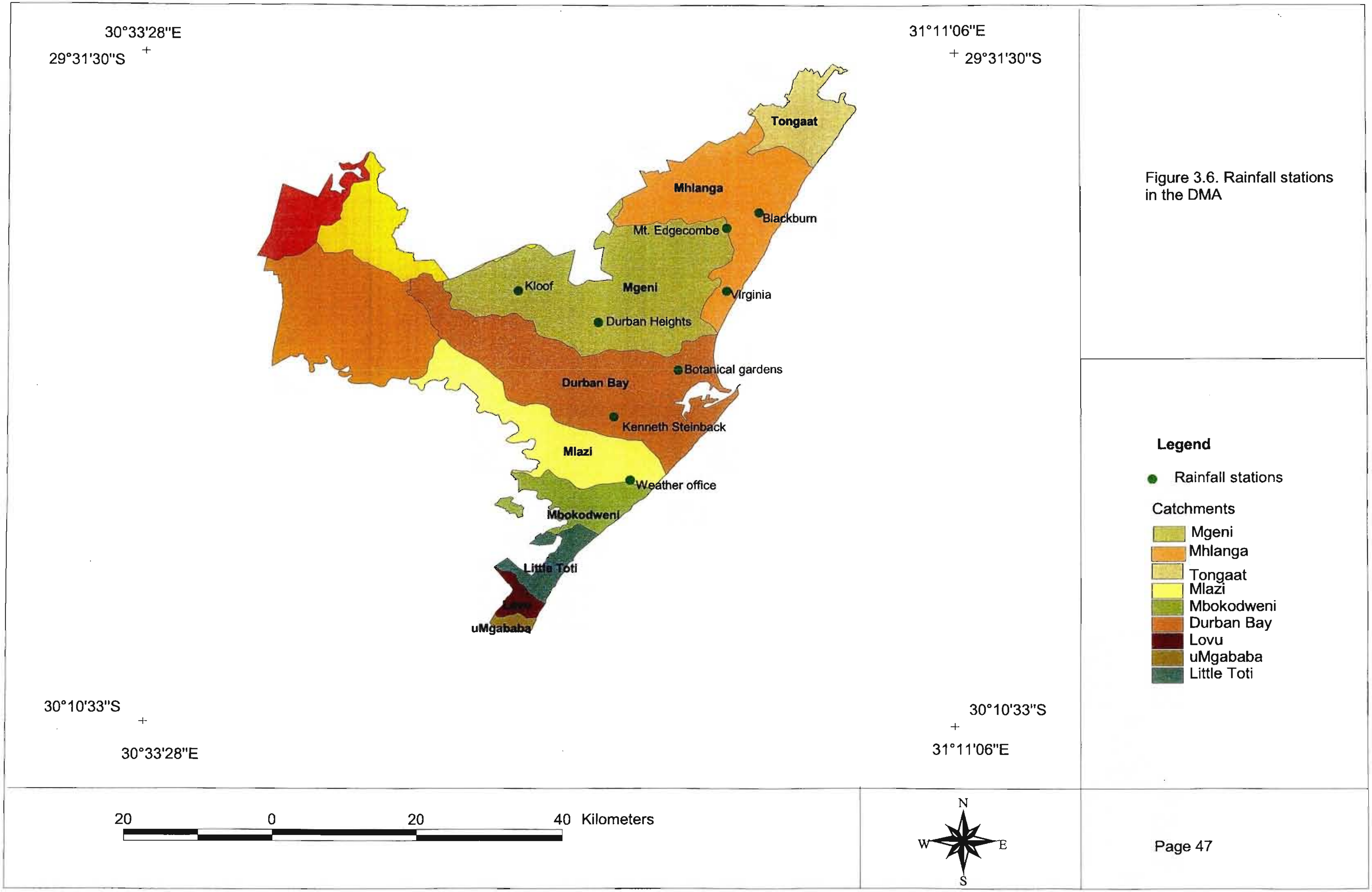


Figure 3.5. Landuse Classes in the DMA

Figure 3.6. Rainfall stations in the DMA



3.3. Spatial Investigation

3.3.1. Water Quality Classes

For this study the investigation of individual parameters over a water quality index were chosen due to the reasons given below. A water quality index is often described as an indicator of the quality of water, obtained, by aggregating several water quality measurements into one number (Demayo, 1992).

A water quality index (WQI) allows 'good' and 'bad' water quality to be quantified by reducing the large quantity of data on a range of determinants to a single number in a simple, objective and reproducible manner (House & Newsome, 1989).
Despite these advantages, indices have been criticized due to:

- a lack of agreement on a common approach to index design,
- an apprehension among water quality experts that indices may be misused and basic data lost or hidden in aggregated data and
- a fear that expert knowledge may become superfluous or at least eroded and devalued (House & Newsome, 1989).

In collaboration with water quality experts, from the Department of Wastewater Management (Hodgeson pers comm, 1998), it was decided that for the purposes of this study the water quality parameters that would be investigated would be that of pH, *E. coli*, DO, turbidity and phosphorus. The guidelines set by the DWAF (1996b & 1996c) for both aquatic ecosystems and recreational use were used as the basis for the water quality investigation to determine the level of a particular parameter, ranging generally from the class poor to acceptable. For rivers of the DMA, water was collected at the various sample points and tested bi-monthly. The collection and analysis was undertaken by staff at the Department of Wastewater Management as part of their program of water quality analysis for a broader set of points including rivers, pools, the beach and outfalls from the treatment sites.

The median, average, maximum and minimum values for each point for each parameter, were calculated. These were calculated using Quattro Pro (Corel Quattro

Pro Ver. 8. 1997), (Appendix 1). These files were then converted to dBASE files, which were compatible for use in ArcView (ArcView vers. 3.0. 1997).

Using ArcView (ArcView vers. 3.0. 1997), the database files were imported from Quattro Pro (Corel Quattro Pro Ver. 8. 1997) and joined to the sample point shape file. For each water quality parameter, a new shapefile was created. The shapefiles for the parameters of *E. coli*, turbidity, pH, DO and phosphorus were created in ArcView. These were divided into classes of good to poor water quality. These categories were based on the ranges that appeared in Tables 2.2, 2.3, 2.4, 2.5 and 2.6, respectively. Using the legend editor in ArcView the average value was used as the classification field for each parameter in producing the different classes of water quality.

The nature of this study relating to it being a mini project as well as time constraints made it impossible to provide detailed analysis for all sample points in the study area. Therefore, in order to provide an overview of water quality for the parameters in the different catchments, as well as to highlight the problematic areas, the analysis was limited to a smaller selection of sample points.

For each parameter (DO, turbidity, phosphorus and *E.coli*), the points that reflected poor water quality (those in the extreme class) were selected. This was done for each of the catchments. The average value for the selected points for each parameter per catchment was calculated. This was undertaken to determine the overall average between catchments of water quality in the extreme (lethal) category. This provided (for a particular variable) a reflection of the degree of poor water quality for each catchment.

In order to highlight those points that consistently fell within the extreme water quality class for the various variables, the following was undertaken. Points that were reflective of poor water quality across the DMA for the combination of water quality variables were determined. Points that shared the category of poor water quality for two or more of the parameters were selected as reflecting problem areas within the DMA. These were also analysed with regard to spatial trends.

3.3.2. Landuse

In order to relate classes of poor water quality with landuse, the landuse categories for each catchment was determined. The landuse coverage shows landuse for the entire DMA. Since the catchment was used to examine the water quality of points within its boundaries, the calculation of the percentage landuse per catchment needed to be determined.

Using ARC/INFO, an overlay was performed using the catchment units and landuse coverages. There are three types of overlays:

i) Identity – computes the geometric intersection of 2 coverages. Only those features overlaying the feature extent of the first specified coverage are preserved. Feature attributes from both coverages are joined in the output coverage.

ii) Intersect - computes the geometric intersection of 2 coverages. Only those features in the area common to both are preserved. Feature attributes from both coverages are joined in the output coverage.

iii) Union - computes the geometric intersection of 2 polygon coverages. All features and attributes of both coverages are preserved.

The intersect overlay was used to combine the catchment and landuse coverages. Using query builder and calculate in ArcView, the area (in hectares) and percentage of the landuse types for each catchment was calculated.

3.3.3. Problem points of the DMA

Using the points that belonged to the extreme class for each parameter (above analysis), the points that were common for the variables were determined (Appendix 2). Those points, which reflected water quality of the extreme class for 3 or more variables were determined. These points are reflective of the most problematic within the DMA.

3.3.4. Population Density

In addition, the spatial component of population density was added to the study. Using the coverage of formal and informal communities, population density was calculated in Arcview. The use of population density was seen as relevant in this study to provide analysis as to areas that were highly populated that may provide some explanation towards poor water quality.

3.4. Temporal Investigation

Rainfall data for the DMA was obtained from the South African Weather Services for the stations of Blackburn, Virginia (Mhlanga catchment), Kloof, Mt. Edgecombe, Durban Heights (Mgeni catchment), Durban – Kenneth Steinback, Durban Botanical gardens (Durban Bay catchment) and Durban Weather Office (Mlazi catchment). No rainfall stations were present for the Tongaat, Mbokodweni, Little Toti, Lovu and uMgababa catchments and as such no temporal analysis was undertaken for these stations. As the study deals with water quality for the DMA for the year 1998, rainfall data for this year for all the above stations were obtained.

Rainfall data for the year 1998 was plotted for all the stations. The data set of sample points for the DMA was too large to individually plot and compare against rainfall. It was therefore decided that in order to select a smaller set, the points that were already selected for the spatial study (those in the extreme class) for each variable would be used. The average values for these points throughout the 12 month period was calculated for each catchment and parameter and plotted and compared with rainfall for the year.

Chapter 4. Results

4.1. Spatial Investigation

4.1.1. Landuse

The results of the calculation of landuse per catchment unit (Table 4.1., see overleaf), indicated that the Tongaat, Mhlanga, Lovu and uMgababa catchments have sugarcane plantations as their predominant landuse. The Mgeni, Durban Bay, and Little Toti catchments have urban formal as their dominant landuse. The dominant landuse in the Mbokodweni catchment was that of urban mixed, whilst in the Mlazi catchment the predominant landuse was shared between urban mixed and urban formal.

4.1.2. Water Quality Classes

4.1.2.1. Dissolved Oxygen

The results for water quality for DO for the DMA show that there is a distinct distribution of classes ranging from target to lethal throughout the DMA (Figure 4.1.). With the exception of the Lovu and the uMgababa catchments, the DO levels for the rest of the catchments were in the lethal category. Poor water quality (belonging to the extreme categories), were evident for the Tongaat, Umdloti, Ohlanga, Seekoei, Mbokodweni and Mgeni rivers. The Mhlanga, Mgeni and Mlazi catchments appear to be the most affected. DO levels for the Tongaat and the Mhlanga catchments were between sub-lethal and lethal.

Table 4.1. Landuse percentage composition for all the catchments of the DMA

Landuse	Tongaat	Mhlanga	Mgeni	D. Bay	Mlazi	Mbokodweni	Lovu	Little Toti	uMgababa
Airport					1.77	2.85			
Commercial	0.42	0.46		3.59					
Forestry	0.46		0.15						
Industrial	0.88	0.86	3.13	8.00	4.06	12.97		6.16	
Market Gardening		1.53		1.58	5.78	0.89			
Other Farming				2.98					
Recreation		0.03	1.28	1.60	0.60			0.41	
Rural		1.01	1.00	0.20	3.12	5.96	0.19	0.23	17.91
Smallholding									
State Institutional		0.14	0.99	1.02					
Sugarcane Plantations	77.54	51.03	7.91	2.36	2.11	0.99	65.47	18.82	60.61
Undeveloped		11.14	12.72	17.9	12.34	9.00	14.27	12.4	0.27
Unused Land	5.85		1.58						
Urban Formal	13.90	25.05	56.48	50.74	26.09	10.28	14.24	56.29	13.48
Urban Informal		6.28	10.00	2.66	10.26	11.97		3.86	1.82
Urban Mixed			0.01	5.07	28.41	40.39			
Unclassified	0.95	2.47	4.75	1.32	7.23	4.70	5.83	1.83	5.91

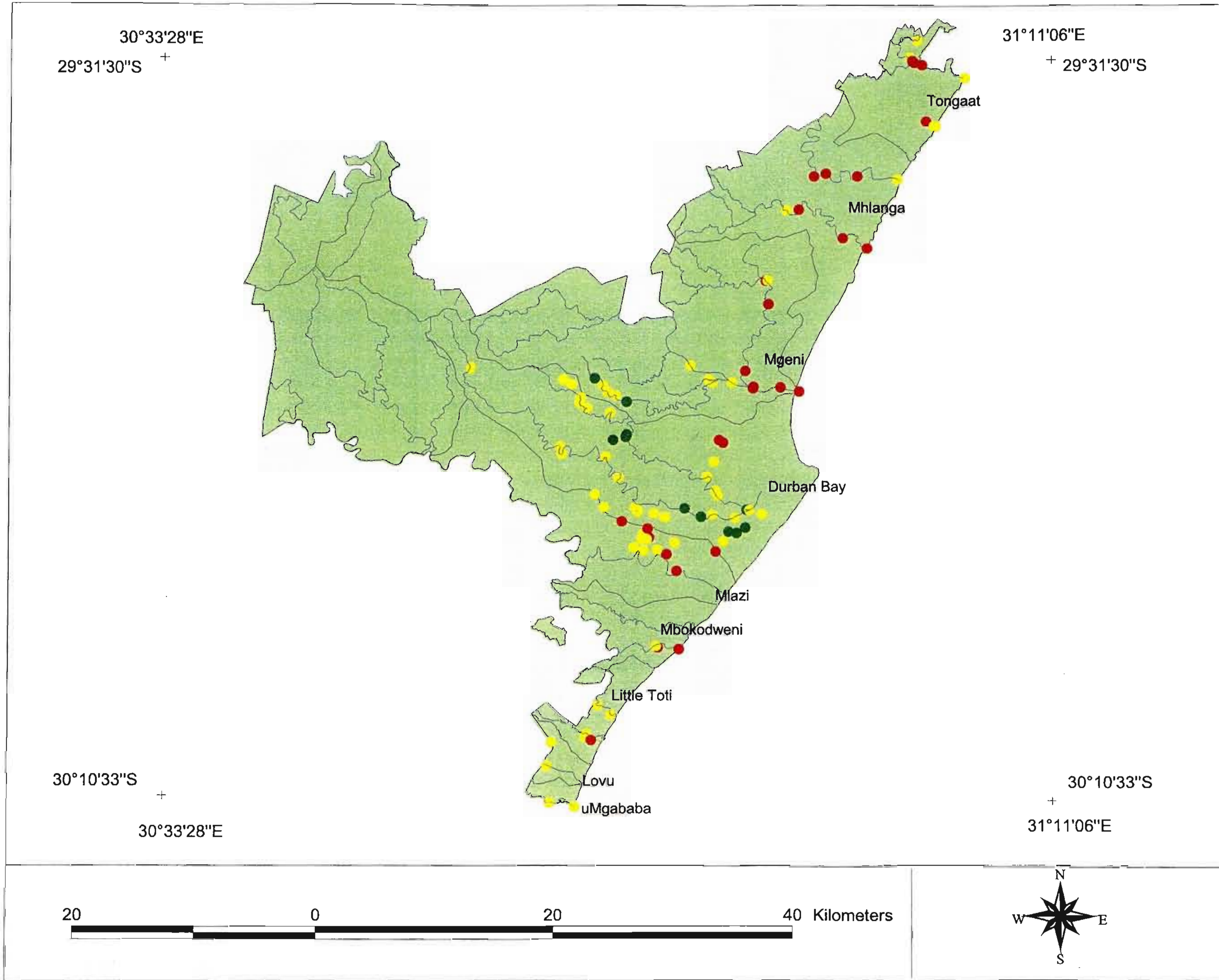


Figure 4.1. Average DO levels

Legend
Rivers
Average Dissolved Oxygen
target
sub-lethal
lethal
Catchment Units

Points that were in the extreme class (reflective of the extreme water quality class of lethal) for DO were selected for all catchments (Table 4.2.).

Table 4.2. Selected points (extreme water quality) for DO for each catchment

Catchment	**Point**	**Landuse**
Tongaat	Hlawe 01 Hlawe 02 Tong 02 Genaz 02	Urban formal/sugarcane plantations Urban formal/ sugarcane plantations Sugarcane plantations Sugarcane plantations
Mhlanga	Ohl 01 Ohl 02 Ohl 07 Hloti 02 Hloti 04 Hloti 05	Urban formal Sugarcane plantations Sugarcane plantations Sugarcane plantations Urban formal/ sugarcane plantations Urban formal
Mgeni	Gane 04 Gane 05 Gane 18 Mgeni 13 Mgeni 71 Mgeni 91 Mgeni 92	Urban formal Sugarcane plantations /industry Industry/urban formal Urban formal Industry Urban formal Industry
Durban Bay	Bell 09 May 14	Urban formal/urban informal Urban formal/urban informal
Mlazi	Chat 07 Chat 08 Chat 10 Nyama 03 Mlaas 18 Mlaas 20	Urban formal Urban formal Urban formal Industry Urban mixed Urban mixed
Mbokodweni	Mboko 01 Mboko 02	Urban mixed/industry Urban mixed/industry
Little Toti	Ltoti 04	Urban formal

The above points were analysed to provide an indication of the averages (for the extreme water quality class) for each of the catchments. These values are reflected in Figure 4.2. This provides an indication of the catchment exhibiting the lowest average for water quality for DO. The Tongaat and Mlazi catchments reflect the lowest average (within the extreme class) for DO.

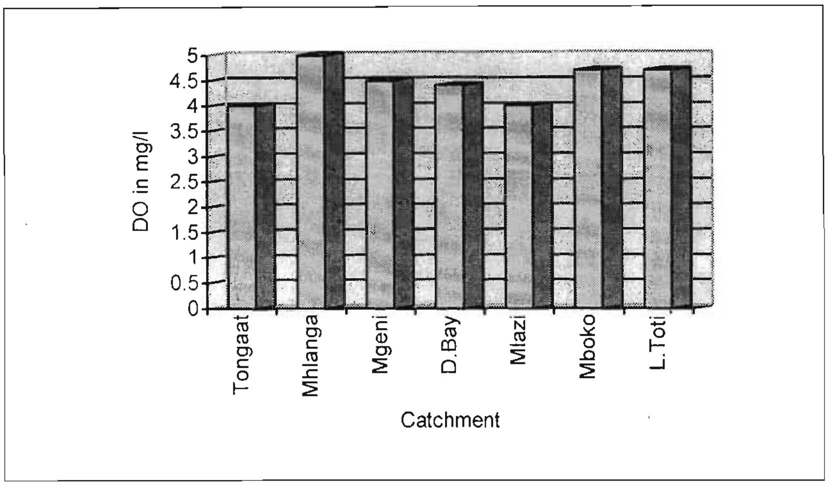


Figure 4.2. Average DO levels of points in the extreme category across catchments of the DMA

4.1.2.2. Turbidity

The average turbidity readings for the DMA reveal that there is no class of excellent water quality. However, the range is from good to unsatisfactory (Figure 4.3.). With the exception of the Lovu, Little Toti and the uMgababa catchments the rest of the catchments indicate turbidity problems.

Points that were in the extreme class (reflective of the extreme water quality class) for turbidity were selected for all catchments (Table 4.3.).

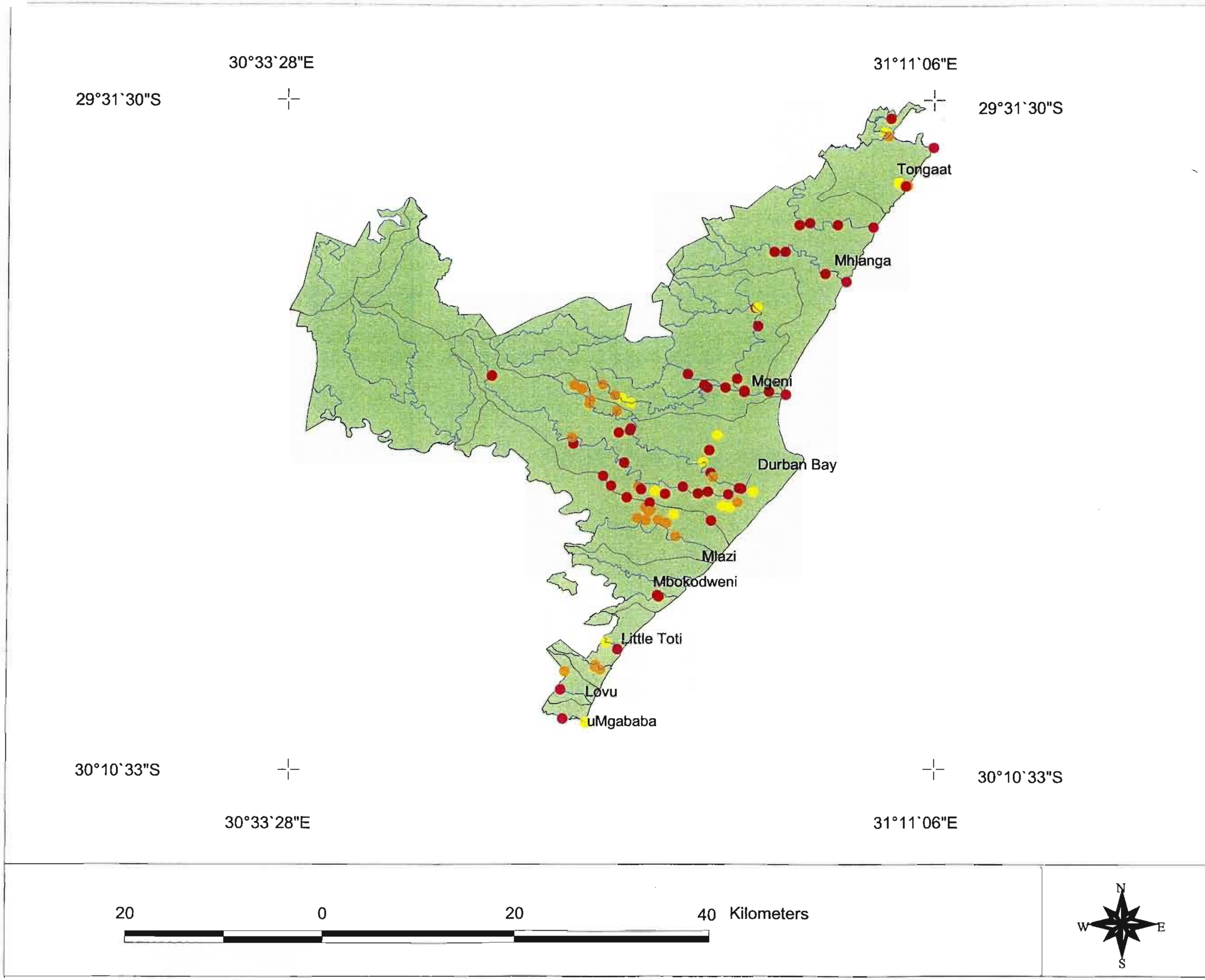


Figure 4.3. Average turbidity levels

Table 4.3. Selected points (extreme water quality) for turbidity for each catchment

Catchment	Point	Landuse
Tongaat	Wewe 01 Sweet 01	Urban formal Urban formal/ sugarcane plantations
Mhlanga	Ohl 02 Ohl 05 Hloti 02 Hloti 05	Sugarcane plantations Urban formal Sugarcane plantations Urban formal
Mgeni	Gane 04 Gane 18 Mgeni 08 Mgeni 71 Mgeni 91 Mgeni 92	Urban formal Industry/urban formal Industry Industry Urban formal Industry
Durban Bay	Zana 29 Zana 30 Zana 80 Zana 81 Baan 05 Bilo 18	Urban formal Urban formal/industry Industry Urban formal Urban formal Urban formal
Mlazi	Chat 07	Urban formal
Mbokodweni	Mboko 02 Mboko 03	Urban mixed/industry Urban mixed/industry

The above points were analysed to provide an indication of the averages (for the extreme water quality class) for each of the catchments. These values are reflected in Figure 4.4. This provides an indication of the catchment exhibiting the highest average of water quality for turbidity. The Mgeni catchment reflects the highest average (within the extreme class) for turbidity.

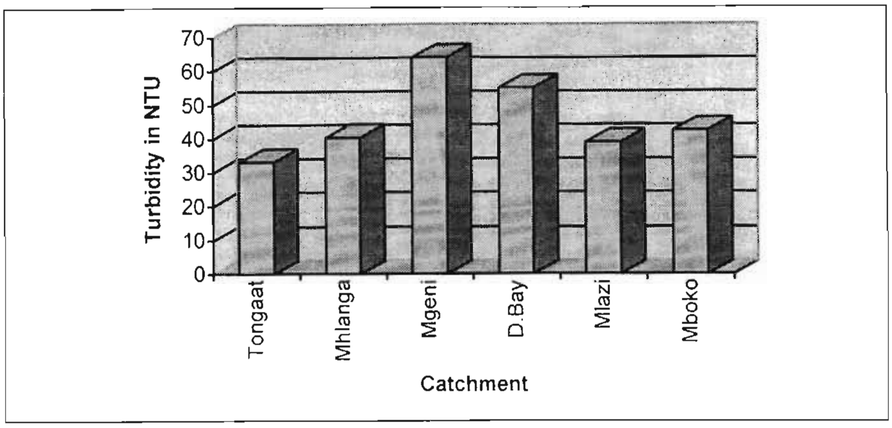


Figure 4.4. Average turbidity levels of points in the extreme category across catchments of the DMA

4.1.2.3. pH

The pH levels for the entire DMA fall within the categories of the target to acceptable ranges (Figure 4.5.).

4.1.2.4. Phosphorus

Average phosphorus concentrations throughout the DMA appears problematic, with water quality falling into the hypertrophic class (Figure 4.6.). The Lovu and the uMgababa catchments exhibit eutrophic conditions.

Sample points along rivers throughout the DMA all exhibit eutrophic or hypertrophic conditions (Figure 4.6.). Rivers that were most affected were the Tongaat, Ohlanga, Seekoei, Mgeni, Umbilo, Mhlatuzana, Mbokodweni and Manzimtoti.

Points that were in the hypertrophic category of water quality (reflective of water quality in the extreme category) for phosphorus were selected for all catchments (Table 4.4.).

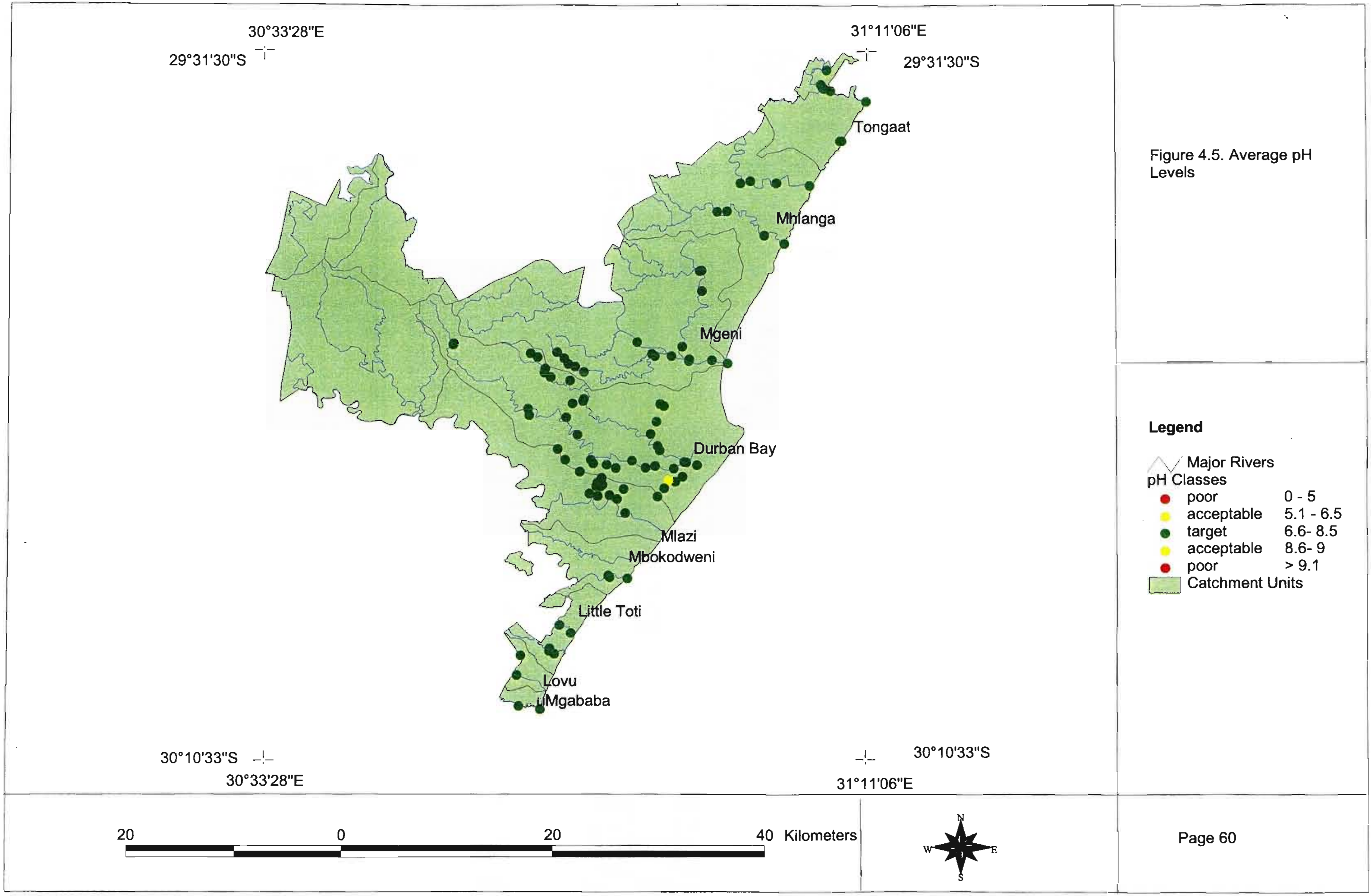


Figure 4.5. Average pH Levels

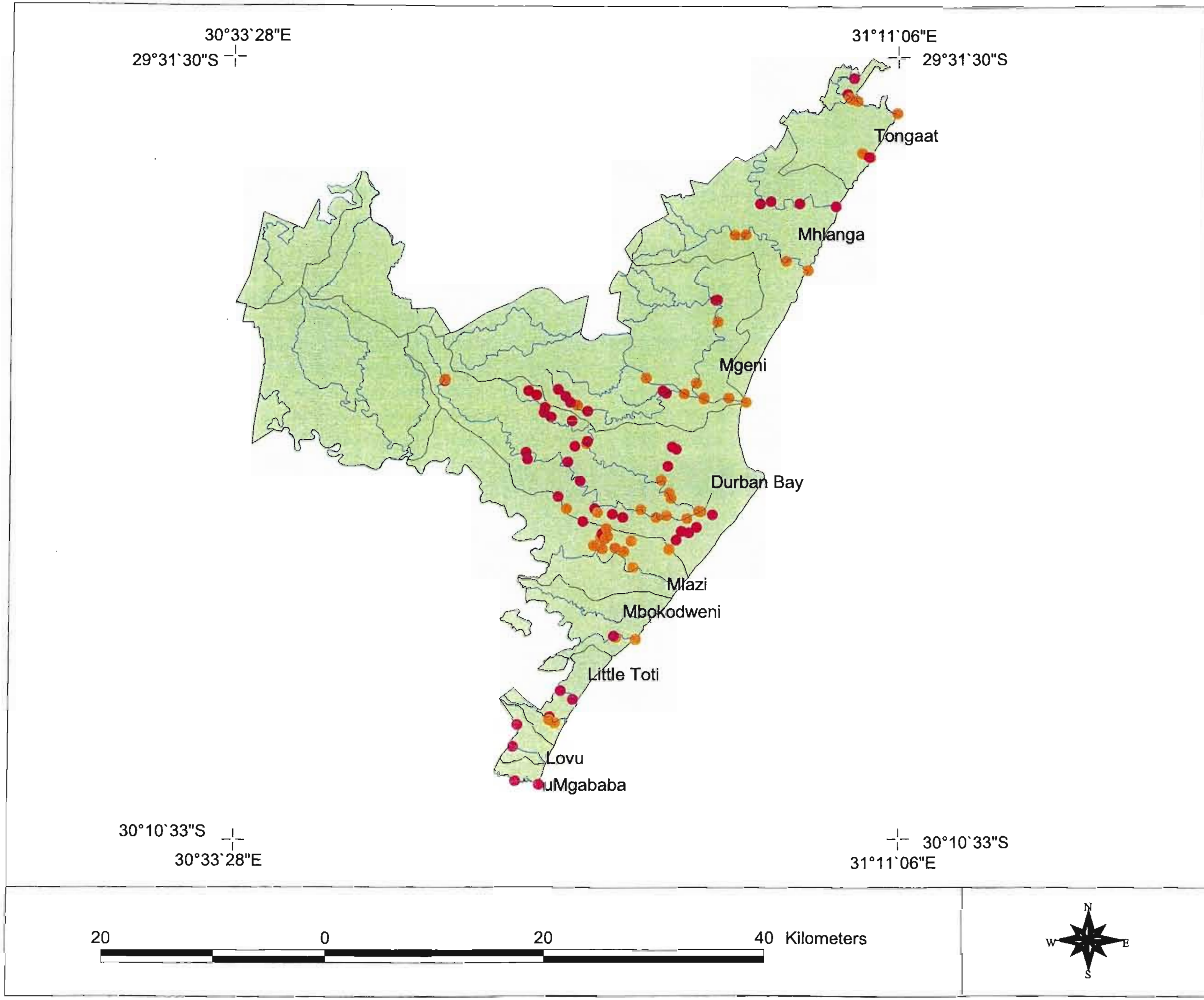


Figure 4.6. Average Phosphorus Levels

Legend

Major Rivers

Phosphorus Classes

●	oligotrophic	< 5
●	mesotrophic	5 - 25
●	eutrophic	26 - 250
●	hypertrophic	> 251

Catchment Units

Table 4.4. Selected points (extreme water quality) for phosphorus for each catchment

Catchment	Point	Landuse
Tongaat	Hlawe 01	Urban formal/ sugarcane plantations
	Hlawe 02	Urban formal/ sugarcane plantations
	Tong 01	Sugarcane plantations
	Tong 02	Sugarcane plantations
	Genaz 01	Urban formal
	Genaz 02	Sugarcane plantations
Mhlanga	Ohl 01	Urban formal
	Ohl 02	Sugarcane plantations
	Ohl 05	Urban formal
	Ohl 07	Sugarcane plantations
Mgeni	Gane 05	Sugarcane plantations /industry
	Gane 18	Industry/urban formal
	Mgeni 08	Industry
	Mgeni 13	Urban formal
	Mgeni 70	Urban formal
	Mgeni 71	Industrial
	Mgeni 91	Urban formal
	Mgeni 92	Industry
	Palm 06	Industry/urban formal
Durban Bay	Bilo 04	Urban formal
	Bilo 11	Urban formal
	Bilo 12	Urban formal
	Bilo 13	Industry
	Bilo 18	Urban formal
	Zana 04	Industry
	Zana 09	Industry
	Zana 10	Industry
	Zana 60	Urban formal
	Zana 80	Industry
	Zana 81	Urban formal
Mlazi	Mlaas 14	Urban formal
	Mlaas 10	Urban mixed
	Mlaas 18	Urban mixed
	Mlaas 15	Urban formal
	Mlaas 20	Urban mixed
	Chat 04	Urban formal
	Chat 08	Urban formal
	Chat 09	Urban formal
	Chat 10	Urban formal
	Nyama 03	Industry
Mbokodweni	Mboko 02	Urban mixed/industry
	Mboko 07	Urban mixed/industry
Little Toti	Ltoti 04	Urban formal
	Ltoti 05	Urban formal

The above points were analysed to provide an indication of the averages (for the extreme water quality class) for each of the catchments. These values are reflected in Figure 4.7. This provides an indication of the catchment exhibiting the highest average of water quality for phosphorus. The Mbokodweni catchment reflects the highest average (within the extreme class) for phosphorus.

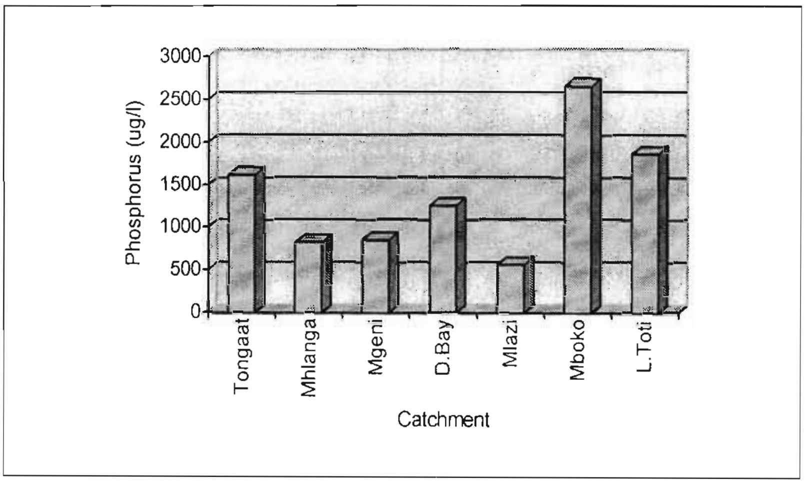


Figure 4.7. Average phosphorus levels of points in the extreme category across catchments of the DMA

4.1.2.5. *E. coli*

The water quality in terms of *E. coli* across all the catchments (Figure 4.8.), indicates that all points fall into the category of poor. Since all points were in the extreme class, those that were common with the other parameters were selected and are reflected in Table 4.5.

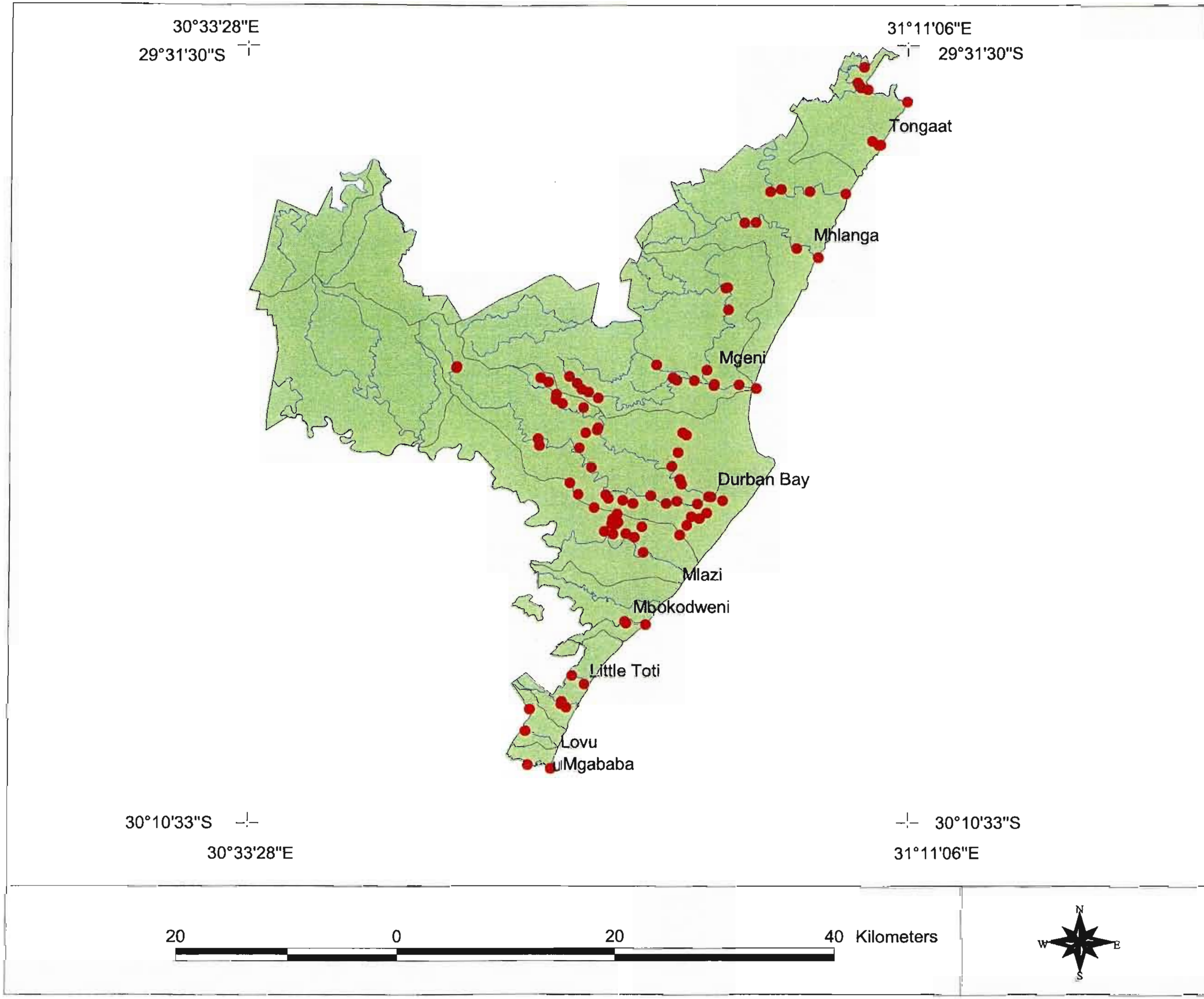


Figure 4.8. Average *E.coli* Levels

Table 4.5. Selected points for *E. coli* for each catchment

Catchment	Point	Landuse
Tongaat	Hlawe 01	Urban formal/ sugarcane plantations
	Hlawe 02	Urban formal/ sugarcane plantations
	Tong 01	Sugarcane plantations
	Tong 02	Sugarcane plantations
	Genaz 01	Urban formal
	Genaz 02	Sugarcane plantations
	Wewe 01	Urban formal
	Sweet 01	Urban formal/ sugarcane plantations
Mhlanga	Ohl 01	Urban formal
	Ohl 02	Sugarcane plantations
	Ohl 05	Urban formal
	Ohl 07	Sugarcane plantations
	Hloti 02	Sugarcane plantations
	Hloti 04	Urban formal/ sugarcane plantations
	Hloti 05	Urban formal
Mgeni	Palm 06	Industry/urban formal
	Gane 04	Urban formal
	Gane 05	Sugarcane plantations /industry
	Gane 18	Industry/urban formal
	Mgeni 08	Industry
	Mgeni 13	Urban formal
	Mgeni 70	Urban formal
	Mgeni 71	Industry
	Mgeni 91	Urban formal
	Mgeni 92	Industry
Durban Bay	Bilo 04	Urban formal
	Bilo 11	Urban formal
	Bilo 12	Urban formal
	Bilo 13	Industry
	Bilo 18	Urban formal
	Bilo 19	Urban formal
	Zana 04	Industry
	Zana 09	Industry
	Zana 10	Industry
	Zana 29	Urban formal
	Zana 30	Urban formal/industry
	Zana 60	Urban formal
	Zana 80	Industry
	Zana 81	Urban formal
	Baan 05	Urban formal
	Bell 09	Urban formal/urban informal
	May 14	Urban formal/urban informal

Mlazi	Mlaas 14 Mlaas 10 Mlaas 18 Mlaas 15 Mlaas 20 Chat 04 Chat 07 Chat 08 Chat 09 Chat 10 Chat 11 Chat 12 Nyama 03	Urban formal Urban mixed Urban mixed Urban formal Urban mixed Urban formal Urban formal Urban formal Urban formal Urban formal Urban formal Urban formal Industry
Mbokodweni	Mboko 01 Mboko 02 Mboko 03 Mboko 07	Urban mixed/industry Urban mixed/industry Urban mixed/industry Urban mixed/industry
Little Toti	Ltoti 04 Ltoti 05	Urban formal Urban formal

The above points were analysed to provide an indication of the averages for each of the catchments. These values are reflected in Figure 4.9. This provides an indication of the catchment exhibiting the highest average of water quality for *E. coli*. The Mlazi catchment reflects the highest average for *E. coli*.

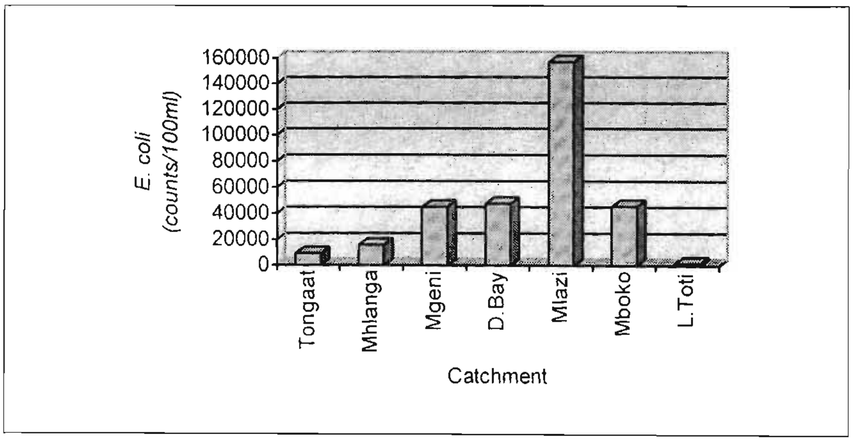


Figure 4.9. Average E. *coli* levels of points in the extreme category across catchments of the DMA

4.1.3. Problem points of the DMA

As indicated by Appendix 2, 65 of the 98 points reflected water quality in the extreme class for more than one water quality variable (phosphorus, *E.coli*, DO, turbidity). Figure 4.10 reflects those sample points with 3 or more variables in the extreme water quality class. The Little Toti, Lovu and uMgababa catchments have no sample points in this category. Both the Mhlanga and Mgeni catchments have a large number of sample points with extreme water quality for a combination of variables. The Tongaat, Durban Bay, Mlazi and Mbokodweni catchments all reflect sample points in this category but to a lesser degree in terms of numbers.

4.1.4. Population Density

Population density map (Figure 4.11), shows distinct concentrations in the DMA. With the exception of the Little Toti, Lovu and uMgababa catchments, the rest of the catchments showed patterns of moderate to very high levels of population density for the DMA.

4.2. Temporal Investigation

4.2.1. Rainfall

Rainfall stations for the DMA are reflected in Figure 3.6. The South African Weather Services does not have rainfall stations for the Tongaat, Mbokodweni, Little Toti, Lovu and uMgababa catchments. As such no temporal analysis has been undertaken for these catchments.

Figures 4.12 to 4.19 reflect the rainfall for the DMA for the year 1998 for each of the rainfall stations. In general, there appears to be a gradual increase in rainfall from the months of September through to January. Rainfall steadily decreases from the months of February through to July. Rainfall peaks for most of the stations in the month of February. These rainfall patterns were used as the basis for comparison against the monthly data for each parameter for the average value for the points

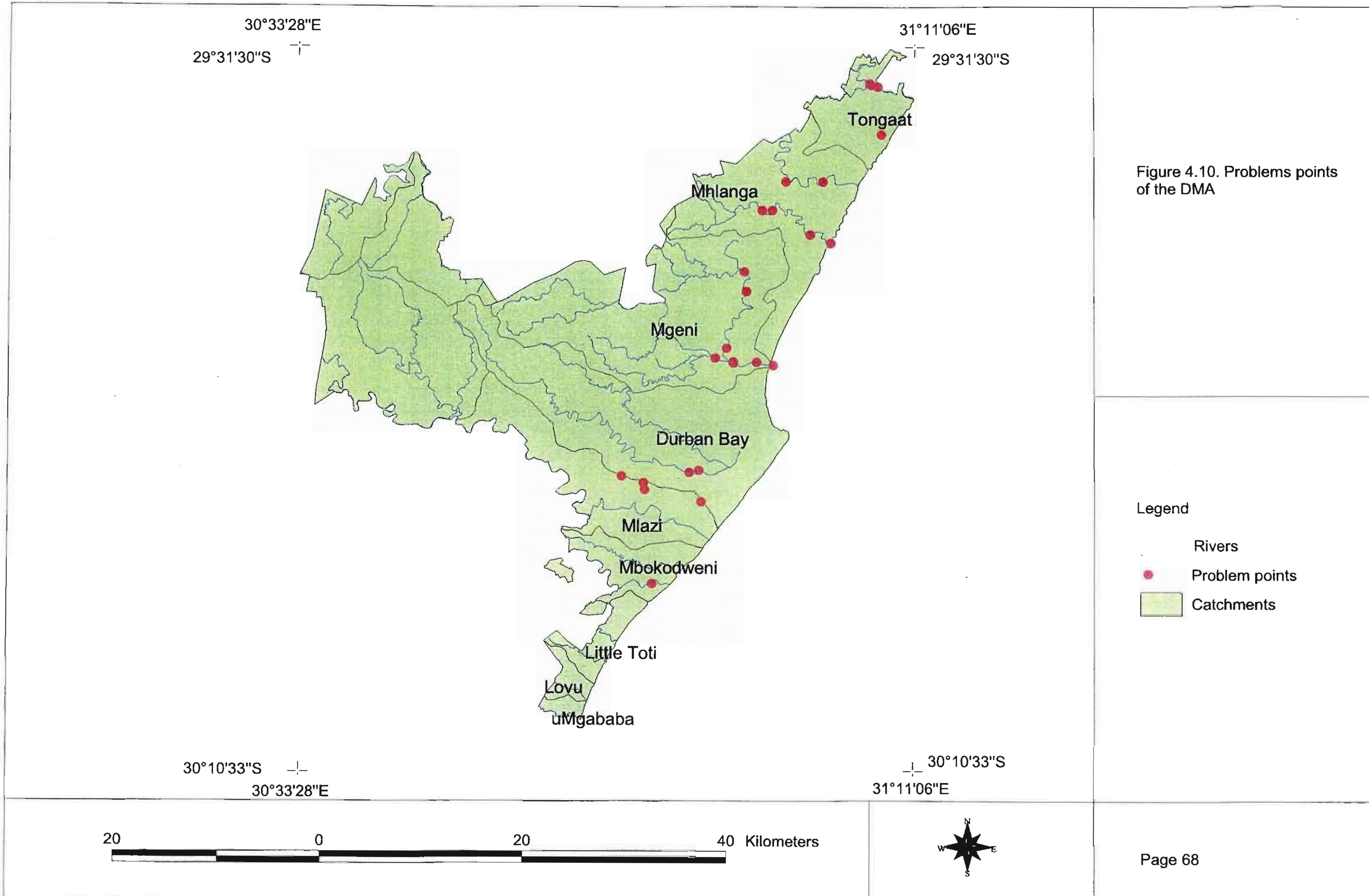


Figure 4.10. Problems points of the DMA

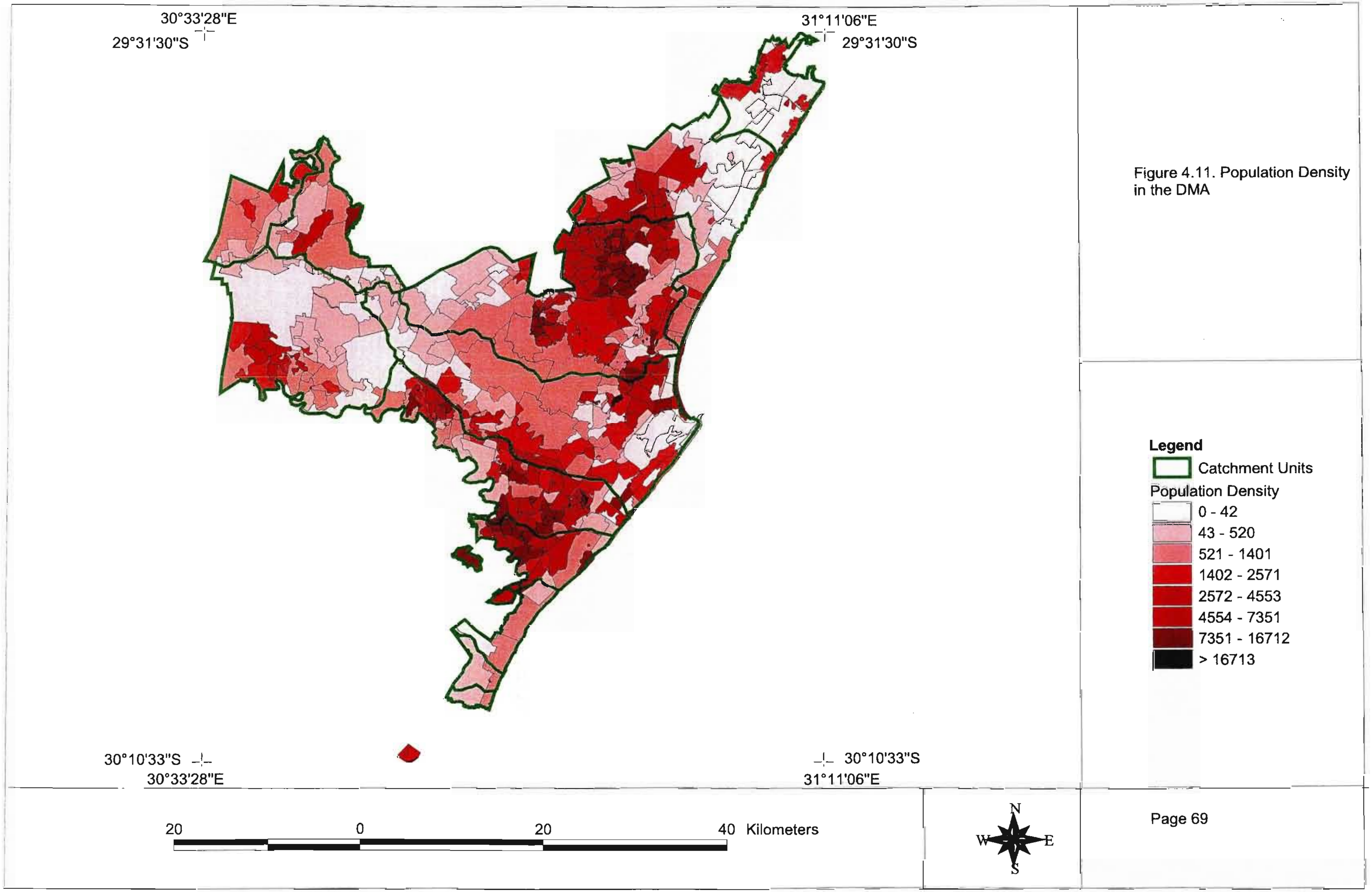


Figure 4.11. Population Density in the DMA

within the extreme category for the selected catchments (those with rainfall stations present).

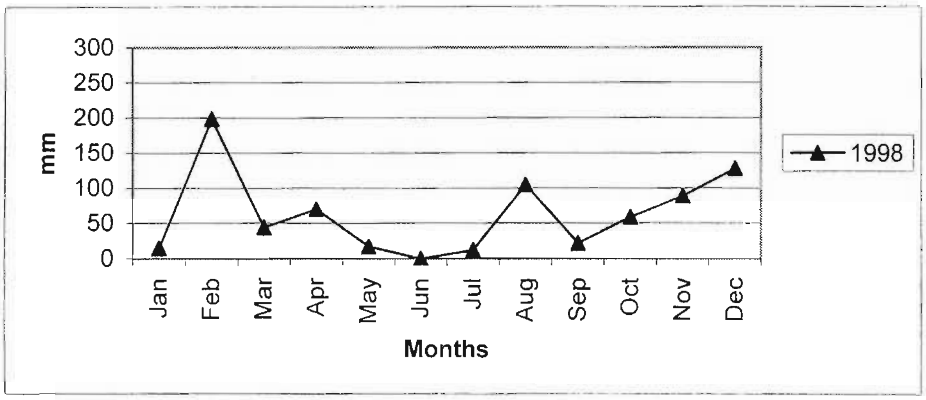


Figure 4.12. Rainfall at Blackburn station (Mhlanga catchment)

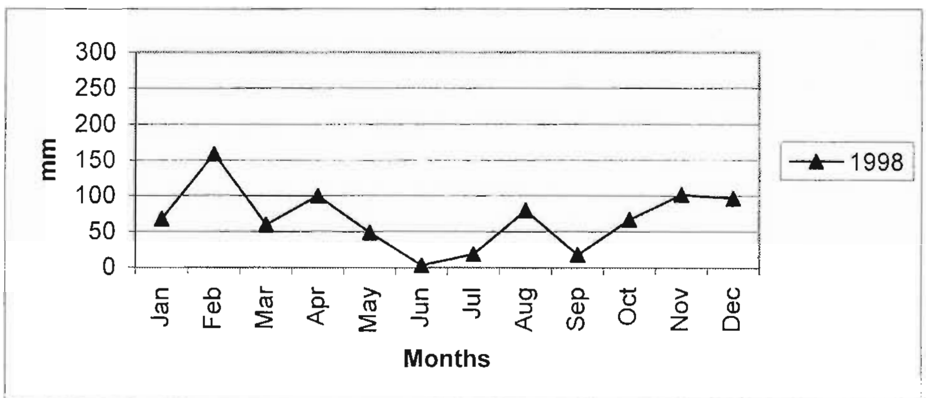


Figure 4.13. Rainfall at Virginia station (Mhlanga catchment)

The rainfall patterns for the year 1998 for the stations in the Mhlanga catchment were very similar with the highest rainfall in February and the lowest rainfall in June.

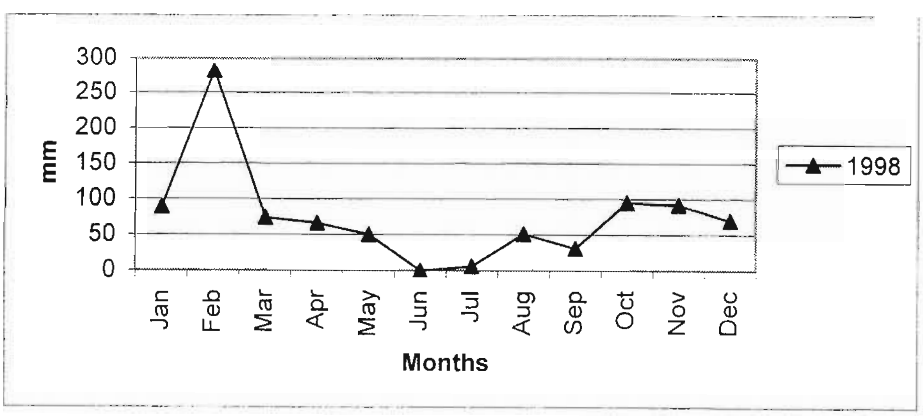


Figure 4.14. Rainfall at Kloof Station (Mgeni catchment)

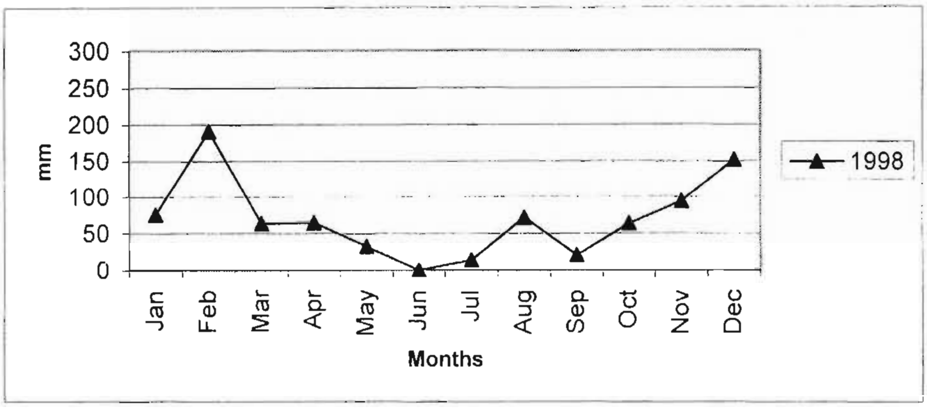


Figure 4.15. Rainfall at Mt. Edgecombe Station (Mgeni catchment)

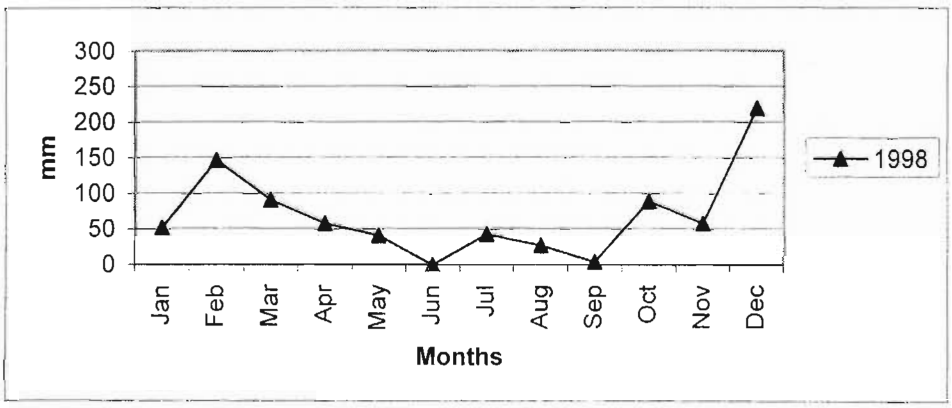


Figure 4.16. Rainfall at Durban Heights Station (Mgeni catchment)

The rainfall patterns for the year 1998 for the stations in the Mgeni catchment were very similar with rainfall peaks in February and a decline in rainfall from the months of March to June with the lowest rainfall occurring in the month of June.

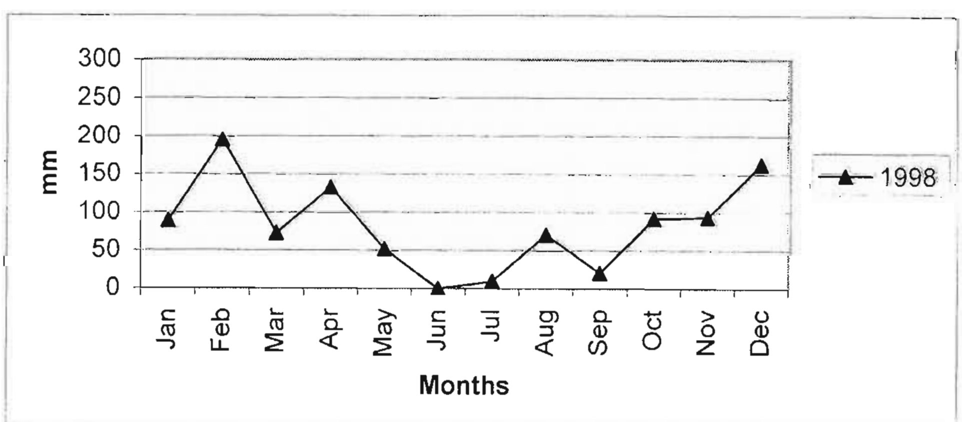


Figure 4.17. Rainfall at Kenneth Steinbank (Durban Bay catchment)

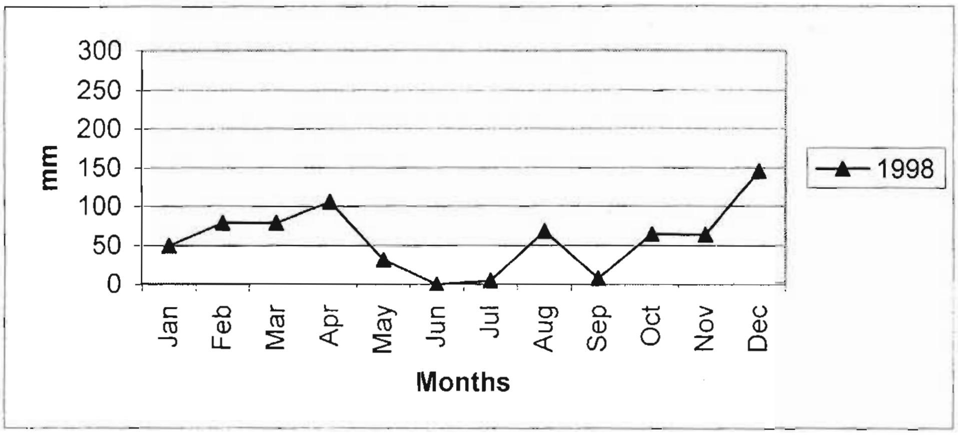


Figure 4.18. Rainfall at Botanical gardens (Durban Bay catchment)

The rainfall patterns for the year 1998 for the stations in the Durban Bay catchment showed similar trends with rainfall decline in the winter months and a general increase during the summer months.

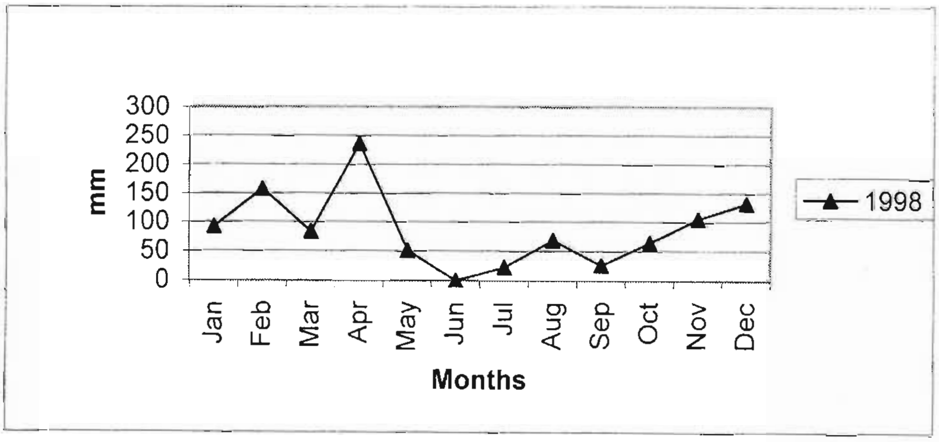


Figure 4.19. Rainfall at Durban Weather Station (Mlazi catchment)

The rainfall pattern for the year 1998 for the only station in the Mlazi catchment showed similar trends with rainfall decline in the winter months and a general increase during the summer months.

4.2.2. Water Quality Classes

4.2.2.1 Dissolved Oxygen

For the points selected (those representing the extreme water quality for DO-Table 4.2), the average was calculated for each month and then plotted as a single graph representing the averages for each catchment for the extreme water quality category.

It is evident from Figures 4.20 to 4.23, that for the catchments (Mhlanga, Mgeni, Durban Bay and Mlazi), there appears to be a gradual increase in DO levels during the winter months. In addition, the peaks for DO levels across the catchments occurs in winter between June and July.

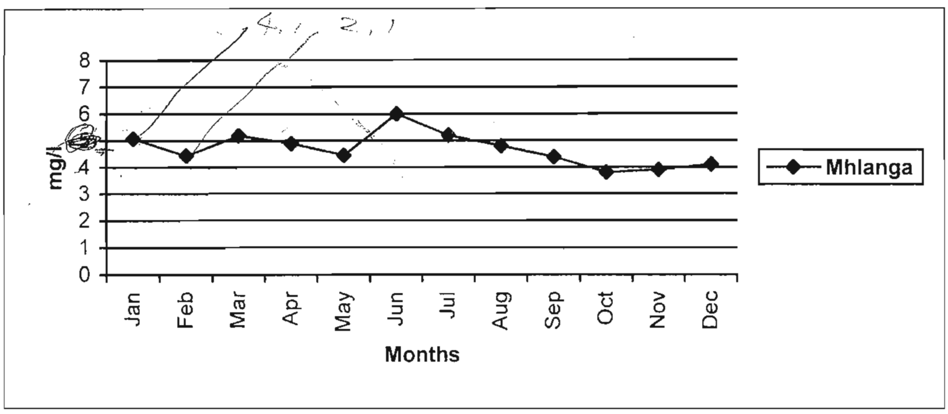


Figure 4.20. Average DO for Mhlanga Catchment

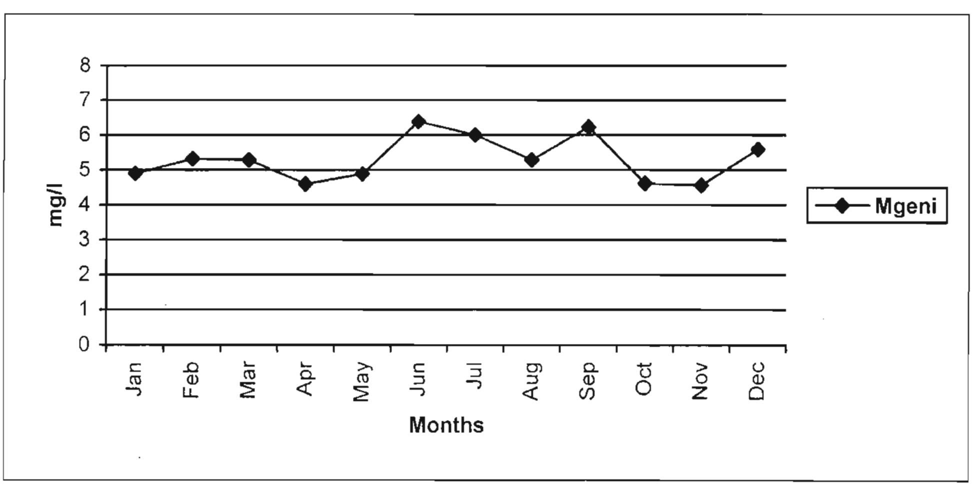


Figure 4.21. Average DO for Mgeni Catchment

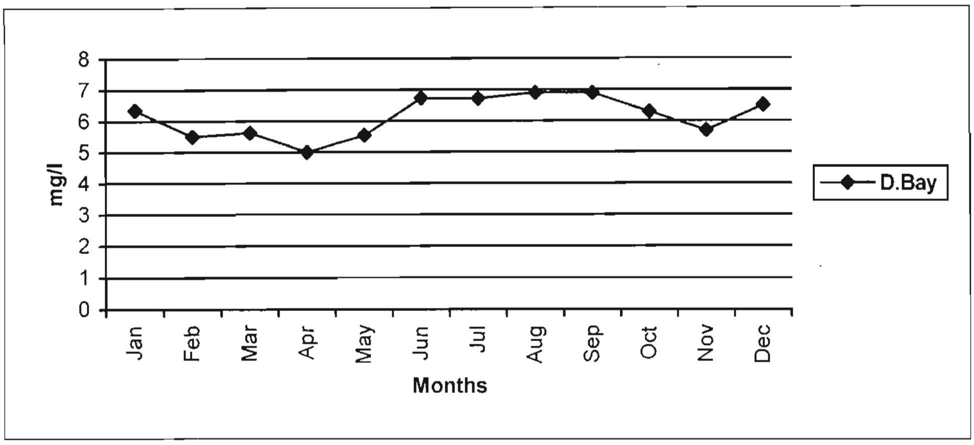


Figure 4.22. Average DO for Durban Bay Catchment

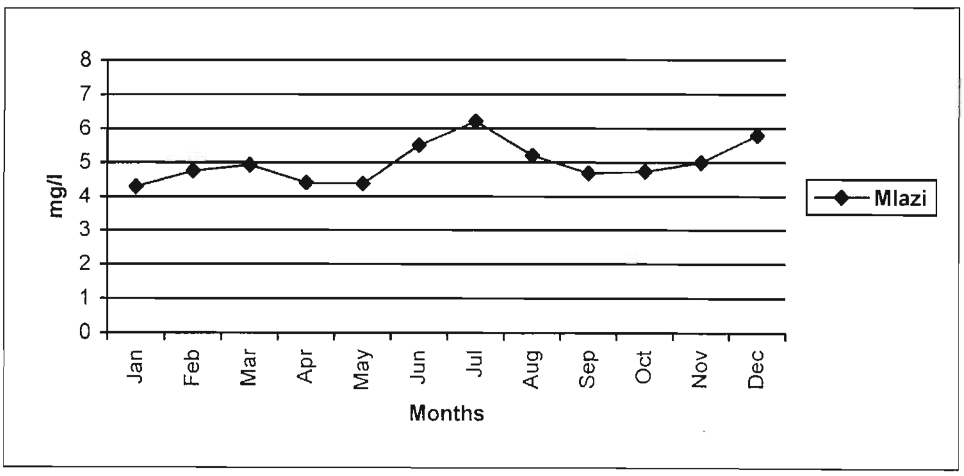


Figure 4.23. Average DO for Mlazi Catchment

4.2.2.2. Turbidity

Figures 4.24. to 4.27., do not indicate any distinct trend with regard to the turbidity levels during the year between catchments.

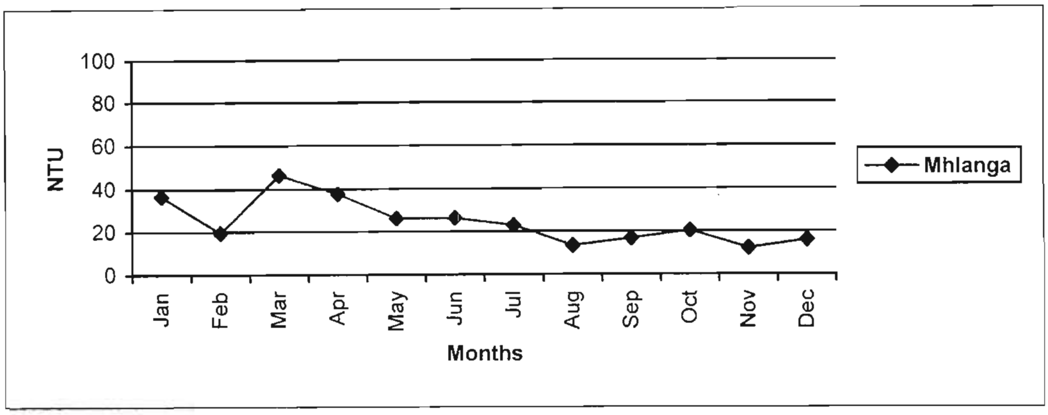


Figure 4.24. Average turbidity for Mhlanga catchment

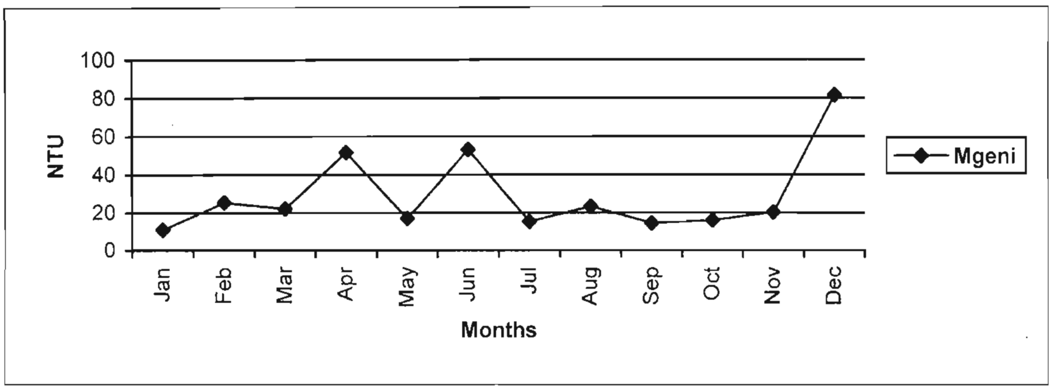


Figure 4.25. Average turbidity for Mgeni catchment

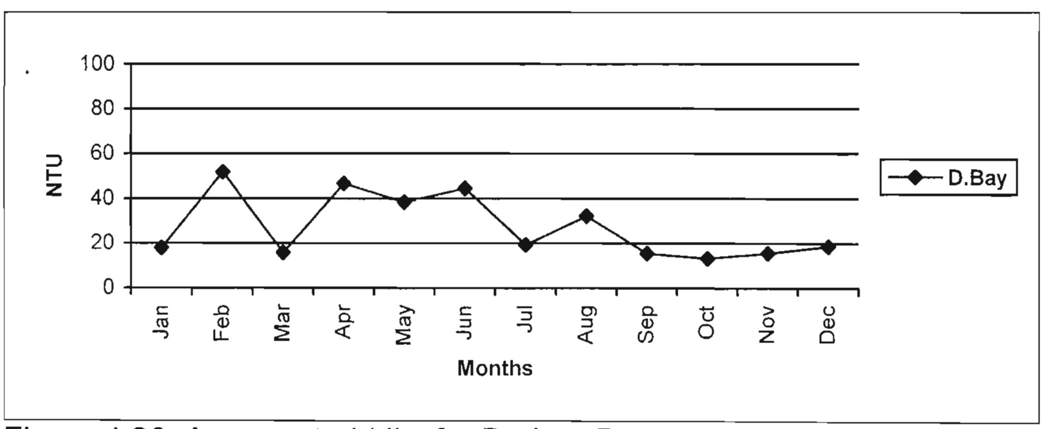


Figure 4.26. Average turbidity for Durban Bay catchment

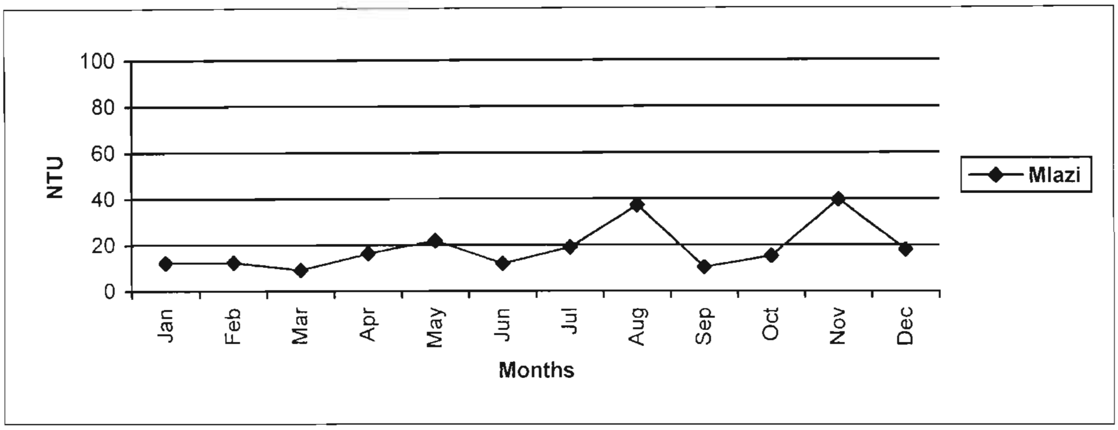


Figure 4.27. Average turbidity for Mlazi catchment

4.2.2.3. Phosphorus

Phosphorus levels for all the catchments investigated (Figures 4.28 to 4.31) show increased levels of phosphorus during the months June to July with declines in December.

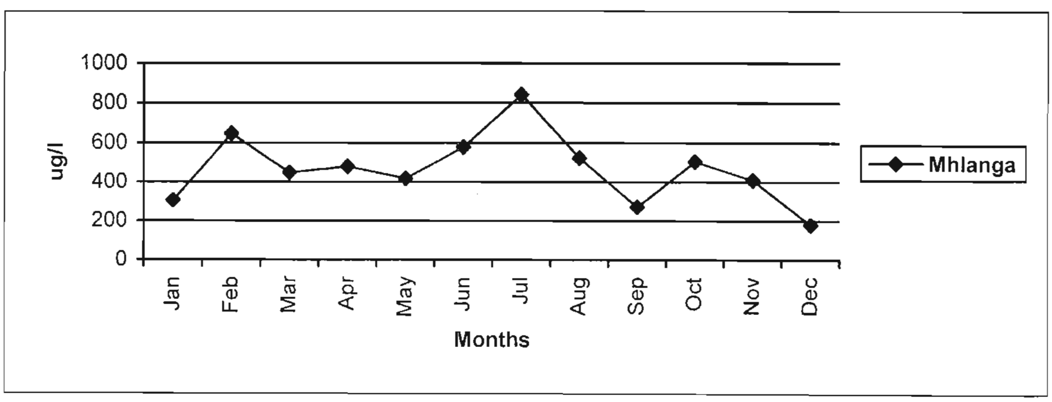


Figure 4.28. Average phosphorus for the Mhlanga Catchment

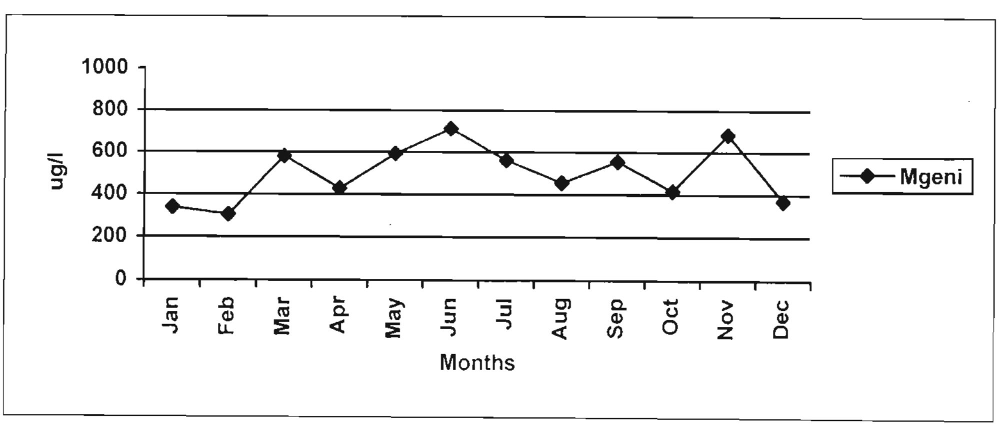


Figure 4.29. Average phosphorus for the Mgeni Catchment

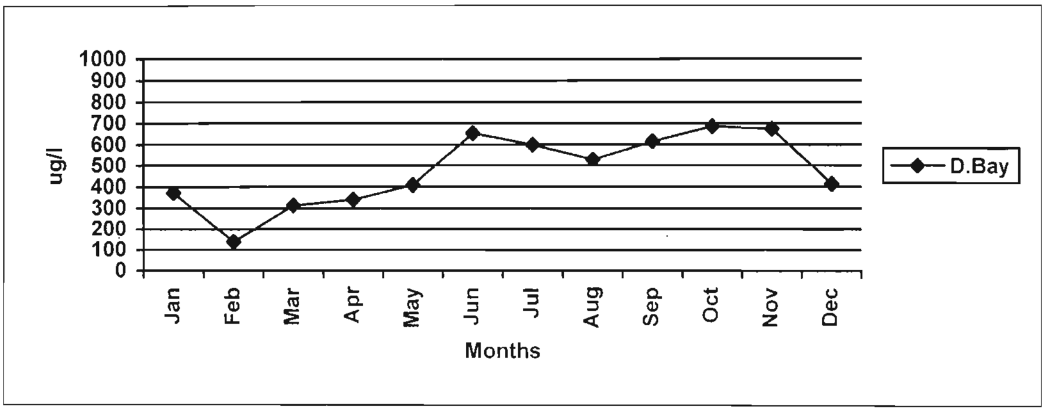


Figure 4.30. Average phosphorus for the Durban Bay Catchment

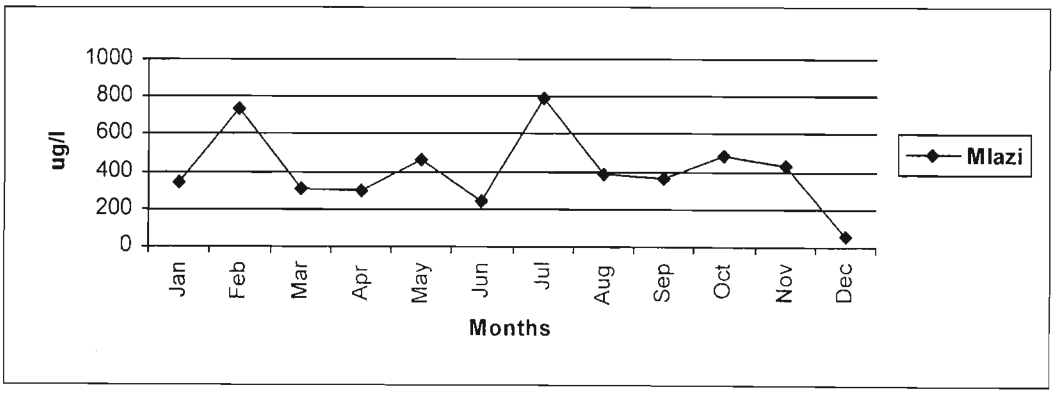


Figure 4.31. Average phosphorus for the Mlazi Catchment

4.2.2.4. *E. coli*

With the exception of the Mhlanga catchment the levels of *E. coli* were low during the months of June and July. It has been difficult to ascertain a temporal trend with regards to *E. coli* levels (Figures 4.32 to 4.35.) with each catchment exhibiting its own distinct pattern during the various months of the year.

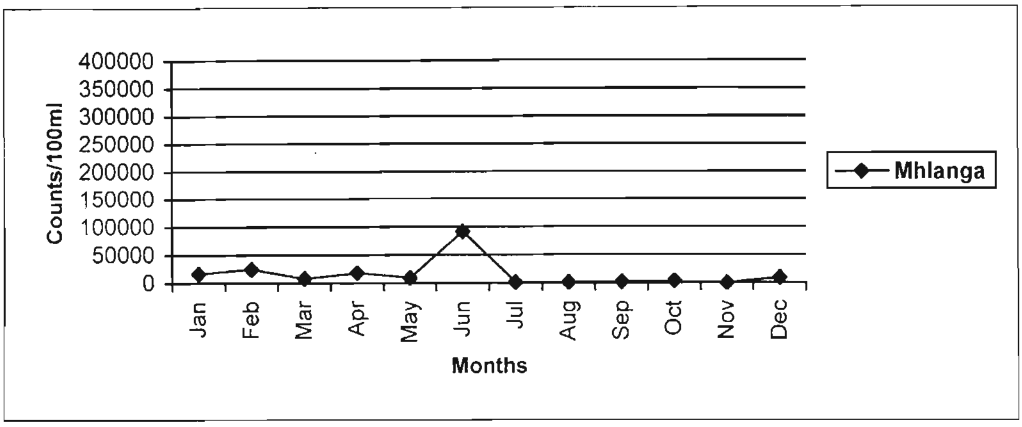


Figure 4.32. Average *E.coli* for the Mhlanga Catchment

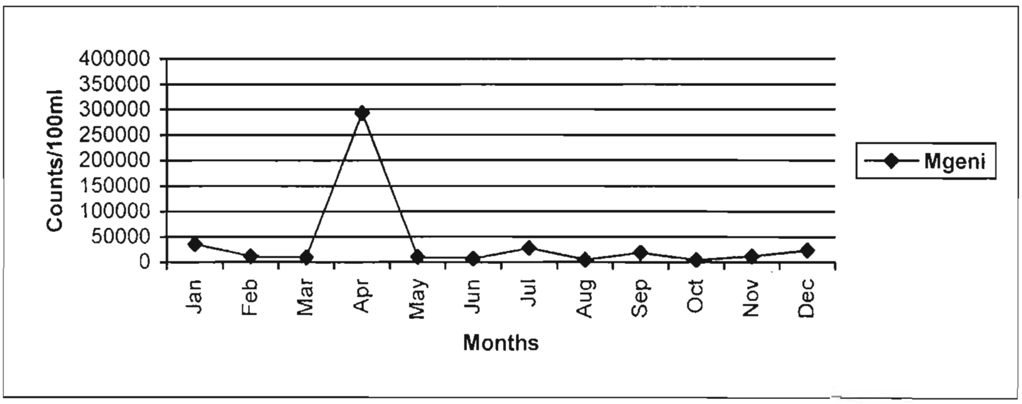


Figure 4.33. Average *E.coli* for the Mgeni Catchment

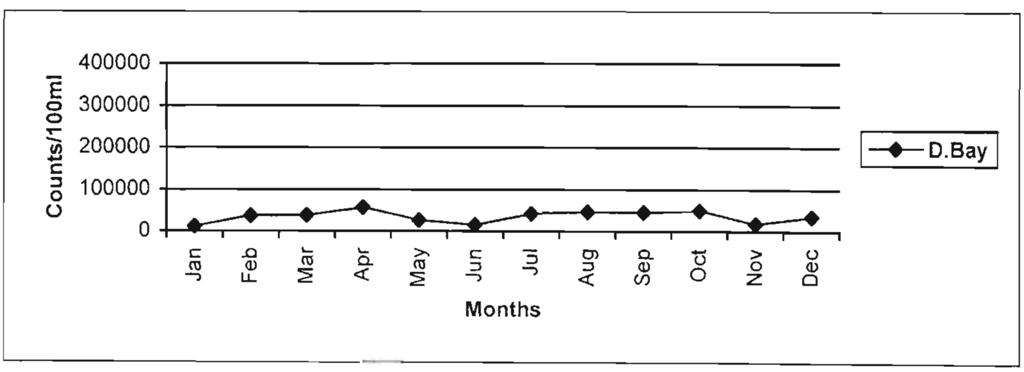


Figure 4.34. Average *E.coli* for the Durban Bay Catchment

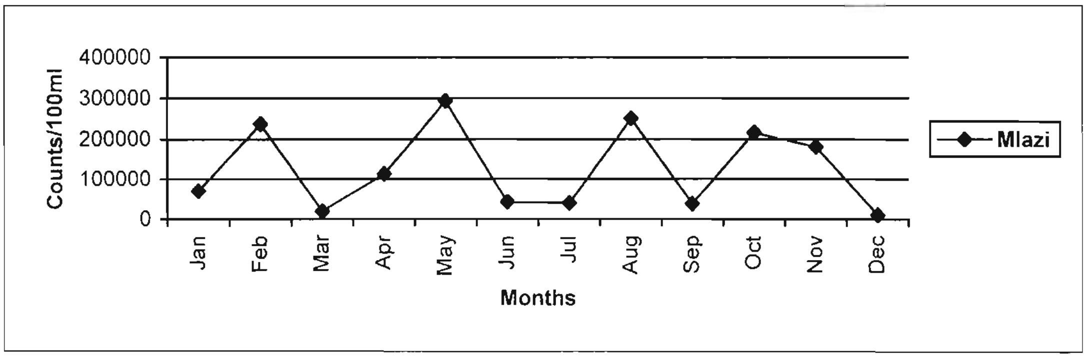


Figure 4.35. Average *E.coli* for the Mlazi Catchment

Chapter 5. Discussion

5.1. Spatial Investigation

5.1.1. Landuse

Landuse practices have a strong influence on the quantity and quality of water in streams and rivers throughout catchments (Mitchell and Stapp, 1990). Although this has been used as indicative of the problems contributing to poor water quality, the temporal factor is also examined later.

5.1.2. Water Quality Classes

5.1.2.1. Dissolved Oxygen

The main factor resulting in the DO concentrations decreasing is the build-up of organic wastes in water bodies. Organic wastes may take the form of sewage, urban and agricultural runoff and discharge from industry (Mitchell and Stapp, 1990). Decreased DO levels are a direct result of increased microbial activity during the degradation of organic matter (Chapman and Kimstach, 1992).

A significant part of urban and agricultural runoff comes from fertilizers, which stimulate extensive growth of algae and other aquatic plants. However, this sort of increase in plant growth consequently leads to an increase in plant decay. Decaying aquatic plants and the bacteria that feed on this organic waste demands oxygen during the process of decomposition (Mitchell and Stapp, 1990).

The predominant land use of sugarcane plantations in the Tongaat and urban mixed in the Mlazi catchments possibly contributes greatly to nutrient run-offs (as a source of non-point pollution), which results in decreased DO levels. Such nutrients may be present in agricultural fertilizers used.

The Mgeni, Mhlanga, Mlazi and Mbokodweni catchments with their highly urbanized landuse, contributes to the decrease in DO levels, probably through sewage discharge. The Little Toti catchment has predominant landuses of sugarcane plantations and urban formal, which will affect DO through agricultural runoffs and sewage discharges.

Results from the analysis of points in the extreme category of water quality showed the predominant land use classes to be those of sugarcane plantations, urban formal and to a lesser degree that of urban informal, urban mixed and industry. The lowest averages were evident for both the Tongaat and Mlazi catchments, which have the predominant land use as sugarcane plantations and urban mixed respectively. This reiterates that the excessively low DO values for these points may have been a result of wastes and runoffs loaded with fertilizers from sugarcane plantations, sewage as well as discharges from industry.

The trends for levels of DO reveal that the intensity of the problem appears to be severe in catchments boasting densely populated areas (Figure 4.11). Zayed *et al* (1995) showed that DO levels were influenced by industrial and human activity along river courses. In keeping with the findings of the study conducted by Zayed *et al*, (1995), in which there was also a spatial variation of DO this study reveals similar trends.

DO does not feature as a variable for the summary of water quality guidelines for domestic use, and as a result will have very little impact for this use. However, DO as discussed earlier (in chapter 2) is essential for the survival of aquatic plant and animal life. Overall these water bodies, which reflect low levels of DO do not bode well as survival habitats for aquatic organisms.

As a management mechanism, an ICM approach should be adopted to alleviate the problem of DO. Proper control over the catchments in terms of stricter regulation of discharges of effluents into river courses needs to be undertaken. However, acceptable levels will only be maintained if regular monitoring is carried out both of the river systems as well as the monitoring of the composition of discharges by industries, as well as sewage treatment works. In addition, the low levels of sanitation facilities in certain areas of the DMA need rapid improvement to assist in the alleviation of poor water quality.

5.1.2.2. Turbidity

Turbidity of rivers is influenced and affected by human activities, such as agriculture, domestic sewage wastes and industrial wastewater discharges (Meybeck *et al*, 1992). Ghambi and Mzumara (1998), have shown in a water quality study, that high levels of turbidity were due to runoffs from agricultural fields, grazing areas as well as domestic discharges. In addition, Howard and Pillay, (1998), have attributed turbidity increase to poor land practices that are present.

Both the Tongaat and Mhlanga catchments, which show turbidity problems (Figure 4.3.), have sugarcane plantations as the major landuse class. Runoffs from sugarcane plantations, are possibly contributing factors to the increased levels of turbidity in these catchments.

The Mgeni and Durban catchments have the predominant landuse class of urban formal. It is therefore not surprising that these heavily urbanized catchments contribute greatly to the high turbidity levels here. The urban mixed landuse in both the Mlazi and Mbokodweni catchments, perhaps plays a vital role in the high levels of turbidity. In addition, industrial discharges may also be a contributing factor. Sewage discharges in the form of treated wastewaters in all of the catchments may also be a contributing factor. Although there is monitoring of these discharged waters, leaks in pipes may contribute towards this.

In addition, slope, affects runoff rates which also contribute to increased loads of pollutants and sediments that foul up water quality downstream and increases turbidity.

Results from the analysis of points in the extreme category of water quality (Table 4.3.), showed the predominant land use classes to be those of urban formal and industry and to a lesser degree that of sugarcane plantations and urban mixed. The highest average was evident for the Mgeni catchment, which has the predominant land use of urban formal. These catchments represent the urbanized and industrialized zones of the DMA. Increased industrial and domestic discharges, together with high runoffs from the urban sectors would increase turbidity.

Turbidity features as a variable for the summary of water quality guidelines for domestic use, and as a result will impact on this use, especially in those areas that lack access to reticulated water. The water quality guidelines for domestic use suggests that the class for turbidity between 0-5 NTU is acceptable and requires no treatment. Those that fall in the range above 30 NTU will require some form of treatment for domestic use. Another threat that may be posed by increased levels of turbidity for domestic use, is that micro-organisms are often associated with turbidity, hence the low levels of turbidity will minimize the potential for transmission of infectious diseases (DWAF, 1993a).

The results of turbidity indicate no water quality falling into the excellent range, which implies not only a major problem for recreational activities but also impact on those communities that rely on this water source for their daily consumption. Ideally, recreational waters should have a low turbidity, which encourages the use of the water body for swimming and other water contact sports.

As a management mechanism, an ICM approach should be adopted to facilitate the improvement of water quality with regard to improvements in the turbidity levels. Local authorities in addition to reinforcing strict compliance for effluent discharge should also work with other sectors such as tourism to ensure that these water bodies are maintained at a level suitable for recreational use. The financial opportunity in the use of a water body must also be taken into consideration and as such this is an opportunity for stakeholders to actively be involved to ensure that benefits of such a resource is properly harnessed.

5.1.2.3. pH

The contribution of pH to changes in water quality in this study is minimal. This is a positive aspect of the water quality in the DMA. As indicated by table 2.1., inorganic chemicals, such as acids and heavy metals, generally lead to pH changes. Sources of these include mining and industrial effluents. Within the study area, there are no mining activities that may have an impact, and although there may be industrial effluents, their impact in this regard is minimal.

Water quality for domestic use (Department of Water Affairs and Forestry, 1993a), suggests the range of 6-9 units as acceptable. The water quality for this study is predominantly in this category and therefore will not have any negative impacts on this use.

5.1.2.4. Phosphorus

Pillay and Howard, (1998), have shown that the poor water quality with regard to phosphorus may be attributable to wastewater discharges. Phosphorus sources include human and industrial wastes and inadequately treated sewage from wastewater plants. Fertilizers containing phosphorus result in nutrient enrichment of water bodies as a result of run-off (Mitchell and Stapp, 1990).

Fertilizers used in the sugarcane plantations in the Tongaat and Mhlanga catchments are most likely to contribute nutrients by run-off and thus cause the eutrophic and hypertrophic conditions present. For the rest of the catchments, the possible problem may be with wastewater discharges and run-off by the urban sectors of the population. Wastewaters high in detergents containing phosphorus, and sewage elevate the phosphorus levels.

Results from the analysis of points in the extreme category of water quality (hypertrophic) showed the predominant land use classes to be a mixture of urban formal, industry, and to a lesser degree that of urban mixed and sugarcane plantations. The highest average is reflected by the Mbokodweni catchment, which has the predominant land use of urban mixed. Increased runoffs from agricultural fertilizers, as well as industrial and domestic discharges all play a role in the increased levels of phosphorus present in these systems.

Phosphorus does not feature as a parameter for the summary of water quality guidelines for domestic use, (DWAF, 1993a) and as a result will have very little impact for this use. However, it is crucial in limiting the growth of nuisance conditions (such as severe algal growth) in river systems. This study reveals that all systems either exhibit eutrophic or hypertrophic conditions, which not only impacts on the recreational user, but also inhibits species diversity within the system. There is a trend visible in that there are no sample points that exhibit an oligotrophic condition of water quality, implying that there is a major problem with regards to nutrient enrichment of the waters of the DMA.

As a management mechanism, an ICM approach should be adopted to deal with the problem of high phosphorus levels in the rivers of the DMA. The problem of nutrient enrichment is caused by numerous factors ranging from run-offs from settlements, effluent discharges as well as agricultural run-offs. The magnitude of the problem indicates that it would take concerted effort and planning within all sectors to ensure that levels of phosphorus are reduced significantly.

5.1.2.5. *E. coli*

The increased population densities and the emergence of squatter settlements in previously vacant plots has resulted in an increase in the amount of raw sewage, for which no facilities have been provided. The treatment of sewage by the DWWM is carefully monitored to ensure that it complies with the set standards at the time of release. However, throughout the DMA, the DWWM has to deal with the problems of blocked sewer pipes and breakages (Jackson, 1998). This impacts greatly on the quality of the receiving water bodies.

Adequate water and sanitation supply is essential for the health and well-being of individuals and communities. These services have major impacts on natural systems through extraction, water supply and waste disposal systems. At present 40 percent of potential users in the DMA have access to only minimal water supplies and 38 percent of households have minimal or no access to sanitation. This sector impacts on water quality due largely to inadequate sanitation provision in informal settlements (Hindson *et al*, 1996).

In some of the formal settlements, the available facilities were not planned to deal with the vast amounts of raw sewage they are currently presented with, and the systems are subjected to overloading and failure (Hindson *et al*, 1996).

Studies conducted by Pillay and Howard (1998), revealed that high *E. coli* levels were attributed to wastewater discharges, raw sewage from broken and blocked sewers and runoff from informal settlements.

The water quality in terms of *E. coli* across all the catchments (Figure 4.8.), indicates that all points fall into the category of poor. This tendency reflects on the magnitude of the problem that the DMA faces with respect to *E. coli* levels in its waters. A combination of factors probably attributes to the excessively high levels of *E. coli* in the DMA. These include the inadequate sanitation facilities that are present in certain areas, the discharge of effluents through treatment works as well as broken pipes with sewage.

Results from the analysis of points in the extreme category of water quality showed the predominant land use classes to be those of urban formal and urban mixed and to a lesser degree that of urban informal, industry and sugar cane. The highest average was evident for the Mlazi catchment, which has the predominant land use shared between urban formal and urban mixed. It is not surprising that this catchment with a large percentage urban mixed and urban informal and a high population density (Figure 4.11), will have high *E. coli* levels.

E.coli poses a risk to any participants of recreational activities in these waters through the transmission of various enteric diseases, including cholera, typhoid fever, salmonellosis, bacillary dysentery, viral gastroenteritis and hepatitis A. Epidemiological studies conducted indicate that levels of *E. coli* in fresh water show high correlation with the occurrence of swimming related gastric illness (DWAF, 1996c). The water quality with regard to *E. coli* within the DMA is very high and this will impact negatively on the users of these water bodies.

E. coli features as one of the variables for water quality guidelines for domestic use. Direct ingestion of such polluted water may seriously impact on the users in the transmission of enteric diseases as discussed above. The presence of *E. coli* in all the catchments of the DMA poses a serious risk of transmission of these diseases to local communities dependant on these waters for their daily use.

As a management mechanism, proper control over the catchments in terms of stricter regulation of discharges of effluents into river courses needs to be undertaken. However, acceptable levels will only be maintained if regular monitoring is carried out both of the river systems as well as the monitoring of the composition of discharges by industries, as well as sewage treatment works. In addition, the low levels of sanitation facilities in certain areas of the DMA need rapid improvement to assist in the alleviation of poor water quality.

This study is based on the assumption that landuse in which the point lies is the contributing factor towards the water quality of that point. However, in order to determine accurately the contributing factors to poor water quality in terms of landuse is to determine the catchment of each point. This study has examined water quality in order to provide a broad overview and therefore lacks that detail.

5.1.3. Problem points of the DMA

As indicated by Appendix 2, 65 of the 98 points reflected water quality in the extreme class for more than one water quality variable (phosphorus, *E.coli*, DO, turbidity). This is a reflection of the status of the water quality for the DMA. Landuse factors within the DMA contribute largely to this. Both the Mhlanga and Mgeni catchments have a large number of sample points with extreme water quality for a combination of variables. These catchments with the respective predominant landuse of sugar cane and urban formal contribute to the above. The Tongaat, Durban Bay, Mlazi and Mbokodweni catchments all reflect sample points in this category but to a lesser degree in terms of numbers. However, these highly urbanized catchments contribute to the problem of poor quality.

A combination of poor water quality for a multitude of variables results in an increase in the intensity of the problem. For example, rate of die-off or disappearance of bacteria after discharge into water is influenced by numerous physical, physiochemical and biochemical factors. These include sunlight, temperature, pH, salinity, nutrient deficiencies, particulate suspension, etc. In combination, extremes of pH, elevated temperatures promote microbial decay, while elevated nutrient concentrations and lower temperatures promote microbial survival (DWAF, 1993a).

5.1.4. Population Density

The population density map (Figure 4.11.), shows distinct concentrations in the DMA. This is generally for areas that have urban formal and urban informal areas. Poor planning facilities have resulted in these areas being densely populated, and as a result have impacted negatively on water quality for many of the parameters investigated. It is a recognized fact that water quality problems tend to be worse near large underserviced communities that use water directly from rivers. Dense human settlements produce large quantities of waste, which if left unchecked pollute rivers and streams. Settlement around large cities is generally uncontrolled, and thus great numbers of South Africans live in large, densely populated settlements with poor services (DWAF, 1998).

Waste that accumulates in the settlements can also be carried into nearby surface and ground waters, and water resources near densely populated, poorly serviced, settlements are often severely polluted. Pollution from densely populated, and inadequately serviced, settlements also impairs the use of downstream water resources for a variety of other users. Pollution from these settlements increases the health risks for recreational users of water bodies, increases the risks for livestock, and impairs use of the water for irrigation purposes. The natural functioning of the water environment, on which all humans ultimately depend, is also severely impaired by pollution from poorly serviced settlements. River systems downstream of these settlements lose some of their natural ability to assimilate wastes, and are typified by a lower biodiversity (DWAF, 1999).

A number of water quality problems are associated with dense settlements. The most important of these are: -

- *Microbiological contamination* by faecal pathogens, which has severe health implications for water users and the community. These mostly come from human excreta, and dirty washing water (grey water). However, high concentrations of faecal bacteria may be found in stormwater runoff, and in livestock faeces.

- *Nutrients,* mainly phosphorus and nitrogen, which cause eutrophication and increase the costs of treating water to potable standards. These mostly come from human excreta and grey water, but may also be present in high concentrations in the stormwater runoff.
- *Solid waste (litter)* from public spaces and from household refuse, which causes ecological, aesthetic and health problems, and affects the functioning of stormwater and sewage services.
- *Sediments* from unpaved areas in the settlements, which accumulate in rivers and dams, affect aquatic habitats, and reduce storage of stormwater run-off.
- *Habitat destruction* mostly by building in the riparian zone, which affects the natural functioning of river ecosystems, and allows waste to get into the rivers " (Department of Water Affairs and Forestry, 1999).

5.2. Temporal Investigation

5.2.1. Rainfall

Seasonal variation in water quality is a common, natural phenomenon. The most important factor governing the seasonality of water quality is the cyclical nature of climatic changes (Demayo, 1992).

The DMA exhibits a strong seasonal rainfall pattern (Archibald, 1995). The region has a summer rainfall regime, receiving most of its rainfall during the months of October to March (Swart, 1998).

Rainfall patterns throughout the selected stations (Figures 4.12 to 4.19) indicate a general trend, with increased rainfall occurring predominantly during the summer months and decreased rainfall during the winter months.

5.2.2. Water Quality Classes

5.2.2.1. Dissolved Oxygen

The highest DO levels for the Mhlanga catchment (Figure 4.20.) occurred in the month of June. The rainfall stations in this catchment (Figures 4.12. and 4.13.) recorded the lowest levels of rainfall during the month of June.

The highest DO values as indicated by Figure 4.21. for the Mgeni catchment occurred in the months of June and September. All rainfall stations for the Mgeni catchment (Figures 4.14 to 4.16.) show a decreased rainfall for the months of June and September.

A similar trend is evident for the Durban Bay catchment, where increased levels of DO were visible during June, July and September (Figure 4.22) and both rainfall stations (Figures 4.17. to 4.18.) for this catchment showed very low rainfall for this period. For the Mlazi catchment (Figure 4.19) the lowest rainfalls occurred in the month of June and July, and corresponding high DO levels were evident for the same period for this catchment (Figure 4.23.).

The gradual increase in DO levels during the winter months as indicated by figures 4.20. to 4.23 can probably be attributed to the fact that rainfall is low during the winter months (as indicated by the rainfall for the respective stations) therefore, no large amounts of run-offs are experienced and the water quality is not as poorly impacted on as in summer.

The lower DO levels of the summer months may be attributed to increased rainfall, which is most likely to carry with it an increased runoff of contaminants and thus affect the DO levels.

5.2.2.2. Turbidity

Turbidity levels may increase, due to natural phenomena such as floods (Friedrich *et al*, 1992). Variations in turbidity occur as a result of heavy rainfalls (Chapman and Kimstach, 1992).

For the Mhlanga and Mlazi catchments (Figures 4.24 and 4.27.) there is a general decrease in turbidity levels during the winter months. The rainfall stations for both these catchments (Figures 4.12, 4.13. and 4.19.) exhibit decreased levels of rainfall.

This general decrease in turbidity for the above catchments during the winter months may be attributed to the decreased rainfall and consequently decreased run-off loads into the receiving water bodies. Increased turbidity levels during the summer months may be attributed to the increased rainfall and the associated increased run-offs.

However, for the Mgeni and Durban Bay catchments there is no clear trend with regard to the corresponding rainfall patterns. However, this is probably due to the fact that other spatial factors may be contributing to the increased levels of turbidity.

5.2.2.3. Phosphorus

Phosphorus levels for all catchments (Figures 4.28. to 4.31.) show increased levels during the winter months. However, rainfall patterns during the winter months are low. As a result increased levels of phosphorus cannot be attributed to increased run-offs as a result of increased rainfalls. However, the increased levels may be attributable to other point sources of pollution such as industry.

5.2.2.4. *E. coli*

Many of the informal settlements have sanitation systems, which consist of inadequately constructed pit latrines. During periods of rain sewage from these latrines may contaminate groundwater and the river systems (Hindson *et al*, 1996).

It has been difficult to ascertain a temporal trend with regards to *E. coli* levels (Figures 4.32 to 4.35). However, there are distinctly extraordinarily high levels for some months, which could possibly be attributed to breakages in sewer pipes or blocked sewers.

It is apparent that temporally, not all parameters exhibit trends. However, turbidity and DO show some influence by rainfall patterns. However, due to the extremity of the problem of water quality within the DMA, it is also very difficult to establish if rainfall patterns influence some of the variables.

5.3. Integrated Catchment Management

It is evident from the discussion that landuse plays a very large part in the contribution to polluted rivers within the DMA. The predominant landuse types ranging from urban formal, urban informal to sugar cane all contribute to this.

ICM proposes that all elements of the physical catchment must be addressed in order to produce improved water quality. As such the causes of poor water quality must be addressed. For the DMA, these point to the landuse types. However, the problem has various facets in that it involves all sectors to work together in order to improve water quality.

For example, the biggest problem is that of settlements with high density. The poor operation, maintenance and use of services is the biggest cause of water quality problems, particularly in urban or peri-urban settlements. This is largely a function of the social and institutional conditions in these settlements. The key to sustainable management of pollution from settlements lies in addressing the *physical* causes of water quality problems, as well as the institutional and social problems underlying the poor operation and maintenance of the services (Department of Water Affairs and Forestry, 1999).

For each contributing factor to poor water quality, there needs to be a plan of action that should involve the various stakeholders to co-operative to bring about a significant reduction in the problem. It is the principle of co-operate by the various stakeholders, ranging from institutional to social through their various contributions that can result in improved water quality.

Chapter 6. Conclusions and Recommendations

It is a fundamental principle that we are living at the mercy of the water cycle (Falkenmark, 1999). As such the need is urgent to maintain water quality and ensure the proper use of it at all levels.

It is evident that there are numerous water quality problems within the catchments of the DMA. With the exception of pH, the water quality parameters of DO, turbidity, phosphorus and *E. coli* all exhibit varying levels of poor water quality within the DMA. It is the dominant landuse in those catchments that impact adversely on the water quality. Problems of poor water quality are exacerbated in catchments by landuse types such as sugar cane plantations, urban formal and urban informal settlements.

However, the most severe water quality issue within the DMA, that requires urgent addressing is that of *E. coli* . In addition, to impacting on river systems, people living in settlements, especially informal are also impacted on by the poor water quality. In many cases, this is the only source of potable water for many people living in these settlements.

It has been estimated that as much as two-thirds of South Africa's citizens live in densely populated settlements, many without adequate services. It has been recognized that as urbanization increases rapidly in South Africa, managing the impacts of densely populated settlements is becoming one of the most urgent water quality management needs facing the country (DWAF, 1998).

The issue of water quality dealing directly with *E. coli* stems from a lack of adequate sanitation facilities in settlements, which generally leads to the deterioration of water quality. It is suggested that an increase in reticulation and sanitation services would greatly reduce the levels of raw sewage and thus *E. coli* within rivers of the DMA and would benefit the local residents.

Although water quality has been addressed to show spatial and temporal changes, it would have proved far more effective if a larger data set was used, preferably one spanning a number of years instead of just one. The establishment of trends would have been more effective in a study of that nature. However, the nature of this study did not facilitate the use of a large data set.

There are numerous other water quality parameters that need to be addressed, as this will help provide further insights into the water quality issues within the DMA. In addition, the introduction of new sample points inland would be able to provide water quality information for those areas not investigated in this study. Although there appears to be regular monitoring of the rivers of the DMA, by the authorities, there has been little attempt in the formation of a structure to deal with the landuse issues, which directly impact on water quality. Issues such as poor sanitation facilities and agricultural practices, which are fundamentally the points of production of pollution are great contributing factors.

Water quality has been impacted by human activity and landuse and as such these should be the focus towards an improvement of water quality. To this end it is envisaged that the approach of an integrated catchment management framework be instituted. This framework takes on a systems approach to the management of water resources, recognizing the fact that in order to improve the quality of water the catchment in which it is located also needs to be managed.

Within the DMA a suggested mechanism is the facilitation and development of a catchment management plan. Management actions must be focused on land, to constrain the impacts of land-based activities on water resources, as well as on the water itself, to ensure adequate storage, distribution and rehabilitation where necessary. All stakeholders should participate in the debate around preferred sequences of actions and their consequences. The selected series of management actions should then be documented as a catchment management plan, which will require formal approval by the Minister of Water Affairs and Forestry. Responsibility for implementation of the catchment management plan would normally rest with a legally constituted catchment authority that represents the interests of all stakeholders (DWAF, 1996a).

Whilst a formal catchment management plan is a prerequisite for effective water resource management on a catchment basis, the mere existence of formal documentation is insufficient. An effective catchment management plan must address the typical management aspects of: planning, co-ordination, implementation or operation, and monitoring, as well as control and auditing of the management process, plus feedback to stakeholders (DWAF, 1996a).

For management to be effective and successful, it must set out agreed policies and strategies, provide leadership to all participants, define roles and responsibilities, be able to communicate effectively with all participants, and be able to mobilize sufficient human, technical and financial resources to undertake the tasks at hand. In the context of water resource management, the management dimension requires a particularly broad-based appreciation of the need to attain a balance between protection of the water resource and meeting the varied needs of stakeholders (DWAF, 1996a).

As such a catchment management plan should be drawn up for each catchment and a committee formed by interested and affected parties, should ensure that the water quality is maintained to meet the requirements of all its users within the DMA. There should be stringent enforcement of water quality guidelines especially for industry and others involved in the discharge of effluents.

An ICM attempts the management of all the components of the catchment and as such, management of both land and water are included. It has been suggested that landuse factors contribute greatly to poor water quality, and in this light management actions should focus on land, to constrain the impacts of land-based activities on the receiving waters.

In addition to the provision of essential services to the community, some attempt should also be made in the form of education programmes aimed specifically at promoting sustainable practices within the catchment, such as for agriculture. However, such an ICM plan requires the coordinated action at catchment level. Key players that need to get involved include national and local government, but most importantly local communities, water and land users, including industry and other such sectors. This will attempt to alleviate the water quality problems that the DMA is faced with.

This study used maps, diagrams and tables to analyse and present the results. Given the scope of the study, it was not possible to use sophisticated GIS techniques. Further studies could be aimed at using Digital Elevation Models to determine catchment areas of (selected) sampling points. These catchment areas could then be intersected with the slope and land use coverages in order to determine statistical parameters (e.g. average and standard deviation of steepness and percentage of land use composition). This data could then be used to statistically relate it to the average water quality measurements at the sampling points.

The findings of this study have highlighted the intensity of the water quality problem in the DMA. Although it has attempted to provide an overview of water quality, and has in some ways failed to provide details with regards to the sources of pollution, it points to the development of a series of catchment management plans as the mechanism towards an improvement in overall water quality in the DMA.

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Appendices

Appendix 1. Spreadsheet for variable DO

SAMPLE POINTS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEDIAN	AVERAGE	MAX	MIN
Tongaat Catchment																
R-WEWE_01	6.10	6.00	4.30		4.70	5.50		7.50	5.50	5.30	5.60		5.50	5.60	7.50	4.30
R-TONG_01	5.20	5.30	5.60		4.70	5.30		7.00	6.10	5.70	5.90		5.60	5.60	7.00	4.70
R-TONG_02		4.40	4.50		2.80	4.60		5.50	4.50	4.80	4.20		4.50	4.40	5.50	2.80
R-TONG_03	5.10	5.40	5.00		4.90	5.10		7.10	5.50	4.60	4.20		5.10	5.20	7.10	4.20
R-HLAWE_01	5.60	4.20	4.30		3.20	3.10		3.80	5.30	3.30	2.90		3.80	4.00	5.60	2.90
R-HLAWE_02	2.50	2.70	3.30		3.60								3.00	3.10	3.60	2.50
R-GENAZ_01	4.50	4.20	4.70		4.90	4.70		6.00	5.80	4.90	5.20		4.90	5.00	6.00	4.20
R-GENAZ_02	5.50	3.50	4.60										4.60	4.50	5.50	3.50
R-SWEET_01	5.70	5.20	5.30	5.30	5.00	6.60	4.60	4.30	5.90	5.50	6.50	5.70	5.40	5.50	6.60	4.30
	5.03	4.54	4.62	5.30	4.23	4.99	4.60	5.89	5.51	4.87	4.93	5.70	4.71	4.77	6.04	3.71
Mhlanga Catchment																
R-HLOTI_01	5.30	4.50	5.60	5.50	4.20	6.70	5.20	4.50	4.80	4.70	4.30	4.10	4.75	4.90	6.70	4.10
R-HLOTI_02	5.00	4.50	5.60	5.40	4.30	6.40	4.10	3.90	3.60	4.30	3.70	3.60	4.30	4.50	6.40	3.60
R-HLOTI_04							4.70	4.40	4.30	3.70	2.30	2.10	4.00	3.60	4.70	2.10
R-HLOTI_05	5.60	3.70	5.40	4.80	4.10		4.80	4.70	4.50	4.10	3.00	4.70	4.70	4.50	5.60	3.00
R-OHL_01	4.90	3.70	5.50	5.60	3.40	5.50		4.90	5.90	3.00	6.50	3.40	4.90	4.80	6.50	3.00
R-OHL_02	5.00	4.00	4.60	4.10	5.20	6.50	6.40	5.60	4.10	3.10	3.20	3.80	4.35	4.60	6.50	3.10
R-OHL_05	4.80	3.00	4.90	5.00	5.30	5.40	6.10	6.40	5.60	4.90	5.30	5.70	5.30	5.20	6.40	3.00
R-OHL_07	4.90	7.60	4.70	4.10	4.70	5.80	5.10	4.10	2.20	2.60	3.10	5.70	4.70	4.60	7.60	2.20
	5.07	4.43	5.19	4.93	4.46	6.05	5.20	4.81	4.38	3.80	3.93	4.14	4.63	4.59	6.30	3.01
Mgeni Catchment																
R-PHOE_03	5.30	6.00	5.20	4.90	5.30	6.00	5.30	3.90		5.50	5.80	6.50	5.30	5.40	6.50	3.90
R-GANE_04	4.60		5.60	3.10		6.10	4.40	3.70		3.90	4.20	6.20	4.40	4.60	6.20	3.10

R-GANE_05	4.80	5.10	5.80	4.60	4.30	5.50	4.20	2.70		2.90	3.00	5.50	4.60	4.40	5.80	2.70
R-GANE_18	4.00	3.90	4.90	4.00	4.20	7.70	5.30	4.60	4.40	3.60	3.40	4.50	4.30	4.50	7.70	3.40
R-MGENI_08	5.60	6.40	4.20	4.70	6.10		6.10	5.00	7.90	3.10	3.00	3.80	5.00	5.10	7.90	3.00
R-MGENI_13	4.60	5.20	5.40	4.20	4.40	5.80	5.80	4.70	5.50	4.40	3.90	3.70	4.65	4.80	5.80	3.70
R-MGENI_70	5.90	7.20	5.70	5.10	5.20	7.00	6.90	5.90	5.10	4.50	4.40	5.90	5.80	5.70	7.20	4.40
R-MGENI_71	4.90	5.40	6.00	4.20	4.80	5.80	5.80	4.50	5.30	3.40	3.20	4.50	4.85	4.80	6.00	3.20
R-MGENI_91	3.70	4.50	4.20	3.10		4.70	4.90	4.50	4.50	5.90	2.20	3.90	4.50	4.20	5.90	2.20
R-MGENI_92	4.50	5.00	6.20	3.80	4.10	5.60	4.90	4.00	4.60	3.30	3.20	3.60	4.30	4.40	6.20	3.20
R-MBONG_01	4.60	5.10	5.10	4.80	5.00	7.10	6.60	5.20	5.70	4.70	5.10	5.20	5.10	5.40	7.10	4.60
R-PALM_01	4.70	5.40	5.10	5.50	5.80	7.30	6.70	5.70	5.80	5.40	5.10	6.10	5.60	5.70	7.30	4.70
R-PALM_05	5.20	5.10	5.40	5.70	5.10	7.30	8.20	7.10	8.90	5.50	6.50	8.10	6.10	6.50	8.90	5.10
R-PALM_06	5.20	5.20	5.40	6.10	4.70	6.20	6.80	6.00	7.80	4.60	6.90	6.70	6.05	6.00	7.80	4.60
R-PALM_07	5.30	5.20	5.10	5.10	4.60	6.40	6.80	7.50	6.90	5.80	5.70	7.20	5.75	6.00	7.50	4.60
R-PALM_08	5.20	5.30	5.10	4.70	4.60	6.70	6.90	7.50	7.30	5.80	6.00	6.90	5.90	6.00	7.50	4.60
R-PALM_09	5.70	5.30	5.50		5.10	7.00	6.90	7.50	7.50	6.20	5.90	7.70	6.20	6.40	7.70	5.10
	4.93	5.33	5.29	4.60	4.89	6.39	6.03	5.29	6.23	4.62	4.56	5.65	5.20	5.29	7.00	3.89
Durban Bay Catchment																
R-BAAN_05		5.10	5.00	4.80	5.40	6.00	4.70	5.40		8.80	6.20	7.50	5.40	5.90	8.80	4.70
R-BELL_09	4.10	3.90		3.00	4.10	3.60	4.80	5.40		4.20	2.10	5.00	4.10	4.10	5.40	2.10
R-MAY_14	2.60	4.20	4.30	3.50	5.10	3.70	3.80	4.70		5.50	5.20	6.50	4.30	4.70	6.50	2.60
R-NYAMA_01	7.40	6.00	3.90	2.70		8.50	5.30	5.70	5.50	5.80	8.80	5.80	5.80	5.90	8.80	2.70
R-NYAMA_02	8.40	7.40	6.90	6.20	6.30	9.80	9.10	6.40	6.30	4.90	7.60	4.50	6.65	7.00	9.80	4.50
R-NYAMA_23	6.20	5.10	5.90	4.60	4.50	10.30	8.90	8.40	5.90	5.70	5.90	4.20	5.90	6.30	10.30	4.20
R-NYAMA_24	8.30		9.60	7.50	8.60	12.40	10.70	7.90	7.90	5.50	10.00	6.00	8.30	8.60	12.40	5.50
R-NYAMA_25	16.60	6.60	7.50	4.70	6.30	9.30	6.70	8.20	9.00	5.70	6.50	7.20	6.95	7.90	16.60	4.70
R-BILO_04	5.80	5.10	5.50	5.50	5.50	4.90	4.10	7.20		7.20	4.90	6.20	5.50	5.60	7.20	4.10
R-BILO_11	5.70	5.30	5.70	5.30		4.70	4.80	8.70		9.30	6.90	7.00	5.70	6.30	9.30	4.70
R-BILO_12	5.50	5.30	5.50	5.50		4.60	4.90	8.60		9.10	6.50	6.80	5.50	6.20	9.10	4.60
R-BILO_13	8.80	5.30	5.60	5.50	5.30	6.30	5.50	8.40		9.20	7.50	7.20	6.30	6.80	9.20	5.30
R-BILO_18	7.40	7.60	7.70		5.00	7.60	6.70	6.40	6.90	6.70	5.30	6.40	6.70	6.70	7.70	5.00
R-BILO_19	8.30	7.80	8.50			9.60	6.80	6.60	6.70	6.90	4.20	6.20	6.85	7.20	9.60	4.20
R-BILO_20	5.20	5.20	5.50	5.70	5.70	6.50	6.60	7.50	8.30	5.40	5.90	7.00	5.80	6.20	8.30	5.20

R-BILO_21	5.10	4.50	4.90	5.60	4.70	6.20	7.30	10.00	9.40	4.90	5.50	7.50	5.55	6.30	10.00	4.50
R-BILO_22	5.30	5.00	5.40	5.20	4.70	6.70	7.30	6.60	7.30	5.70	5.00	7.20	5.55	6.00	7.30	4.70
R-BILO_23	5.20	5.10	5.40	5.00	4.70	6.70	6.00	6.00	6.80	5.00	5.40	7.00	5.40	5.70	7.00	4.70
R-BILO_24	5.40	5.20	5.30		5.10	6.60	6.90	7.30	7.30	5.80	5.90	7.20	5.90	6.20	7.30	0.00
R-BILO_27	3.40	5.70	5.50		5.10	6.90	7.50	7.30	8.40	6.00	5.20	8.00	6.00	6.30	8.40	3.40
R-CHAT_12	4.50	4.50	3.80	4.40		7.60	7.70	6.10	4.50	4.60	5.10	6.50	4.60	5.40	7.70	3.80
R-CHAT_13	7.80	5.00	4.70	4.10	5.50	8.50	8.10	6.10	7.90	6.50	5.70	6.10	6.10	6.30	8.50	4.10
R-CHAT_14	7.60	4.60	4.50	3.90	5.40	6.90	8.20	4.80	6.70	7.50	6.00	6.50	6.25	6.10	8.20	3.90
R-CHAT_15	6.40	4.60	5.30	3.90	5.70	6.90	8.50	5.10	7.90	6.90	6.00	6.00	6.00	6.10	8.50	3.90
R-ZANA_04	8.60	6.00	5.60	5.50	5.50	7.30	8.10	7.20	6.90	6.40	5.60	9.50	6.65	6.90	9.50	5.50
R-ZANA_09	5.00	5.00	4.50	4.30	5.70	5.30	5.30	4.10		6.50	5.60	5.90	5.30	5.20	6.50	4.10
R-ZANA_10	5.70	4.20	5.70	4.40	5.10	7.00	5.40	8.30		7.20	7.20	6.00	5.70	6.00	8.30	4.20
R-ZANA_29	5.10	6.60	4.90	5.00	6.20	5.70		7.20	6.60	5.00	3.70	6.10	5.70	5.60	7.20	3.70
R-ZANA_30	6.60	6.50	6.40	7.10	5.90	5.80		7.00	6.30	6.60	5.80	7.00	6.50	6.50	7.10	5.80
R-ZANA_31	5.60	6.10	6.10	6.70	5.80	5.70		7.50	5.80	5.80	4.30	6.50	5.80	6.00	7.50	4.30
R-ZANA_32	6.10	6.50	5.60	5.40	6.20	5.90		7.10	6.80	7.40	5.40	7.10	6.20	6.30	7.40	5.40
R-ZANA_33	6.44	6.30	6.60	7.40	6.00	5.80		7.40	5.80	4.90	4.00	6.50	6.30	6.10	7.40	4.00
R-ZANA_34	5.50	5.40	4.80	4.90	5.40	5.40		7.30	6.00	5.80	4.60	6.00	5.40	5.60	7.30	4.60
R-ZANA_35	6.20	6.50	4.80	4.20	5.50	5.40		7.60	5.70	6.10	5.10	6.30	5.70	5.80	7.60	4.20
R-ZANA_60	5.60	4.70	5.70		5.00	6.80	8.10	6.60	7.30	6.50	6.50	5.70	6.50	6.20	8.10	4.70
R-ZANA_80	6.10	4.50	5.60	5.60	6.20	7.90	8.70	6.90	6.50	6.10	5.60	7.60	6.15	6.40	8.70	4.50
R-ZANA_81	5.50	5.40	4.20	3.90	6.00	4.10	5.10	7.90		6.20	3.80	6.40	5.40	5.30	7.90	3.80
	6.36	5.49	5.62	5.03	5.54	6.73	6.72	6.94	6.90	6.31	5.69	6.54	5.90	6.15	8.44	4.21
Mlazi Catchment																
R-CHAT_04	5.20		6.90	4.70	5.50	6.40	7.80	5.20	4.10	5.10	5.60		5.35	5.70	7.80	4.10
R-CHAT_05	5.30	5.40	5.90	4.40	5.30	5.80	7.90	6.10	4.80	4.90	5.50		5.40	5.60	7.90	4.40
R-CHAT_06	4.90	5.30	6.30	4.50	4.90	5.40	8.00	5.10	4.70	5.30	5.80		5.30	5.50	8.00	4.50
R-CHAT_07	2.80	4.20					3.50	3.80	5.10	4.30	5.20		4.20	4.20	5.20	2.80
R-CHAT_08	4.70	6.00	4.80	4.10	3.20	3.30	4.70	4.00	3.80	4.20	5.10		4.20	4.40	6.00	3.20
R-CHAT_09	5.20	5.30	5.70		5.10	6.20	6.40	6.30	3.80	5.10	5.70		5.50	5.50	6.40	3.80
R-CHAT_10		5.50	5.00	4.00	3.40		5.40	3.80	4.10	4.00	4.90		4.10	4.50	5.50	3.40
R-CHAT_11	5.10	4.80	4.10	3.90	5.60	6.80	6.80	4.30	6.40	4.30	4.90	6.40	5.00	5.30	6.80	3.90

R-MLAAS_10		5.80	5.80	4.50	5.10	6.90	8.60	6.60	5.50	5.80	6.20		5.80	6.10	8.60	4.50
R-MLAAS_10		5.80	5.80	4.50	5.10	6.90	8.60	6.60	5.50	5.80	6.20		5.80	6.10	8.60	4.50
R-MLAAS_14	4.60	5.30	4.20	5.30	4.50	4.40	4.40	5.50	4.80	6.20	5.50		4.80	5.00	6.20	4.20
R-MLAAS_15	5.40	3.80	4.30	5.60	4.10	4.40	6.10	6.10	5.50	5.50	5.20		5.40	5.10	6.10	3.80
R-MLAAS_18	1.90	2.60	4.40		3.40		5.10	6.10	5.80	4.80	2.10		4.40	4.00	6.10	1.90
R-MLAAS_20	1.80	2.90	2.20	3.00	2.20	4.10	4.40	3.80	2.00	1.40	1.40		2.20	2.70	4.40	1.40
R-NYAMA_03	4.60	4.00	3.60	4.40	3.90	5.50	5.50	4.70	4.40	4.40	5.70	5.20	4.50	4.70	5.70	3.60
	4.29	4.76	4.93	4.41	4.38	5.51	6.21	5.20	4.69	4.74	5.00	5.80	4.80	4.96	6.62	3.60
Mbokodweni Catchment																
R-MBOKO_01	5.20	5.00	4.60	4.60	4.80	5.60	3.40	4.60	4.20	4.00	3.80	4.70	4.60	4.60	5.60	3.40
R-MBOKO_02	5.60	5.20	5.00	4.50	4.00	5.30	4.80	4.60	4.80	6.50	4.30	3.50	4.80	4.80	6.50	3.50
R-MBOKO_03	5.20	5.60	5.60	5.10	5.60	6.20	5.10	5.50	5.90	4.40	4.90	6.50	5.55	5.50	6.50	4.40
	5.33	5.27	5.07	4.73	4.80	5.70	4.43	4.90	4.97	4.97	4.33	4.90	4.98	4.97	6.20	3.77
Little Toti Catchment																
R-TOTI_01	5.20	4.80	5.20	4.60	4.50	5.90		8.70	6.10	11.40	4.00		5.20	6.00	11.40	4.00
R-TOTI_02	5.60	5.00	5.80	6.60	5.60	7.60		7.00	7.30	6.30	5.90		6.10	6.30	7.60	5.00
R-LTOTI_02	5.00		5.70	5.70	5.20	7.30	6.70	7.00	6.30	5.10	4.70	4.40	5.70	5.70	7.30	4.70
R-LTOTI_04	5.80		12.00	1.90	4.00	5.30		4.20	3.10	1.90	4.40	4.80	4.20	4.70	12.00	1.90
R-LTOTI_05	6.20		6.00	4.40	4.00	6.30		7.80	5.30	4.60	4.50		5.30	5.50	7.80	4.00
	5.56	4.90	6.94	4.64	4.66	6.48	6.70	6.94	5.62	5.86	4.70	4.60	5.30	5.64	9.22	3.92
Lovu Catchment																
R-LOVO_02	4.40	4.00	5.00	4.40	5.10	5.60	6.50	7.70	6.70	5.90	5.60	5.30	5.45	5.50	7.70	4.00
R-LOVO_03		4.80	4.90		5.10	5.10	6.50	7.40	5.80	5.00	4.90		5.10	5.50	7.40	4.80
	4.40	4.40	4.95	4.40	5.10	5.35	6.50	7.55	6.25	5.45	5.25	5.30	5.28	5.50	7.55	4.40
uMgababa Catchment																
R-MBAZI_01	4.50	5.80	4.20	5.00	5.40	4.50	6.30	7.60	5.30	5.70	4.10	4.50	5.15	5.20	7.60	4.10
R-MBAZI_02	4.50	5.80	4.20	5.00	5.40	4.50	5.70	7.40	7.40	6.40	4.80	4.60	5.20	5.50	7.40	4.20
	4.50	5.80	4.20	5.00	5.40	4.50	6.00	7.50	6.35	6.05	4.45	4.55	5.18	5.35	7.50	4.15

Appendix 2: Problem points for the DMA

Sample Point	Catchment	Dissolved Oxygen	Turbidity	Phosphorus	*E.Coli*	pH
Mlaas 14	Mlazi			•	•	
Mlaas 10				•	•	
Mlaas 18				•	•	
Mlaas 15				•	•	
Mlaas 20				•	•	
Chat 04				•	•	
Chat 07		•	•		•	
Chat 08		•		•	•	
Chat 09				•	•	
Chat 10		•	•	•	•	
Chat 11					•	
Chat 12					•	
Chat 15			•		•	
Nyama 03		•		•	•	
Mlaas 18		•			•	
Mlaas 20		•			•	
Mboko 01	Mbokodweni	•			•	
Mboko 02		•	•	•	•	
Mboko 03			•		•	
Mboko 07				•	•	
Ltoti 04	Little Toti	•			•	
Ltoti 05				•	•	
Palm 06	Mgeni			•	•	
Gane 04		•	•		•	
Gane 05		•		•	•	
Gane 18		•	•	•	•	
Mgeni 08			•	•	•	
Mgeni 13		•		•	•	
Mgeni 70				•	•	
Mgeni 71		•	•	•	•	
Mgeni 91		•	•	•	•	
Mgeni 92		•	•	•	•	
Bong 01			•		•	
Bilo 04	Durban Bay			•	•	
Bilo 11				•	•	
Bilo 12				•	•	
Bilo 13				•	•	
Bilo 18				•	•	
Bilo 19					•	
Zana 04				•	•	

Zana 09				•	•	
Zana 10				•	•	
Zana 29			•		•	
Zana 30			•		•	
Zana 60				•	•	
Zana 80			•	•	•	
Zana 81			•	•	•	
Baan 05			•		•	
Bell 09		•			•	
May 14		•			•	
Hlawe 01	Tongaat	•		•	•	
Hlawe 02		•		•	•	
Tong 01				•	•	
Tong 02		•		•	•	
Genaz 01				•	•	
Genaz 02		•		•	•	
Wewe 01			•		•	
Sweet 01			•		•	
Ohl 01	Mhlanga	•		•	•	
Ohl 02		•	•	•	•	
Ohl 05			•	•	•	
Ohl 07		•		•	•	
Hloti 02		•	•		•	
Hloti 04		•			•	
Hloti 05		•	•		•	