DEVELOPMENT OF WATER QUALITY INDEX (WQI) FOR THE JUKSKEI RIVER CATCHMENT, JOHANNESBURG.

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A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in partial fulfilment of the requirements for the Master of Science in Engineering

Johannesburg, 2014

DECLARATION

I declare that this research report is my own unaided work. It is being submitted for the Master of Science in Engineering to the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

ACKNOWLEDGEMENTS

I would like to thank my supervisor Prof. John Ndiritu, for his sustained guidance and advice during the course of this study. His critical review and assessment of this work has in no doubt refined this work in all aspects. I would also like to thank my family for sparing their precious time to complete my work.

ABSTRACT

Water quality monitoring is a key component of integrated water resources management. Information generation from the data produced during this monitoring exercise is therefore critical in the process of deciding which rehabilitation or pollution control measures need to be undertaken. Water quality index (WQI) is useful in achieving this through simplifying complex water quality data into a single value that can therefore be classified to indicate the water quality.

The objectives of the research were as follows:

- To evaluate water quality data analysis and interpretation methods being employed in the City of Johannesburg (COJ),
- To develop a water quality index (WQI) for Jukskei catchment in the COJ as a practical method of presenting complex water quality data simply,
- To apply the developed index to evaluate the water quality data,
- To determine the levels of pollution in the Jukskei catchment using the index and identify the highly polluted locations,
- To determine the water quality trends in the Jukskei catchment using the WQI.

The methodologies used to achieve the above objectives consisted of literature review, data analysis and determination of appropriate water quality index and determination of trend on highly polluted areas identified using the water quality index determined.

The current data analysis methods being employed by the City of Johannesburg and associated problems were discussed. The study also brings to the fore the benefits of using the water quality index in analysing the data and producing the simple water quality status report on monthly and quarterly basis to align it with City of Johannesburg reporting periods. The study recommends that the City of Johannesburg employs the proposed water quality index to complement existing methods of analysing and interpreting water quality data and reporting this information. This could improve the understanding of surface water quality conditions and decision making.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Until recently the global water crisis was considered to be a problem of water scarcity. Currently, however, there is the recognition that water quality is an equally-important component of the problem (Zhulidov *et al*., 2001). South Africa is water scarce, being the 29th driest of 193 countries and having an estimated 1 110 m^3 of water per year in 2005 while its rainfall varies dramatically from season to season, and the limited available water is distributed unevenly across the country (Muller *et al*., 2009).The scarcity of water is closely linked with water pollution because pollution renders water unfit for various purposes thereby making that water unavailable for immediate use. Water quality problems are often as severe as those of water availability but less attention has been paid to them, particularly in developing regions (Macatsha, 2008). Sources of water quality problems include discharges of untreated sewage, chemical discharges, petroleum leaks and spills, dumping in old mines and pits and agricultural chemicals that are washed off or seep downward from farm fields (Chilundo *et al*., 2008).

According to Zhulidov *et al*. (2001), the contribution of water pollution to problems of water scarcity is mainly through loss of beneficial use from polluted water that cannot be cost-effectively used for municipal and industrial uses and, in some cases, even for agricultural production. Water pollution may have a major economic impact, which, in addition to public health effects can have a serious detrimental effect to national economies as a result of increasing contribution to scarcity of water. In 1990, it was found that the cost of surface water pollution to the China economy was 0.5 percent of the gross national product, which was more than the total 1990 exports (Zhulidov *et al*., 2001). Poor water quality leads not only to water related diseases but also reduces agricultural production, which means that more foodstuff and agricultural products must be imported.

In Egypt, the cost of environmental degradation, mainly due to water quality deterioration, has emerged as a development issue (Abdel-Dayem, 2011). The total damage cost to health and quality of life (mortality, morbidity and quality of life) due to water pollution is estimated at about 0.9% of gross domestic product (World Bank, 2007). Abdel-Dayem (2011) found that the cost of damage to natural resources (ecosystems) from municipal and industrial wastewater in Egypt was about 0.1% of gross domestic product.

Poor water quality also limits economic development options, such as water-intensive industries and tourism, a situation that is potentially disastrous to developing countries (van Niekerk *et al*., 2002). South Africa as one of developing countries of the Southern African Development Community (SADC) is not immune from water quality problems. South Africa's major surface water resources are facing severe damage due to pollution from storm water runoff from urban areas, failing or under capacity sewer infrastructure, industrial discharges and grey water from informal settlements. These river systems pose major environmental and health problems especially to high-density low-income settlements (Owusu-Asante, 2008). The extent of pollution of available surface water resources although highly publicized is poorly understood. The impacts of climate change are becoming very serious with increasing temperatures and changing rainfall patterns. Surface water resources are affected the most due to combined affect caused by the decreased precipitation and increased potential evaporation as a result of rising air temperature (Altansukh and Davaa, 2011).

1.2 PROBLEM STATEMENT

Water quality data is composed of numerical values for a range of variables measured over time for a specific monitoring point. Depending on frequency of sampling and analysis, the data grows into a large database. The water quality in rivers and impoundments of the City of Johannesburg (COJ) is deteriorating at an alarming rate due to pollution from rapid urbanisation, wastewater discharge from industries, sedimentation, informal settlements, raw sewage and grey water from poorly plumbed buildings (COJ, 2008). COJ like most other municipalities in South Africa suffers from data-rich but information-poor syndrome. The monitoring program is generating a lot of water quality data but no analysis that could reveal the water quality trends has been identified. The identification of water pollution hotspots is also not very systematic (Burke and Bokako, 2004).

The data being generated is not properly being converted to information to enable the municipality administration to implement proper interventions to reduce the impacts of pollution. With rising threat of Acid Mine Drainage (AMD) in and around the COJ, the threats are severe and information generation from the water quality monitoring data can be of great importance in pinpointing areas being affected by AMD (Durand, 2012; Ramontja *et al*., 2011). Water quality analysis is typically presented as statistics of levels of pollution of many parameters that scientists comprehend easily. However, water quality analysis results also need to be meaningful to managers and decision makers in the water sector who want to base their decisions on the state of their local water bodies (Akkoyunlu and Akiner, 2012). A water quality index (WQI) that would summarize the data into a single representative value indicating the water quality is considered as more understandable by managers and decision makers who are not scientifically inclined.

1.3 SIGNIFICANCE OF RESEARCH

Poor analysis, presentation and reporting of water quality monitoring data has serious implications because managers and decision makers would not be able to focus necessary resources to water quality problem areas. As managers and decision makers continue failing to identify and address sources of water pollution, river water quality continuously deteriorates thereby exposing the public and water users in general to water borne, water based and water related diseases such as cholera, typhoid and diarrhoea. Water quality monitoring and the management of the resultant data require huge budgets to maintain. The data being generated, if not being transformed to useful information about the status of the water quality in the catchment, translate to wastage of limited financial resources. The study seeks to develop and test a method of simplifying water quality data analysis and reporting. This simplified approach could assist COJ in understanding the water quality status of the Jukskeiand other river basins better, save costs and focus necessary remedial works and pollution prevention interventions.

1.4 RESEARCH OBJECTIVES

The study is aimed at achieving the following objectives:

(a) To evaluate water quality data analysis and interpretation methods being employed in the City of Johannesburg (COJ),
(b) To develop a water quality index (WQI) for Jukskei catchment in the COJ as a practical method of presenting complex water quality data simply,
(c) To apply the developed index to evaluate the water quality data, and
(d) To determine the levels of pollution in the Jukskei catchment using the index and identify the highly polluted locations,
(e) To determine the water quality trends in the Jukskei catchment using the WQI.

CHAPTER 2: LITERATURE REVIEW

2.1 WATER QUALITY MANAGEMENT AND INTEGRATED WATER RESOURCES MANAGEMENT

Biswas (2009) defined Integrated Water Resource Management (IWRM) as a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. This definition recognises the management of the resource holistically maintaining a balance between socio-economic and environmental impacts (Pollard and du Toit, 2008). Human beings impact on water resources in many ways including dumping of solid waste, siltation due to erosion from cultivated lands, mining, discharge of chemicals from industrial processes, discharge of raw or partially treated sewage and diversion of stream flow. The natural ecosystem must be protected from human activities because it is the source of water (Leendertse *et al.*, 2008).

According to South African water quality guidelines for aquatic ecosystems (DWAF, 1996a), water quality is used to describe the physical, chemical, biological and aesthetic properties of water that determine its fitness for a variety of uses and for the protection of the health and integrity of aquatic ecosystems. Many of these properties are controlled or influenced by constituents that are either dissolved or suspended in water. Water quality management, therefore involves the maintenance of these properties thereby ensuring the fitness for use of water resources on a sustained basis, by achieving a balance between socio-economic development and environmental protection (Barrington *et al.*, 2013). Maintaining the fitness of water involves a number of activities including the ongoing process of planning, development, implementation and administration of water quality management policy, the authorization of water uses that may have, or may potentially have, an impact on water quality, as well as the monitoring and auditing of the aforementioned (Abbaspour, 2011).

Since the impacts are manmade, water quality management therefore involves controlling and managing a wide range of human activities causing pollution and rapid deterioration of surface and groundwater resources. Biswas and Tortajada (2011) indicated that most of the research conducted to date has focussed on the physical scarcity of water with less emphasis on water pollution issues. As a result most water bodies within and around the urban centres of Asian, African and Latin American developing counties are already heavily polluted due to poor water management and widespread neglect of water quality considerations, both politically and socially (Biswas and Tortajada, 2011). Jordaan and Bezuidenhout (2012) found that the water quality of the Vaal river system which serves Gauteng has drastically deteriorated and the major water quality problems evident currently include salinisation, eutrophication and microbiological pollution are due to constant disposal of industrial and domestic waste into the river and its tributaries. Other researchers have cautioned that the continuous deterioration of water quality will become the driving force behind water scarcity problems in the future especially in developing countries (Biswas and Tortajada, 2011; Jain and Singh, 2010). International rivers are also under immense pressure due to upstream pollution which may result in tensions among the riparian countries (Jain and Singh, 2010). Chilundo *et al.* (2008) found that the Limpopo River Basin was highly polluted with high levels of Phosphorus by riparian countries including South Africa which could render the river eutrophic.

Consideration of the major water quality management problem areas should show where the failures have occurred and, thus, where the solutions may be found (Lovett *et al*., 2007). It is clear from this argument therefore that research must be conducted on a river basin to characterise the water quality conditions of the basin. This is achieved by instituting a properly designed water quality monitoring programme. Water quality monitoring (environmental monitoring) is a time series of measurements of physical, chemical, and/or biological variables, designed to answer questions about environmental change (Lovett *et al*., 2007). According to Lovett *et al*. (2007) monitoring is a crucial part of environmental science, costs very little relative to the value of the resources it protects and the policy it informs, and has added value in that basic environmental monitoring data can be used for multiple purposes. Effective monitoring programs address clear questions, use consistent and accepted methods to produce high-quality data, include provisions for management and accessibility of samples and data, and integrate monitoring into research programs that foster continual examination and use of the data (Lovett *et al*., 2007).

2.2 WHY MONITOR WATER RESOURCES?

According to Strobl and Robillard (2006), water quality monitoring can be defined as the effort of procuring quantitative information on the physical, chemical, as well as biological characteristics of a water body over time and space by means of representative samples taken from the water resource being monitored.

Since the goal of water quality monitoring is the cost-effective detection of past and potential changes in water quality, water quality monitoring design must be optimized through proper selection of the number and location of sampling stations, sampling frequencies, and relevant water quality constituents, given a specific monitoring objective, fixed budget constraint, and logistical limitations (Strobl and Robillard, 2006),

The compelling reasons for environmental monitoring arise from the numerous and complex problems associated with global environmental change, such as climate change, loss of biotic diversity, contaminants, nutrient enrichment, and land-use change (Hale and Hollister, 2008). Water resources are vital sources for drinking water that are vulnerable to pollution (Han *et al*., 2009). Water resources are exposed to various pollutants harmful to human and aquatic ecosystems. Anthropogenic activities and natural processes can easily degrade the quality of surface and groundwater resources and impair its usability. Regularly monitoring of water quality is therefore a key component to guide the essential practices for protecting surface water resources from pollution (Han *et al*., 2009).

Pollution of surface water with toxic chemicals and excessive nutrients, resulting from a combination of transboundary transport, storm water runoff, point and non-point leaching and groundwater discharges has become an issue of environmental concern worldwide (Ouyang, 2005). One of the drivers of pollution events is the recent world population growth that resulted in increasing urbanization and industrialization. For that reason, water pollution and reduction of river flows has become a major threat for the public and environmental health in such a way that the policy makers have called for the design and operation of monitoring networks in river systems to minimize the negative effects of those pollutants (Park *et al*., 2006).

Since the 1990s, ecological river restoration has gradually become a promising way to recover impaired river systems in terms of ecosystem structure and functions (Song and Frostell, 2012, Gonzalez del Ta´nago *et al*., 2012). Song and Frostell (2012) defined ecological restoration as “an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability”. This mean therefore that river restoration is intended to “assist the establishment of improved hydrologic, geomorphic, and ecological processes in a degraded watershed system and replace lost, damaged, or compromised elements of the natural system”, with the focus on addressing causes of system degradation (Nakano *et al*., 2008).

The impacts of poor water quality may result in socially less desirable behaviour, negatively affecting the wellbeing of society and placing strain on social services (Nel*et al.*, 2013). In cities where urban agriculture is common, poor quality water may severely compromise food production, which is a source of income for many. Ultimately poor water quality poses a significant threat to human health, aquatic biodiversity and the added value that good quality water brings to the economy (Nel*et al.*, 2013).

Water quality monitoring data generated from the water quality monitoring program serves as early warning system reflecting problem areas so that necessary corrective measures can be focussed through restoration projects. Water quality data is also very useful to track the performance of river restoration projects. Song and Frostell (2012) observed that water quality improvement was placed as a top priority of three goal categories of river restoration projects in the United States of America where water quality monitoring data and indicators served as the main basis for identifying water quality changes and pressures (stressors) in the ambient environment. River restoration planning and efforts must target the main contributing factors that have exerted the most significant pressures and impacts on river ecosystems which are identified from the analysis of water quality data.

In essence, as mentioned in Dehua *et al*. (2012), water quality monitoring is used to monitor and determine the type of water pollution, the concentration of various water pollutants, the changing tendency and to direct management actions. It is therefore an important means of water resources management and water environment protection. If it is carried out effectively and efficiently, the source, the type, and the range of pollution can be discovered in time so that the appropriate contingency plans can be determined, which has a good effect on human health and safety (Dehua *et al*., 2012). According to Chilundo *et al*. (2008) water quality monitoring forms an integral part of the monitoring cycle concept developed by the United Nations Economic Commission for Europe. The monitoring cycle defines water quality monitoring as a sequence of related activities that starts with the definition of the information needs and ends with the production and use of the information product (Figure 2.1).

These successive activities in the monitoring cycle should be specified and designed in light with the required information product as well as the preceding part of the chain (Chilundo *et al*., 2008). The ultimate goal of a monitoring programme is to provide the information needed to answer specific questions during decision making process, thus it is important to clearly define and specify the requirements in terms of information (Chilundo *et al*., 2008). After the specification of the information needs, assessment strategies are followed by the design and operation in such a way that the required information is obtained.

In simple terms, water quality monitoring is one of the essential components of water quality management process which involves answering the following questions (Chilundo *et al.*, 2008):

- defining the monitoring objectives - why do we monitor?
- monitoring network design - how do we monitor, including the essential components of where, when, and what do we monitor?
- Monitoring-programme audience or clientele - who uses the resultant information?
- Monitoring-programme evaluation - how will monitoring network procedures incorporate developing technologies and change in the future?

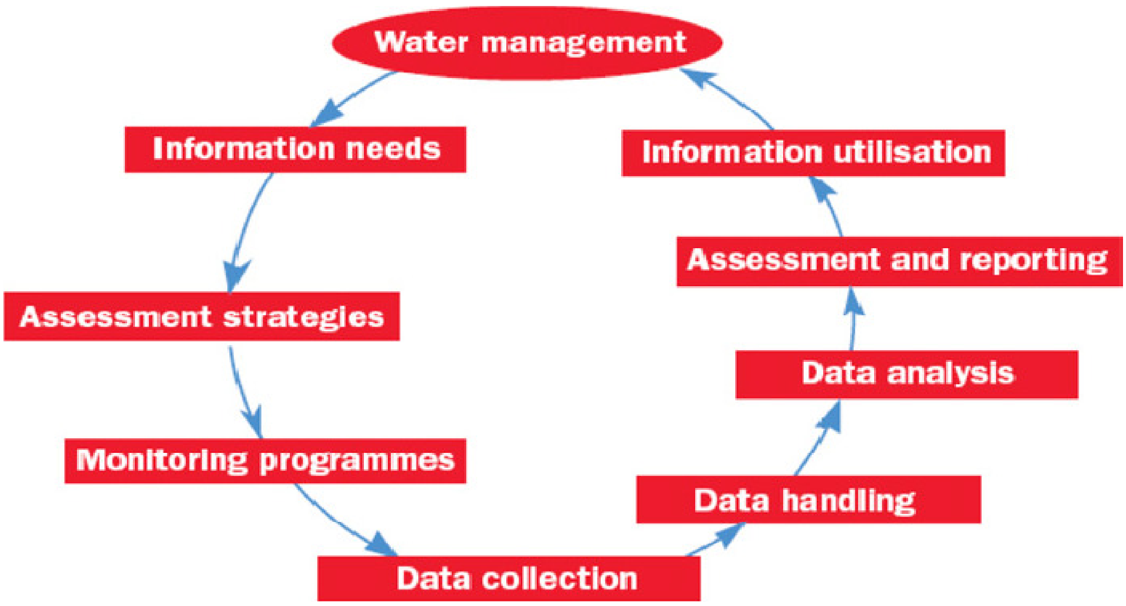

Figure 2.1: The Monitoring Cycle

Water quality monitoring programs aid in understanding various water quality processes as well as provide water managers with the necessary information for water resources management in general and water quality management in particular (Khalil, 2010). The quality of a water body is usually described by sets of physical, chemical and biological variables that are mutually interrelated. Water quality can be defined in terms of one variable to hundreds of compounds and for multiple usages. Antonopoulos *et al.* (2001) summarized the compelling reasons that necessitate water quality monitoring including the following:

- assessment of compliance with Water Quality Objectives;
- trend assessment;
- general surveillance.
- to provide a system-wide synopsis of water quality,
- to detect actual or potential water quality problems if such problems exist
- to determine specific causes
- to assess the effect of any corrective action.

Water quality monitoring therefore provides information which can be used as an early warning regarding water pollution. Prevention of river pollution requires effective monitoring of physico-chemical and microbiological parameters (Kolawole *et al.*, 2011). Without monitoring anthropogenic pressures on the water environment, it is difficult to set realistic river restoration targets in relation to water quality (Song and Frostell, 2012).

In water quality monitoring simply determining the presence of pollutants is often insufficient. Accurate determination of concentrations, speciation or sources can all be critical information to determine, for example, drinking water safety or identify the origin of pollution (Bullough *et al.*, 2013).

2.3 TRENDS IN WATER QUALITY MONITORING

The conventional water quality measurements and evaluation have depended upon costly, time and labour-intensive onsite sampling and data collection, and transport to land-based or shipboard laboratories for evaluation, and they are too limited on temporal and spatial scales to address real-time water quality information for the timely routine and contingent management plans of water utility and local authorities (Xiao-gang and Ting-lin, 2009).Recently, there has been an increasing pressure for real-time data transfer. Online satellite-based data-relay systems have been developed for obtaining so-called "real-time" data. Over time, such needs may be anticipated for certain water quality variables. Real-time monitoring, which has the characteristics of rapid response time, fully automated, sufficient sensitivity, high rate of sampling, minimal skill and training, can provide data that can be used in multiple purposes, such as environmental hazard assessment, water resources management, natural hazard warning (Xiao-gang and Ting-lin, 2009). Accordingly, demands for field instrumentation for in situ measurements will be increasing. In efforts to detect certain forms of contamination as soon as possible, "early-warning" monitoring strategies will be used more.

Dehua *et al*. (2012) highlighted the need to change to automatic sensors rather than physical collection of water samples for analysis at the laboratory. The real-time data can be continuously measured and recorded by the water quality automatic monitoring system. This involves the use of multi-parameter water quality monitor and GPRS module which transmit the data to the server (Dehua *et al*., 2012). The challenge with these systems is that of security as they are installed in remote areas and are therefore exposed to vandalism.

2.4 CHOICE OF WATER QUALITY PARAMETERS

The monitoring objectives are the basis for determining what exactly will be measured (Olsen and Robertson, 2003). Simply defining what parameters or constituents are to be measured is not sufficient for developing a monitoring program because most parameters can be monitored using many different techniques. Knowing what will be monitored, what will be measured, when and how frequently it will be measured, and where it will be measured, are all essential elements of a monitoring design (Olsen and Robertson, 2003).

The baseline data must be collected during surveys to assess ambient water quality and associated hydrological conditions (Strobl and Robillard, 2008). This serves as an important stage towards determining the spatial dimension through reconnaissance-level surveys of the catchment. In this case, the whole ranges of normal water quality parameters are considered in order to understand the river basin. The appropriate selection of water quality constituents to be sampled is inherent to the design and subsequent operation of a monitoring network. The water quality variable(s) to be monitored greatly influences both the sampling location and sampling frequency designation and should be selected based on the specific monitoring objectives or a clearly defined information "need." (Strobl and Robillard, 2008).

2.5 WATER QUALITY DATA MANAGEMENT

Data management is defined as the process of organizing, storing, retrieving and maintaining the data collected (Klima *et al*., 2003). Having a data storage, management, and retrieval system is essential for every monitoring program. According to Klima *et al*. (2003), data management is an essential component of the monitoring programme within the monitoring programme implementation which involves the following 10 steps:

- Monitoring Strategy

- Monitoring Objectives
- Monitoring Design
- Core Indicators
- Quality Assurance
- Data Management
- Data Analysis/Assessment
- Reporting
- Programmatic Evaluation
- General Support and Infrastructure

Data management systems range from the simplest to more complex and sophisticated tailor made computer programs. The more familiar computer programmes used for this purpose therefore include Microsoft Access, Microsoft Excel and other higher-powered database management system. Microsoft excel software is easy to use and it can be used to track data in columns and rows, filtering the data, perform calculations on data, and show graphs. Microsoft access is a type of Relational Database Management System where the data is stored in tables that can be related to each other via common IDs, data can be manipulated via Queries and the data can be entered via Forms and retrieved via Reports

Some of tailor made powerful data management systems include Storage and Retrieval (STORET) of water quality monitoring data developed by EPA, the National Water Information System (NWIS) developed by U.S. Geological Survey (USGS) (Klima *et al.*, 2003). Other systems include Water Management System (WMS) developed by Department of Water Affairs and Emanti Management (Pty) Ltd eWQMS (Emanti Water Quality Management System), EQWin software developed by Gemtek environmental inc. The Laboratory Information Management System (LIMS) designed primarily for the collection, processing, storage and retrieval of laboratory data and results is also being used (Broodryk and de Beer, 2003).

2.6 DATA ANALYSIS, INTEPRETATION AND INFORMATION GENERATION

Understanding long-term changes in the state of the environment represents a priority, but the amount of data required for representative and meaningful assessments can be substantial, and the interpretation of the data is often a matter of controversy (Wahlin and Grimvall, 2008). According to Khalil *et al.* (2010) the quality of a water body is described by a combination of a set of physical, chemical and biological variables that are mutually interrelated. The resulting data from water samples can be in the form of complicated matrix with vast parameters. In most cases it is difficult to approach and to produce meaningful information from a complex water quality data set (Han *et al.*, 2009).

Water quality data resulting from continuous samples collection and analysis is presented in the form of values or figures. The data must be continually retrieved, analysed and interpreted for information generation and reporting. There are various methods of analysing, interpreting and presentation of the data to generate information. In addition to graphical interpretation that can easily be performed in Microsoft Excel, box plots which are based on percentiles, and are one of the most useful graphical methods for data analysis can be very useful for the purpose of water quality data, interpretation and presentation (Helsel, 2003).

Many organisations responsible for water quality monitoring store these data in very powerful computer databases. These values are of very little or no use to many people and needs to be converted to information using various computer softwares. The transformation of data into information is an essential component of any monitoring network (Klima *et al.*, 2003). In the recent years ArcGIS is increasingly becoming the industry standard for visualizing and processing geographic data and managing geodatabases because of its flexibility and the tools it affords. It can be customized using several programming languages to take full advantage of its capabilities and streamlining the preprocessing of data for analysis with other programs.

2.6.1 Statistical Methods

The methods to analyse, interpret and present water quality data vary depending on information goals, target audience, type of samples and the size of sampling area (Alobaidy *et al.*, 2010). Data analysis and interpretation forms the key part in water quality monitoring for the production of information necessary to determine pollution levels, sources and water quality change over time in order to implement proper control measures. Powerful statistical methods can reveal remarkable spatio-temporal patterns in measured water quality data and this may lead to new interpretations regarding the human impact on aquatic environments.

Long-term trends in measured parameters concentrations can be more extensively influenced by changes in sampling and laboratory practices than by actual changes in the state of the environment (Wahlin and Grimvall, 2008). Long term data collection and analysis enables determination of trend over time which is considered key in revealing environmental change. Dawe (2006) analysed the existence and significance of trend over time using statistical methods including moving averages, the Student's t test statistic, and Spearman's rank correlation coefficient. Fan *et al*., (2012) employed one way analysis of variance (ANOVA) in order to measure the variation of water quality parameter among stations and between dry and wet seasons in Pearl River Delta in China.

Multivariate statistical techniques including factor analysis and cluster analysis are known as suitable tools for obtaining consequentially reduced data and interpreting various parameters (Han *et al*., 2009; Xu *et al*., 2012; Wang *et al*., 2013). Wang *et al*. (2013) employed the Cluster Analysis and Principal Component Analysis/Factor Analysis to evaluate temporal/spatial variations in water quality and identify latent sources of water pollution in the Songhua River Harbin region. The cluster analysis grouped 6 monitoring sites into three regions which could assist in focussing the monitoring and rehabilitation efforts while reducing costs. The Principal Component Analysis\Factor Analysis indicated that the parameters responsible for water quality variation in the region were mainly related to organic pollution and nutrients.

Han *et al*. (2009) used Multivariate methods to study the water quality of the Nakdong catchment where the factor analysis indicated the strong effect of Biological Oxygen Demand, Chemical Oxygen Demand and Total Phosphate on the river. Cieszynska *et al*. (2012) used the Cluster Analysis to differentiate watercourses according to water quality. Different water courses were clustered according to various parameters including Dissolved Oxygen, Temperature, Biological Oxygen Demand, Chemical Oxygen Demand, Total Phosphate and Total Nitrogen. When applied for different watercourses, Cluster Analysis supports recognition of regions with similar physicochemical properties of water and enables detection of factors controlling water quality. Cluster Analysis is an extremely useful tool which supports interpretation of large and multidimensional sets of environmental data. Cieszynska *et al*., (2012) found that Cluster Analysis was beneficial as compared to other methods (e.g. principal components analysis) as it accounts for the whole variation in the data and no simplification of the information is necessary.

According to Papazova and Simeonova (2013), the Multivariate analysis studies are performed to try to assess the river water quality or to optimize the monitoring procedure. The Multivariate analysis also useful in determining the linkage of the sampling locations, trying to establish special relationships between and among sampling locations and parameters; detection of specific linkage between water quality parameters for identification of polluting sources; modelling of the contribution of each detected source to the formation of the total concentration of the given chemical tracer; and clarification of the whole data set structure. Statistical methods such as regression have also been widely used in analysis of water quality data (Khan *et al.*, 2003). All these methods involves the application of complex mathematical equations and statistical methods which are in most cases very difficult to understand by decision makers, managers and the general public. Water quality index is therefore chosen as it simplifies the water quality data for ease of understanding and quick conveyance of the message on the status of the water quality in the catchment.

2.6.2 Trend Analysis

Trend analysis determines whether the measured values of a water quality parameter increase or decrease over the period of record. Water quality variables are measured over time and space as part of water quality monitoring programs. Of interest to scientist and the general public is often whether or not a trend over time is present in the water quality variable and, if there is, to characterize and quantify this trend.

There exist two groups of statistical tools to calculate trends depending on the data set characteristics including the parametric method, based principally in linear and residual models, and the non-parametric method (Bouza-Dean˜o *et al.*, 2008). The parametric methods are more powerful than non-parametric ones, but they require the data be independent and normally distributed. Bouza-Dean˜o *et al.*, (2008) found that in the cases of data set with a seasonal component or with variables correlated, parametric techniques show false positives in some cases.

Water quality data have many characteristics that in most cases complicate statistical analyses. Because of the volume of data to be analyzed, and the various characteristics of the data (distribution, seasonality, missing observations, outliers, censored data, serial dependence), many trend analysis techniques such as classical parametric methods like regression, analysis of covariance, and traditional time series are either unsuitable or too time consuming to perform (Hamill *et al.*, 2003; Bouza-Dean˜o *et al.*, 2008). Consequently, such data are often analyzed using nonparametric methods.

Antonopoulos *et al.* (2001) found that testing water quality data for trend over a period of time has received considerable attention. According to Antonopoulos *et al.* (2001), the interest in methods of water quality trend arises for two reasons. The first is the intrinsic interest in the question of changing water quality arising out of the environmental concern and activity. The second reason is that only recently has there been a substantial amount of data that is amenable to such an analysis.

Accordingly, the seasonal Mann Kendall slope estimator to assess the magnitude of trends for each variable at each site is ideal (Hamill *et al*., 2003). According to Hamill *et al*. (2003), the minimum time period of monthly sampling over 5-year is required for trend detection power. According to Naddeo *et al*. (2013), Mann Kendall tests can be used when data are either incomplete or when a significant amount of them is missing (Xu *et al*., 2012). When data are collected from more than one sampling site within the same area or the same hydrological basin, it is worthwhile to evaluate these trends using non-parametric tests (Naddeo *et al*., 2013).

A general assessment about the presence or absence of trends can be meaningful if trends show precise direction, upward or downward the importance of determining trends assist in cases where there is a need to alter monitoring programme. Naddeo *et al*. (2013) recommended that when evidence of downward or steady-state trends is found in a sampling station it is possible to extend the sampling frequency up to a six months period but when strong upward trends are defined in a specific station, it is required to run accurate analyses, and no sampling frequency modifications should be allowed. Naddeo *et al*. (2013) found that nonparametric tests can be useful when planning water quality control and monitoring systems. With the rising costs of sampling and analysis and also being the critical aspect of water resources monitoring application of nonparametric methods, it is possible to obtain a reduction of the sampling expense of about 1/3 when downward trends are shown, with the possibility to redistribute resources in the monitoring sites that present peculiar criticalities (Naddeo *et al*., 2013).

2.6.3 Water Quality Index (WQI)

Water Quality Index is a scale used to estimate an overall quality of water based on the values of individual water quality parameters (Amadi *et al*., 2010; Alobaidy *et al*., 2010, Salih *et al*., 2012; Tyagi *et al*., 2013). It is a mathematical expression used to transform large quantities of water quality data into a single number and it is a measure of how the water quality parameters compare to the water quality guidelines or objectives for a specific area (Kannel *et al*., 2007; Mophin-Kani and Murugesan, 2011).

Sometimes referred to as water quality information communicator, it is considered the most powerful tool in communicating useful information to decision makers and the general public (Mophin-Kani and Murugesan, 2011). Kannel *et al.* (2007) observed that water resources professionals generally evaluated water quality variables individually and presented this information in terms of values or figures. While this technical language is understood within the water resources community, it does not readily translate into meaningful information to those communities having profound influence on water resources policy, the lay public and policy makers. Increasingly these communities expect a comprehensible response to their right to know about the status of their environment (Cude, 2001). The cooperation in management of the water resources is likely to improve when the public understand the status of water quality around them. The policy makers and decision makers will also do their bit too by developing proper policies and planning and funding necessary interventions aimed at improving the water quality (Alobaidy *et al.*, 2010).

Salih *et al.*, (2012) observed that it is difficult to determine the water quality from a large number of samples, each containing concentration for many parameters. The objective of water quality index is to turn complex water quality data into information that is understandable and used by the public (Pinto *et al.*, 2012). A water quality index based on some very important parameters can provide a single indicator of water quality (Thakor *et al.*, 2011; Salih *et al.*, 2012)). A great deal of consideration has been given to the development of WQI methods since Horton (1965) proposed the first WQI. The basic differences among these indices are the way their sub-indices were developed.

While appreciating the importance and usability of WQIs, it is important to understand the limitations of WQIs. There are limitations in the use of WQIs including the issue of loss of information by combining several variables to a single index value; the sensitivity of the results to the formulation of the index; the loss of information on interactions between variables; and the lack of portability of the index to different ecosystems (Tyagi*et al.*, 2013). A single number cannot tell the whole story of water quality as there are many other water quality parameters that are not included in the index but a WQI based on some very important parameters can provide a simple indicator of water quality for a particular resource (Kotadiya *et al.*, 2013). As a result the WQIs are not intended to replace a detailed analysis of environmental monitoring and modelling, nor should they be the sole tool for the management of water bodies (Armah *et al.*, 2012).

According to (Armah *et al.*, 2012) some the advantages of using water quality index include the fact that WQIs conveniently summarizes complex water quality data, it facilitates clear communication of results to a large general audience, it provides mechanism to gauge/trend several parameters over several years and lastly a wide range of parameters can be used simultaneously within the index, including the use of biological indicators (bacteria levels), physical parameters (dissolved oxygen, turbidity, dissolved solids), and chemical parameters (concentration of heavy metals, petroleum products). WQI eliminates the use of jargon and technical complexity in describing water quality. Looking at the overall objective of WQI, it can therefore be argued that WQI is central to decision-making and planning on water quality at different spatio-temporal scales as it strives to reduce an analysis of many factors into a simple statement (Armah *et al.*, 2012).

2.6.4 Water Quality Indices Types

There are different water quality indices computation methods currently. Horton (1965) was the first to develop the WQI in United States by selecting 10 most commonly used water quality variables like dissolved oxygen (DO), pH, coliforms, conductivity, alkalinity and chloride and has been widely applied and accepted in European, African and Asian countries. Modifications over time resulted in development of various water quality indexes recently. Bharti and Katyal (2011); Tyagi *et al.* (2013)found that most of the developed WQI types follow the same approaches as described in the following three steps:

1. Parameter Selection: This is carried out by judgment of professional experts, agencies or government institutions that is determined in the legislative area. The selection of the variables from the 5 classes namely oxygen level, eutrophication, health aspects, physical characteristics and dissolved substances, which have the considerable impact on water quality, are recommended
2. Determination of Quality Function (curve) for each parameter considered as the Sub-Index: Sub-indices transform to non-dimensional scale values from the variables of its different units (ppm, saturation percentage, counts/volume etc.).
3. Sub-Indices Aggregation with Mathematical Expression: This is frequently utilized through arithmetic or geometric averages.

Some of the WQI including Weight Arithmetic Water Quality Index (WAWQI), National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), Oregon Water Quality Index (OWQI) have been developed and are applied in specific areas. These indices are often based on the varying number and types of water quality parameters as compared with respective standards of a particular region and therefore depending on the choice of parameters, the results at any given time and combination of parameters will differ.

National Sanitation Foundation Water Quality Index (NSFWQI)

This WQI is based upon nine water quality parameters such as temperature, pH, turbidity, faecal coliform, dissolved oxygen, biochemical oxygen demand, total phosphates, nitrates and total solids (Bharti and Katyal, 2011). The water quality data are recorded and transferred to a weighting curve chart, where a numerical value of Q_i is obtained. The mathematical expression for NSF WQI is given by

$$\mathbf{WQI} = \sum_{i=1}^{n} I_i W_i$$

Where, I_i is sub-index for i^{th} water quality parameter; W_i is weight associated with i^{th} water quality parameter; n is number of water quality parameters.

Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI)

According to Bharti and Katyal (2011), this method has been developed to evaluate surface water for protection of aquatic life in accordance to specific guidelines. The parameters related with various measurements may vary from one station to the other and sampling protocol requires at least four parameters, sampled at least four times. The calculation of index scores in CCME WQI method can be obtained by using the following relation:

$$\mathbf{WQI} = 100 - \left(\frac{\sqrt{F_1 2 + F_2 2 + F_3 2}}{1.732}\right)$$

Where, F_1= [No. of variables whose objectives are not met /Total no of variables]*100; F_2 represents Frequency: The frequency by which the objectives are not met, F_2= [No of tests whose objectives are not met /Total no of tests]*100; F_3 represents Amplitude: The range to which the failed tests are above the guideline. It is determined through three steps as follows:

(a) The case when the test value must not exceed the objective:

The number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective is called an "excursion).

Excursion $=\left(\frac{Failed\ Test\ Value_i}{Objective_j}\right)-1$

(b) The case in which the test value must not fall below the objective:

Excursion $=\left(\frac{Objective_j}{Failed\ Test\ Value_i}\right)-1$

(c) The collective amount by which the individual tests are out of compliance is calculated summing the excursions of individual tests from their objectives and then dividing the sum by the total number of tests. This variable referred to as the normalised sum of excursions (nse) is calculated as follows:

nse $=\left(\frac{\sum_{i=1}^{n} excursion_i}{number\ of\ tests}\right)$

F3 is then calculated by an asymptotic function that scales the normalised sum of the excursion from objectives (nse) to yield a value between 0 and 100.

F3 $=\left(\frac{nse}{0.01nse+0.01}\right)$

Oregon Water Quality Index (OWQI)

Tyagi *et al.* (2013) observed that this method combines eight water quality variables into a single number. The parameters covered in this method are temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), pH, ammonia and nitrate nitrogen, total phosphorus, total solids and faecal coliform. The original OWQI was designed after the NSFWQI where the Delphi method was used for variable selection. It expresses water quality status and trends for the legislatively mandated water quality status assessment. The index is free from the arbitration in weighting the parameters and employs the concept of harmonic averaging. This WQI allows the most impaired variable to impart the greatest influence on the WQI and it gives the significance of different variables on overall water quality at different times and locations (Poonam *et al.*, 2013). The mathematical expression of this WQI method is given by

$$\textbf{WQI} = \sqrt{\frac{n}{\sum_{i=1}^{n}\frac{1}{{SI_i}^2}^2}}$$

Where, SI_i is sub-index of i^{th} parameter obtained from the following expression, n= number of sub-indices.

$SI_i = W_i * q_i$

Where W_i is Weighting factor and q_i is the rating based on concentration of i^{th} parameter

Weighted Arithmetic Water Quality Index Method

Weighted arithmetic water quality index method classified the water quality according to the degree of purity by using the most commonly measured water quality variables (Tyagi *et al.*, 2013). The method has been widely used by the various scientists and the calculation of WQI was made by using the following equation:

$$WQI = \sum_{i=1}^{n} q_i \; w_i$$

Where q_i is the quality of the i^{th} parameter, w_i is the relative weight of the i^{th} parameter while n is the number of the water quality parameters applied.

The quality rating scale (q_i) for each parameter is calculated by using this expression:

$$q_{i=\left(\frac{C_i}{S_i}\right)* 100}$$

Where, C_i is estimated concentration of i^{th} parameter in the analysed water, S_i is the ideal value of this parameter which is 0 (except pH =7.0 and DO = 14.6 mg/l) is recommended standard value of i^{th} parameter.

A comparison of the four water quality indices by Tyagi *et al.* (2013) is presented in Table 2.1.

Table 2.1Merits and Demerits of Selected Water Quality Indices (Tyagi *et al.* (2013)

Merits	Demerits
National Sanitation Foundation (NSF) WQI	
• Summarizes data in a single index value in an objective, rapid and reproducible manner. • Evaluation between areas and identifying changes in water quality. • Index value relate to a potential water use. • Facilitates communication with lay person.	• Represents general water quality, it does not represent specific use of the water. • Loss of data during data handling. • Lack of dealing with uncertainty and subjectivity present in complex environmental issues.
Canadian Council of Ministers of the Environment (CCME) WQI	
• Represent measurements of a variety of variables in a single number. • Flexibility in the selection of input parameters and objectives. • Adaptability to different legal requirements and different water uses. • Statistical simplification of complex multivariate data. • Clear and intelligible diagnostic for managers and the general public. • Suitable tool for water quality evaluation in a specific location • Easy to calculate • Tolerance to missing data • Suitable for analysis of data coming from automated sampling. • Combine various measurements in a variety of different measurement units in a single metric.	• Loss of information on single variables. • Loss of information about the objectives specific to each location and particular water use. • Sensitivity of the results to the formulation of the index. • Loss of information on interactions between variables. • Lack of portability of the index to different ecosystem types. • Easy to manipulate (biased). • The same importance is given to all variables. • No combination with other indicators or biological data • Only partial diagnostic of the water quality. • F_1 not working appropriately when too few variables are considered or when too much covariance exists among them.
Oregon WQI	
• Un-weighted harmonic square mean formula used to combine sub-indices allows the most impacted parameter to impart the greatest influence on the water quality index. • Method acknowledges that different water quality parameters will pose differing significance to overall water quality at different times and locations. • Formula is sensitive to changing conditions and to significant	• Does not consider changes in toxics concentrations, habitat or biology. • To make inferences of water quality conditions outside of the actual ambient network site locations is not possible. • Cannot determine the water quality for specific uses nor can it be used to provide definitive information about water quality without considering all appropriate physical, chemical and biological data. • Cannot evaluate all health hazards (toxics, bacteria, metals, etc.).

impacts on water quality.	
Weight Arithmetic WQI	
• Incorporate data from multiple water quality parameters into a mathematical equation that rates the health of water body with number. • Less number of parameters required in comparison to all water quality parameters for particular use. • Useful for communication of overall water quality information to the concerned citizens and policy makers. • Reflects the composite influence of different parameters i.e. important for the assessment and management of water quality. • Describes the suitability of both surface and groundwater sources for human consumption.	• WQI may not carry enough information about the real quality situation of the water. • Many uses of water quality data cannot be met with an index. • The eclipsing or over-emphasizing of a single bad parameter value • A single number cannot tell the whole story of water quality; there are many other water quality parameters that are not included in the index. • WQI based on some very important parameters can provide a simple indicator of water quality.

2.7 EVOLUTION OF WATER QUALITY MONITORING IN SOUTH AFRICA

Until the 1990s, South Africa focused on controlling the natural water system to address the lack of water for agricultural and industrial development. Very little attention was paid to the effect of these development activities on the natural environment, including the water environment (Nomquphu, Braune and Mitchell, 2007). The country's world-class hydrological monitoring programmes were focused mainly on surface water quantity and, to a lesser extent, on water quality for the purpose of water supply and infrastructure management. The advent of the National Water Act of 1998 (NWA) has shifted the focus from supply-driven water development to managing a scarce resource in which on going, integrated monitoring and assessment are critical for the management and protection of water resources as stipulated under Chapter 14 of the Act.

According to van Niekerk *et al.* (2009) these requirements resulted in emerging of various water quality information requirements that led to the initiation of a number of additional national water quality monitoring programmes, namely:

(a) The National Microbial Water Quality Monitoring Programme (NMMP),
(b) National Chemical Monitoring Programme (NCMP)
(c) The National Eutrophication Monitoring Programme (NEMP),
(d) The National Toxicity Monitoring Programme (NTMP),
(e) The River Health Programme (RHP) and
(f) The National Radioactivity Monitoring Programme (NRMP).

The NCMP is the oldest monitoring programme. Although the NCMP has been operated by DWA over the period of more than 30 years, it had to be aligned with the requirements of National Water Act. Until 2003 the NCMP had grown into a large white elephant with no set monitoring objectives or a documented design (van Niekerk, 2004). According to van Niekerk *et al.* (2009), the NCMP focussed on areas were the suitability of water for irrigation and the nutrient concentrations at hydrometric flow gauging stations and reservoirs. These monitoring efforts were motivated by the fact that significant changes in salinity can have serious implications for a number of water uses, such as irrigation, live stock watering, domestic use, industrial use, biodiversity (van Niekerk *et al.*, 2009). The realisation by the then Department of Water Affairs and Forestry that the monitoring of major salts is insufficient for detection of long term changes in water quality and changing legislative requirements as well as dwindling fresh water resources led to the design and implementation of additional national monitoring programmes for eutrophication, microbiology, ecosystem health, toxicity and radioactivity to determine the long term data for trend detection (van Niekerk *et al*., 2009).

The review of water quality monitoring and addition of water quality monitoring programmes also stems from the changing dynamics in terms of the approach to water quality management. The NWA adopts the Integrated Water Resources Management (IWRM) principles and as a result makes the distinction between “water quality” and “water resource quality”. As per NWA, water quality merely refers to chemical, physical and biological characteristics of the water component of the water resource while the water resource quality consists of not only the water component, but also other aspects of the aquatic ecosystem, such as riparian vegetation, water quantity, geomorphology (DWAF, 1998: DWAF, 2004). The monitoring sites for NCMP are on the main stream of the river and are often located on bridges or river gauging stations.

van Niekerk *et al*. (2002) stated that there are three tiers of water quality monitoring in South Africa, namely national level, catchment (regional) level and local level. The main objective of a national monitoring programme is to provide information on the status and trends of water quality in the country as a whole. Catchment (regional) monitoring programmes focus on the provision of information for catchment management purposes. Catchment monitoring is the responsibility of catchment management agencies. The objective of local monitoring programmes is to fulfil the information needs of local organizations and groups. Local monitoring is currently being conducted by municipalities, water user associations and water users. The latter is only responsible as part of water use licence conditions and data is reported to Department of Water Affairs as a licensing authority. The level of detail (spatially and temporally) needed generally increases as the geographic area decreases. The three levels of monitoring are not necessarily independent as data and information from the various levels of programmes can feed into each other to help ensure more cost-effective data collection (van Niekerk *et al*., 2002). Data from the national monitoring programmes can in turn feed into international monitoring programmes.

2.8 WATER QUALITY MANAGEMENT IN THE CITY OF JOHANNESBURG

COJ is located on a major hydrological divide demarcating the two major catchments including Jukskei which drains towards the Limpopo River which ultimately discharges into the Indian Ocean and Klip catchment which is drained by Klip River which flows into Vaal River and ultimately discharges into the Atlantic Ocean. Incidents of water pollution due to poor storm water drainage systems, sewer leaks, inadequate sanitation, effluent discharge, mining, litter and silt loads due to erosion are frequent (Burke and Bokako, 2004). The Jukskei River is fed by a number of streams which drain some highly developed areas and urban centres of COJ such as Sandton, Randburg and Midrand. The catchment also boasts a number of industrial areas such as Wynberg, Modderfontein, Kya Sands and Linbro Park. Informal settlements which are having severe impacts on the quality of surface water resources are growing immensely. Some of the major informal settlements within the catchment are located in Diepsloot, Alexandra, Ivory Park, Zand spruit and Kya Sands.

2.8.1 City of Johannesburg Water Quality Monitoring Programme

One of the critical aspects of water quality management in the COJ is its surface water quality monitoring programme. COJ runs a water monitoring network composed of 120 sampling points (Burke and Bokako, 2004). A total of 62 surface water quality monitoring points are distributed across the Jukskei River and its tributaries including Little Jukskei, Sand spruit, Modderfontein spruit, Braamfontein spruit, Pampoen spruit, Kaal spruit.

There are no monitoring objectives in place, no proper management of the network, no document exist informing the design of the network. The rapid industrial development, influx of people from rural areas and proliferation of informal settlements have put a lot of pressure on the need for development of a cost effective, optimal water quality monitoring network. The other aspect that comes with this growth is escalating expenditure on water quality monitoring for COJ while budgets become even more limited. Coverage of sampling and continuity with respect to sample collection and analysis becomes an issue of serious concern in this regard. There is a need to develop or redesign COJ water quality monitoring network applying scientific approaches that would optimize response to the needs and objectives of the city.

Location of the sampling stations across COJ Rivers were selected based on accessibility, bridges, existing projects (Alexandra Renewal Project and other projects such as COSMO city), location of waste water treatment works (WWTW). Samples were also collected by Environmental Health and submitted to Johannesburg Water Cydna laboratory owned by COJ on a monthly basis. Water samples are collected once per month from each monitoring point and submitted to Cydna lab for chemical and bacteriological analysis. The collected samples are analysed for conventional parameters including turbidity, total dissolved solids, pH, conductivity, and nutrients (ortho-phosphate, total phosphate, ammonia-nitrogen, nitrate+nitrite- nitrogen, total nitrogen) as indicators for chemical water quality, which assess the presence of chemicals and nutrients due to illegal industrial effluent discharges, domestic activities, and chemical impact of sewage pollution. *E.coli* is being measured to determine the impacts of sewage pollution.

Other additional parameters reported separately include heavy metals as an indicator of pollution from industrial activity, sewage, and other natural processes including weathering. This is done once per year during dry season. Chlorophyll monitoring is done on a monthly basis along with chemical sampling but sampling is only done on impoundments to determine growth of algae. Cholera monitoring only runs during the wet seasons which commences from October and ends in March every year. This is because micro-organisms (*Vibrio Cholerae* strains) multiply very quickly when the water temperature is above 15 degrees Celsius during the warmer seasons. There are 8 monitoring sites selected for this purpose from 120 sampling sites and this is based on areas of constant high levels of Esteria coli (*E.coli*) counts near dense settlements such as Diepsloot, Ivory park and Alexandra. The *E. Coli* is used as an indicator for sewage pollution.

2.8.1.1 Water Quality Data

COJ water quality data is received from Cydna laboratory in an excel spreadsheet format. Two officials, each responsible for a specific catchment are charged with the responsibility of managing the water quality data. These include among others analysis, interpretation and reporting among other responsibilities. The data is received via emails and hard copies of printed results. The data is received as monthly and quarterly records. The quarterly records are organised into May-July, August-October, November-January and March-April each year. May-July and March-April are regarded as dry season while August-October and November-January are regarded as wet season.

2.8.1.2 Analysis, Interpretation and Reporting

The data is analysed on a spreadsheet by simply comparing the measured values with the water quality guidelines published by Department of Water Affairs (DWAF, 1996a). Individual water quality parameters are assessed for a specific month and monitoring point compared to values of the previous month and similar month the previous year. The data is also averaged on quarterly basis according to municipal financial year which runs from June to April the following year. Four quarterly reports are generated each year. These quarterly reports are therefore useful in determining the pollution levels. The quarterly averages are also compared to previous quarter and the similar quarter the previous year.

The quarterly values are evaluated and if the values for a specific monitoring point indicate an unacceptable water quality as compared with DWA target water quality range, it is declared a water quality hotspot which is then dealt with through a focussed program where an action plan containing the description of the problem, actions required, responsible institution and time frames. The report still contains a great deal of figures and values. The report is produced by Catchment and Water Quality Management within the Water and Biodiversity Management Directorate of Environment and Infrastructure Services (EISD)for consideration by the unit manager.

The report forms part of the EISD Departmental performance reports that are assessed by various committees of the COJ. These reports are also used to budget for planning purpose in preparation of the budgets for rehabilitation measures and pollution control measures. The Unit Manager being the first decision maker makes sense of the report and identifies problem areas to inform the budgeting for specific activities and projects to address the water quality problem. Once the budgets have been made available, necessary activities and related projects are undertaken and the monitoring program continues to assist in tracking the change in water quality. An example of similar projects include river bank stabilisation by constructing gabions as well as river clean up projects which are also linked with education and awareness campaigns to educate communities on environmental issues.

There are various external stakeholders that also use the data including Department of Water Affairs, Catchment Management Forums, Residents Associations, Research Institutions, Canoeing clubs and other interested and affected parties. Burke and Bokako (2004) found that while incidents of water pollution due to poor storm water drainage systems, sewer leaks, inadequate sanitation, effluent discharge, mining, litter and silt loads due to erosion were frequent, the analysis, interpretation of water quality data was inadequate in the COJ to paint the whole picture of state of water quality of their water resources. In the COJ, there were many institutions which concentrated on different aspects of water quality management which led to fragmented approaches. Data generated was not properly converted to information causing confusion to decision makers. Necessary rehabilitation measures and pollution control projects could not be implemented as pollution hotspots were not properly identified.

2.8.2 Water Quality Standards

The DWAF guidelines for aquatic ecosystems protection (DWAF, 1996a) as well as Jukskei and Klip River guidelines (www.reservoir.co.za) are used to determine the water status using the Microsoft excel spreadsheet. The measured values are compared with the guidelines to determine the category at which the value falls (Ideal, Acceptable, Tolerable or Unacceptable).

2.8.3 Pollution Control and Enforcement

Pollution control and enforcement is the function of sector departments including Environment and Infrastructure Services Department (EISD), Environmental Health and Johannesburg Metro Police Department (JMPD). As soon as EISD receives the data from the lab, it is circulated among service delivery institutions including Joburg Water sewer department, Housing, ARP, Urban Management, and Environmental Health. At the same time, EISD analyses the water quality data. COJ has developed public health bylaws which prohibit any resident or business entity to pollute the environment. These are enforced by Environmental Health and JMPD bylaw unit who can issue notices and fines or take legal action against the polluter. Water quality data also becomes very useful as evidence in this case.

EISD assess the data and identify pollution from the data and alerts Environmental Health Officers. As soon as Environmental Health receives the water quality data and the alerts, site visits are conducted to sampling points indicating evidence of pollution for investigations. Investigations are also conducted to areas of pollution reported by community members to the City. Once the source of pollution has been located, Environmental Health and JMPD issue compliance notices and fines depending on type of offense as specified by COJ bylaws.

In COJ, most cases of environmental pollution emanates from informal settlements, disused and dilapidated buildings, Waste Water Treatment Works which are owned and operated by other City departments or municipal owned entities. Informal settlements and dilapidated buildings are the responsibilities of Housing Department while Waste Water Treatment Works are operated by Joburg Water. Environmental Health is prohibited from issuing a compliance notice or imposing a fine to another City's department. The maximum amount that Environmental Health can issue as specified in the bylaws is R1500 which is very little.

Companies decide to discharge waste water to rivers and pay the fines. Although systems are in place, the pollution control and enforcement is not effective in the COJ leaving the rivers continually polluted.

The managers and decision makers in the COJ have problems understanding the water quality reports being produced currently. As a result, very minimal efforts are being made to identify, prioritise and rehabilitate or resolve water pollution in the COJ. The WQI would help to analyse and simplify the complex water quality data and produce quality reports to enable decision making for necessary pollution control measures.

2.9 SUMMARY OF LITERATURE REVIEW

In summary, the review of literature shares some light on the background of integrated water resources management and the importance of water quality monitoring and the complex nature of water quality monitoring data. To bring the matter closer, the evolution of water quality monitoring in South Africa and the City of Johannesburg indicate that necessary tools which include among others the institutions and legislative framework are in place to facilitate the water quality monitoring efforts. Various methods of analysing and interpreting the data to produce necessary information have been applied by governments and other institutions. Burke and Bokako (2004) also found that water quality monitoring data formed the baseline of identification of water pollution hotspots and this was being compromised by improper water quality data interpretation and reporting. Different methods of analysing and reporting water quality data have been applied as alluded to in Section 2.6.3 and the use of water quality index method is considered a proper step towards addressing this. There is a need to determine the trend over time especially in areas where pollution is detected as this can assist in deciding on a water quality hot spots (areas of excessive and continuous pollution) to optimise resources.

CHAPTER 3: STUDY AREA AND DATA PREPARATION

3.1 THE JUKSKEI RIVER CATCHMENT

Jukskei catchment is the main catchments in the northern part of the City of Johannesburg and can be divided into several sub-catchments as shown on Figure 3.3. The sub-catchments of Jukskei include the Braamfontein spruit, Wilge spruit, Modderfontein spruit, Upper Jukskei, Sand spruit, Middle and Lower Jukskei, Klein Jukskei, Kaalspruit and Upper Jukskei. Sections 3.1.1 to 3.1.5 provide background information on the Jukskei.

3.1.1 Climate

Climatic conditions in the area are temperate, with strongly seasonal rainfall patterns. Most rainfall (85 to 90%) occurs as thunderstorms during the summer period of October to April and the Mean Annual Precipitation (MAP) ranges from 650 to 900 mm (COJ, 2008; Schoeman, 1976). The MAP is relatively uniform across most of the catchment. Winter conditions across the catchment are cold and dry while warm to hot during summer.

The mean annual temperature ranges between 18 and 20°C. Maximum and minimum temperatures are experienced during January and July respectively. Summer time temperatures average 25.76°C and the minimum average is 16.83°C; winter temperatures average about 13°C and only occasionally dip below freezing, with the minimum average being 5°C. Incidences of frost from (13-42 days) have been recorded, but are longer at higher elevations (Mucina and Rutherford, 2006).The region experiences about eight hours of sunlight per day in both winter and summer (SA Weather Bureau, 1997).

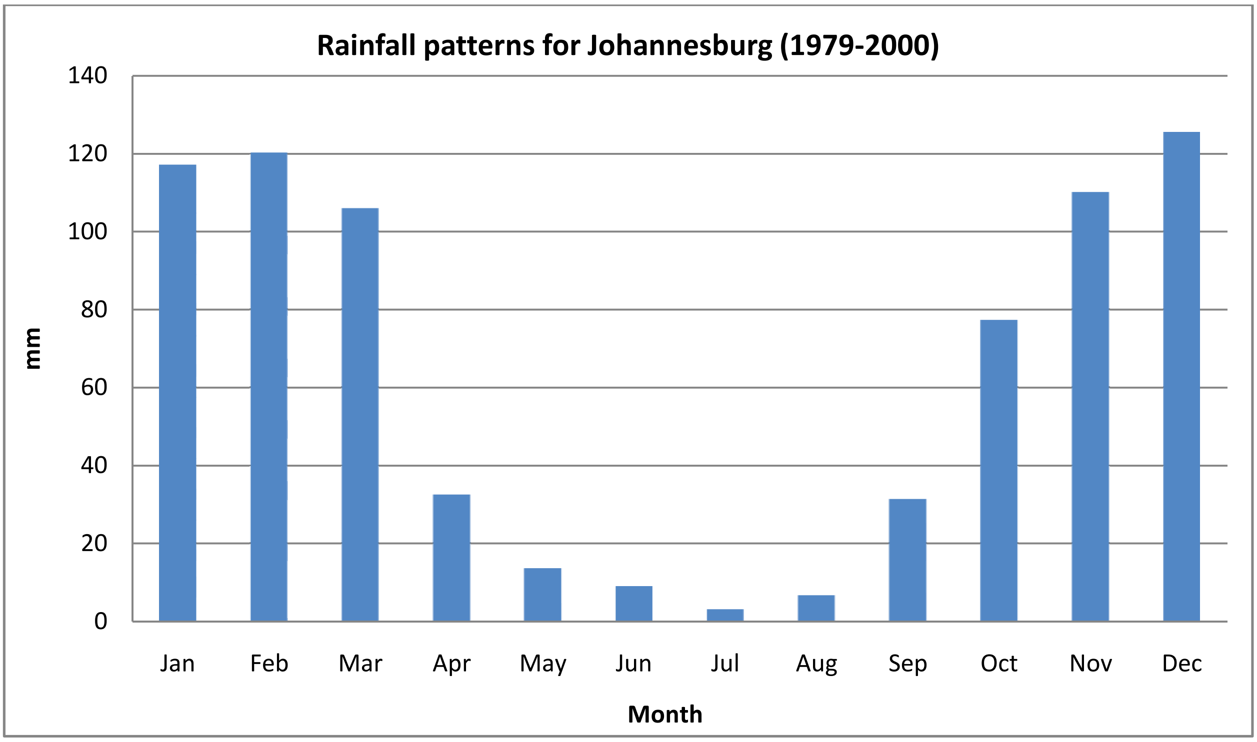

Figure 3.1Average monthly rainfall patterns (Johannesburg International Airport station 1979-2000 data) (CSAG, 2014).

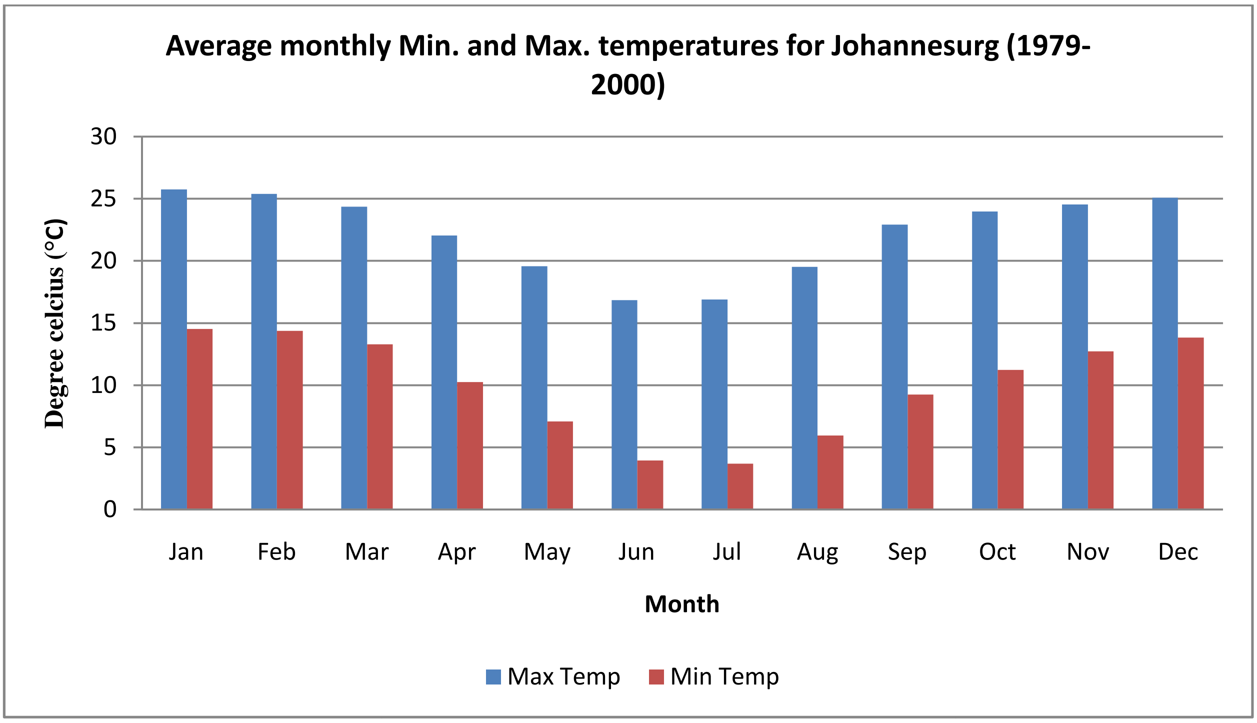

Figure 3.2 Average monthly temperatures (Johannesburg International Airport station 1979-2000 data) (CSAG, 2014).

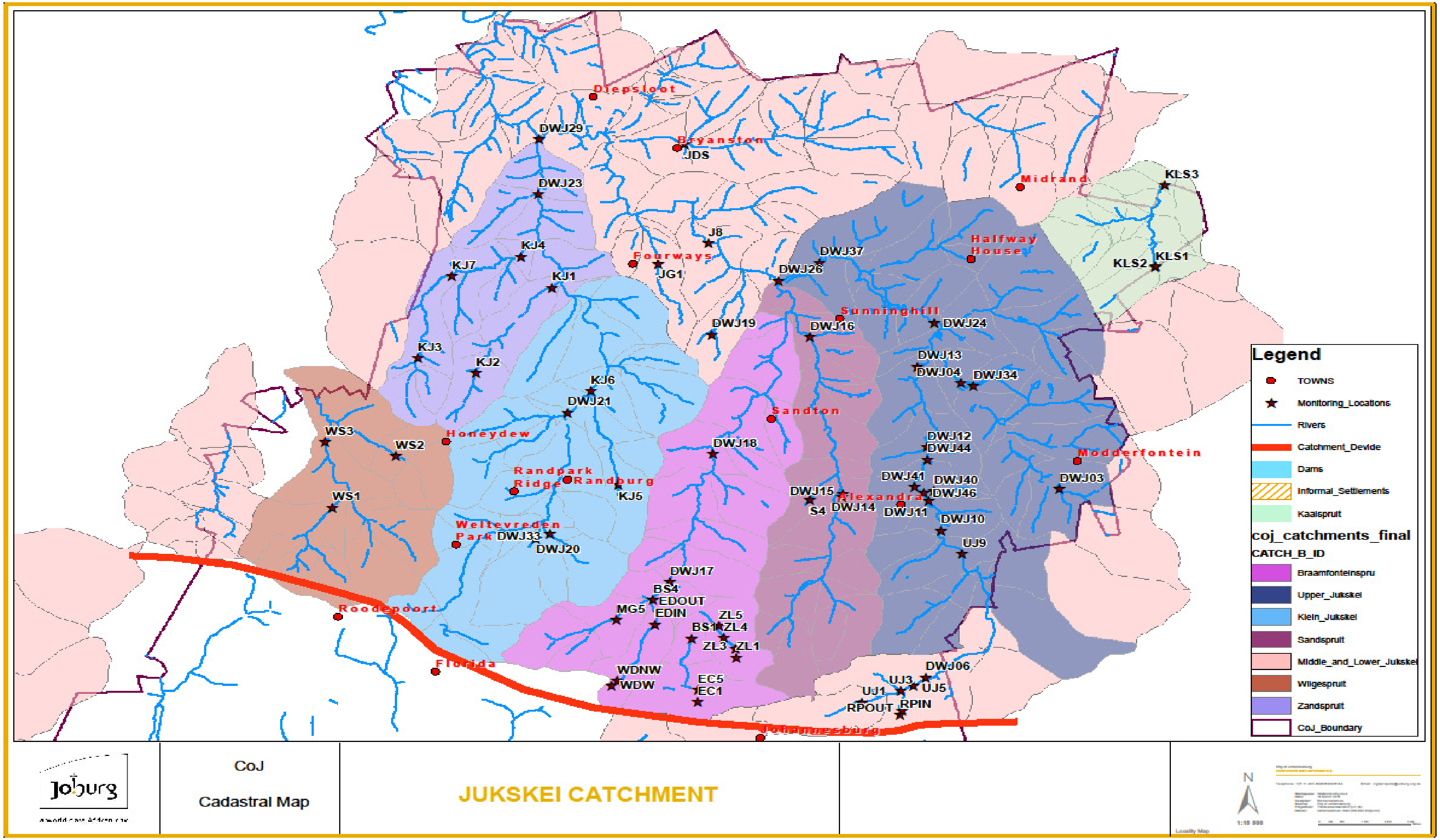

Figure 3.3Jukskei Sub-catchments

3.1.2 Vegetation and Land Use

The upper reaches of Jukskei catchment around Johannesburg a total of 16.1% is covered by trees both non-indigenous, imported, forest and residual indigenous forest. Adjoined by green open spaces, Johannesburg's trees form a system of soft, ecological spaces to represent something unique in an otherwise pressurised urban environment, and to show the complex and contradictory nature of urban form (Schäffler and Swilling, 2013).

The catchment is made up by two vegetation biomes, namely the Grassland and Savanna biomes (Mucina and Rutherford, 2006). These two biomes incorporate various bioregions, being Dry Highveld Grassland, Mesic Highveld Grassland and Central Bushveld. The vegetation types with the most amount of transformation the catchment include Rand Highveld Grassland, Gauteng Shale Mountain Bushveld and Egoli Granite Grassland. The remaining vegetation is highly fragmented, due to cultivation, urbanisation and mining/quarrying. Natural features outside of conservation areas are at risk of being threatened from development and land use change, i.e. parts of the ridges in the central and southern portions of the city, koppies and plains (Mucina and Rutherford, 2006).

The upper catchment is characterised by the highly urbanised towns and townships and industrial areas of Johannesburg, Mogale, Ekurhuleni and Tshwane Metropolitan municipalities. The southern catchment area (northern Johannesburg) is densely populated and heavily industrialised, whereas the northern part consists mainly of agricultural areas. The Jukskei-Crocodile River system received effluent from many different sources including power station blow-down (mineralising effect), industrial and sewage effluent (Allanson,1961). The Crocodile River drained what was then a predominantly agricultural area and accordingly contained water of a higher quality (Allanson, 1961). Mining activities in the catchment include sand mining from the river and quarries, the risk of Acid Mine Drainage has not been established in the Jukskei catchment. The impacts of informal settlement are severe across the catchment. The main threat of industrial pollution relates to AECI explosives and Kelvin power station and other light industries spread around the catchment.

3.1.3 Topography and Drainage

The Jukskei catchment is largely located in the Highveld region of South Africa. The topology in the northern suburbs of the Johannesburg is characterised by an undulating profile which is formed by a series of “koppies”. These koppies have an altitude of between 1

275 to 1 450 m.a.s.l in the northwest and between 1 450 to 1 600 m.a.s.l in the northeast. Just south of the Johannesburg CBD, quartzites form the east west striking Witwatersrand Ridge, South Africa's major watershed with an altitude of between 1 700 to 1 805 m.a.s.l (COJ, 2010). Generally the altitude of the catchment ranges between 1200 and 1800m above sea level.

Jukskei catchment forms part of the Crocodile West Marico Water Management Area. The catchment is drained by the Jukskei-Crocodile river system. Other prominent tributaries of the Jukskei River include Modderfontein spruit, Kaal spruit, Klein Jukskei, Sand spruit and Braamfontein spruit. The Jukskei River has its source in the Witwatersrand mountain range at a height of 1 700 m.a.s.l. The northern suburbs of Johannesburg, as well as parts of adjacent cities such as Kempton Park and Krugersdorp are situated in this sub-catchment.

3.1.4 Geology and Soils

The Jukskei catchment consists mostly of sedimentary rock and quartzitic rocks, Magaliesberg being the prominent feature. Large portions of the catchment composed of the halfway house granite and basement granitic rocks with portions of quartzite of the transvaal supergroup and Ventersdorp lavas towards the catchment divide which runs east-west direction known as Witwatersrand ridge (Huizenga and Harmse, 2005).

Soil types of the catchment are broadly classified as moderate to deep clayey loam in most of the catchment. Most of the clayey loam soils in particular are highly suitable for commercial agriculture when sufficient water is provided (DWAF, 2005).

3.1.5 Population and Settlement Pattern

Of the 4.3 million population of Johannesburg, about 1.25 million people reside in the Jukskei catchment with most of them residing in Alexandra, Diepsloot and Ivory Park townships (COJ, 2010).

The Jukskei catchment encompasses major urban and informal parts of Johannesburg which are densely settled (DWAF, 2005). These include areas such as Alexandra, Ivory Park, Midrand, Sandton, Johannesburg CBD, Randburg, Diepsloot, Modderfontein and Fourways. Diepsloot, Zandspruit, Alexandra and Ivory Park areas are comprised mostly informal dwelling which are poorly serviced and therefore create major environmental challenges on Jukskei catchment.

3.2 DATA PREPARATION

The study involves the analysis of available surface water quality data from the City of Johannesburg (COJ) water quality monitoring programme. The data comprised monthly records of the 62 monitoring points on the following parameters: pH, Chemical Oxygen Demand (COD), Ammonia (NH_4), Nitrate, Nitrite, Sulphate (SO_4^{2-}) and Phosphate (PO_4^{3-}). The City of Johannesburg has discontinued analysing for Turbidity since December 2012 and as such it was omitted from the analysis and WQI determination. The Escherichia coli (*E.coli*) data was also omitted due to unreliability where highly contaminated areas are in some cases reported zero *E.*coli. The appropriate WQI was therefore determined using the monthly records averaged into quarterly records for each of the seven parameters.

Before using data, it is imperative that its quality be first assessed. Four years of data for the periods 2010 to 2013 from the 62 monitoring stations was available for analysis. The four years data was averaged into quarterly records for each variable in each monitoring point on Excel spreadsheet. This is in line with the reporting methods of COJ which requires that the four reports according to municipal financial year plan be prepared and submitted during the four quarters of the year (May-July, August-October, November-January and February-April).

All parameters are measured in mg/L, except for pH which does not have units. The assessed data time series (averaged quarterly concentrations) were plotted on a log scale to accommodate both smaller and larger values. The plotted data for selected monitoring points (Figures 3.4through to Figure 3.13) reveal the nature of any environmental data with great variability over the study period in each of the selected sites which are shown in figure 3.3.

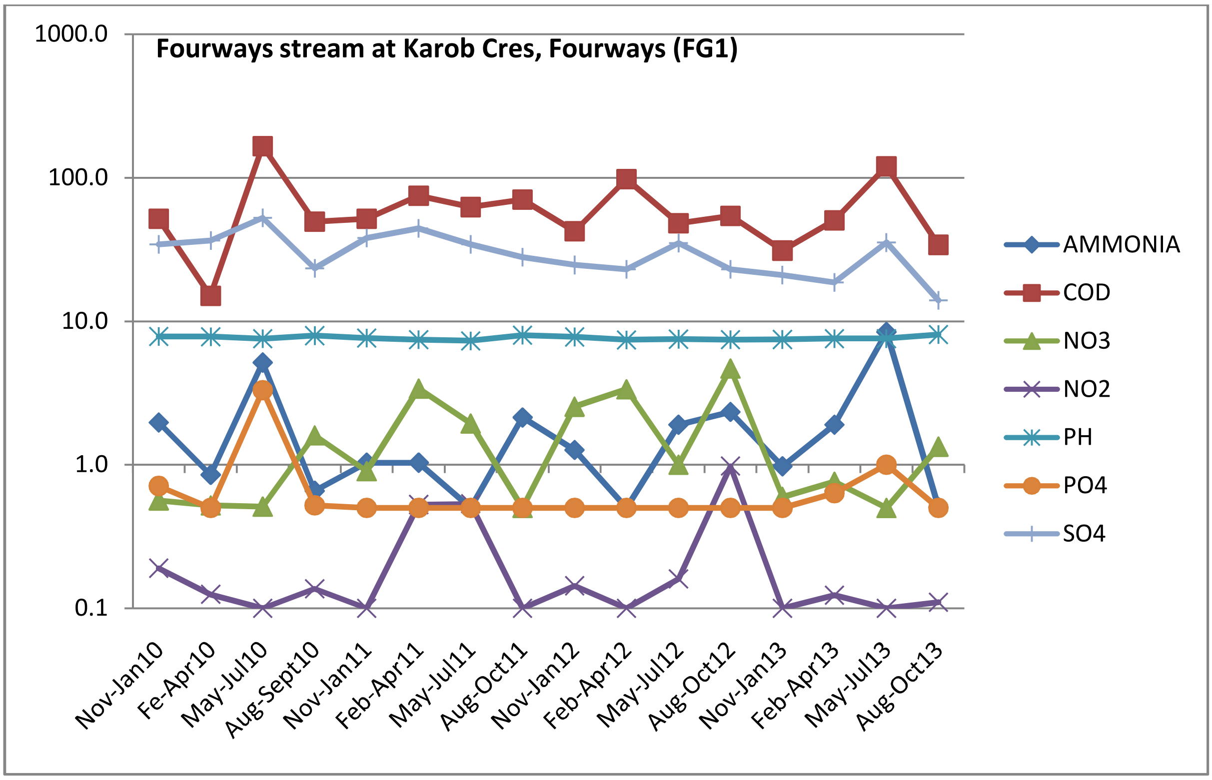

Figure 3.4Log plots of Physico-chemical data at FG1

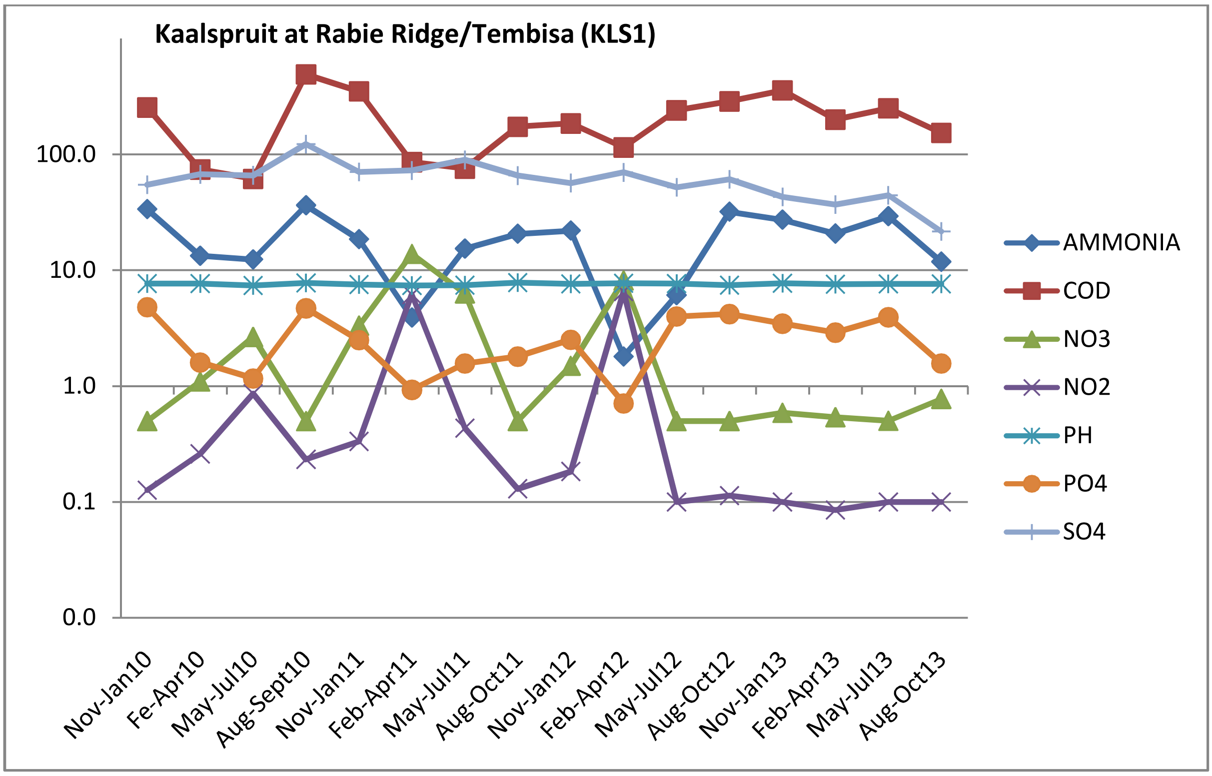

Figure 3.5Log plots of Physico-chemical data at KLS1

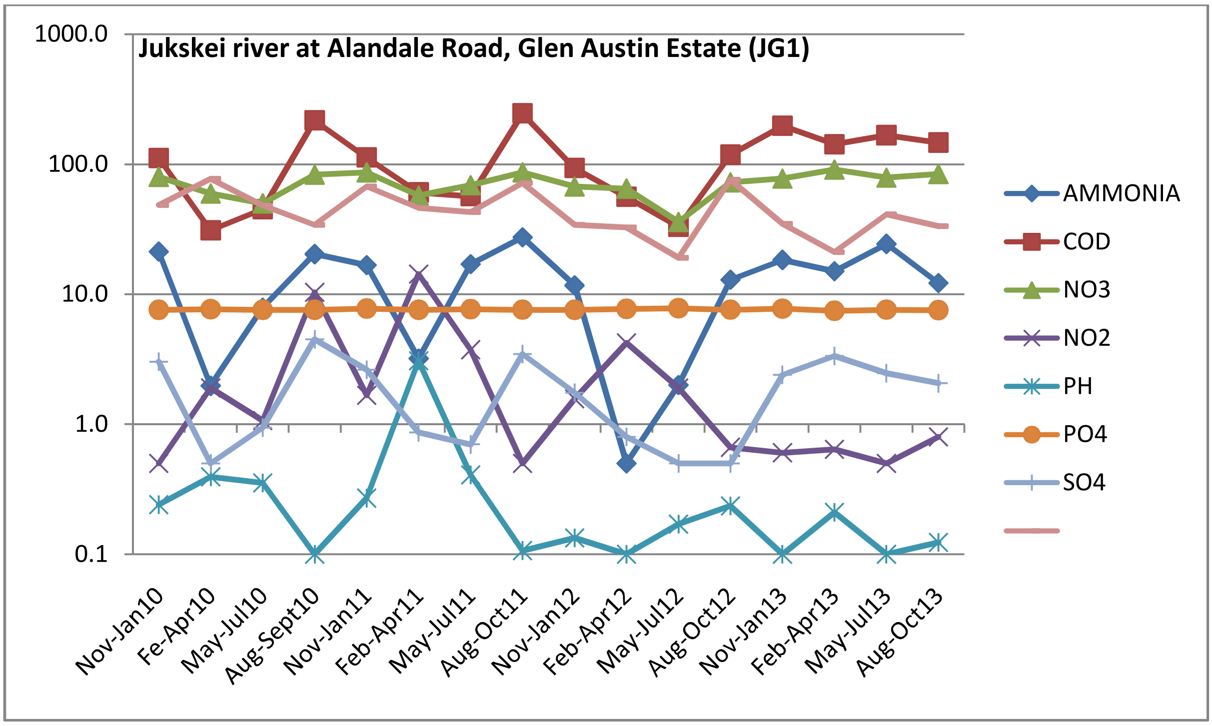

Figure 3.6Log plots of quarterly Physico-chemical data at JG1

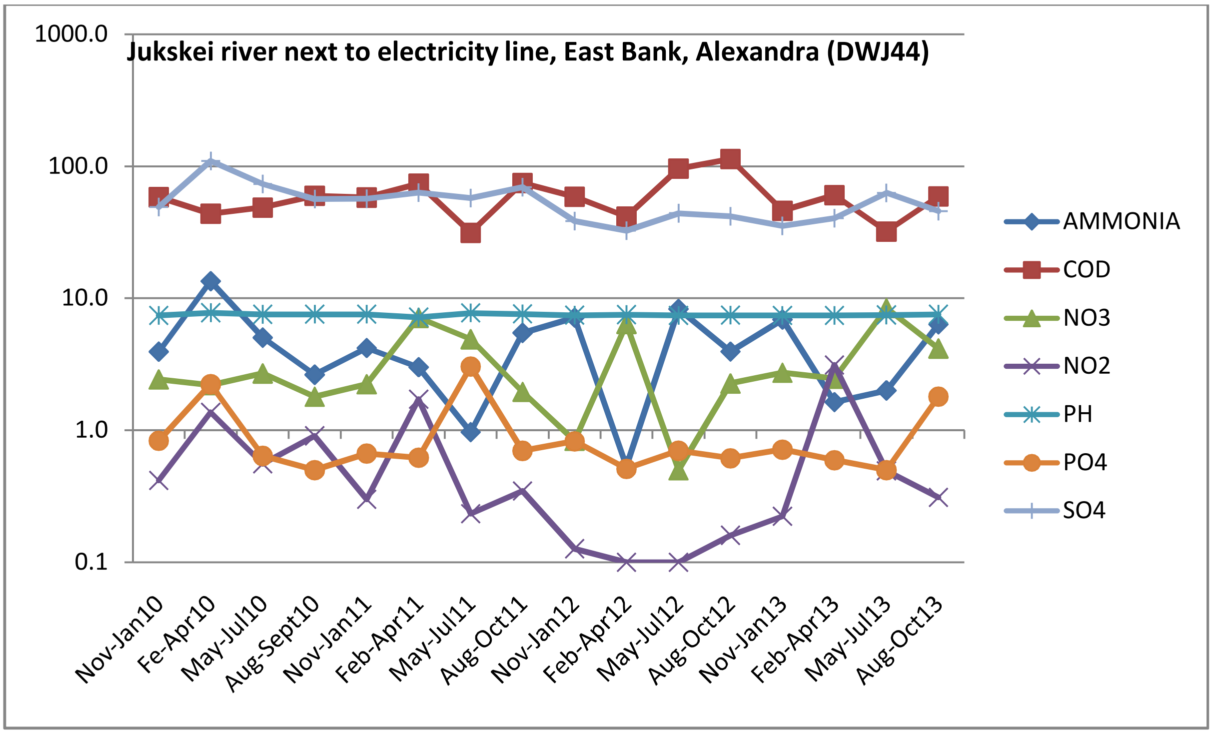

Figure 3.7 Log plots of quarterly Physico-chemical data at DWJ44

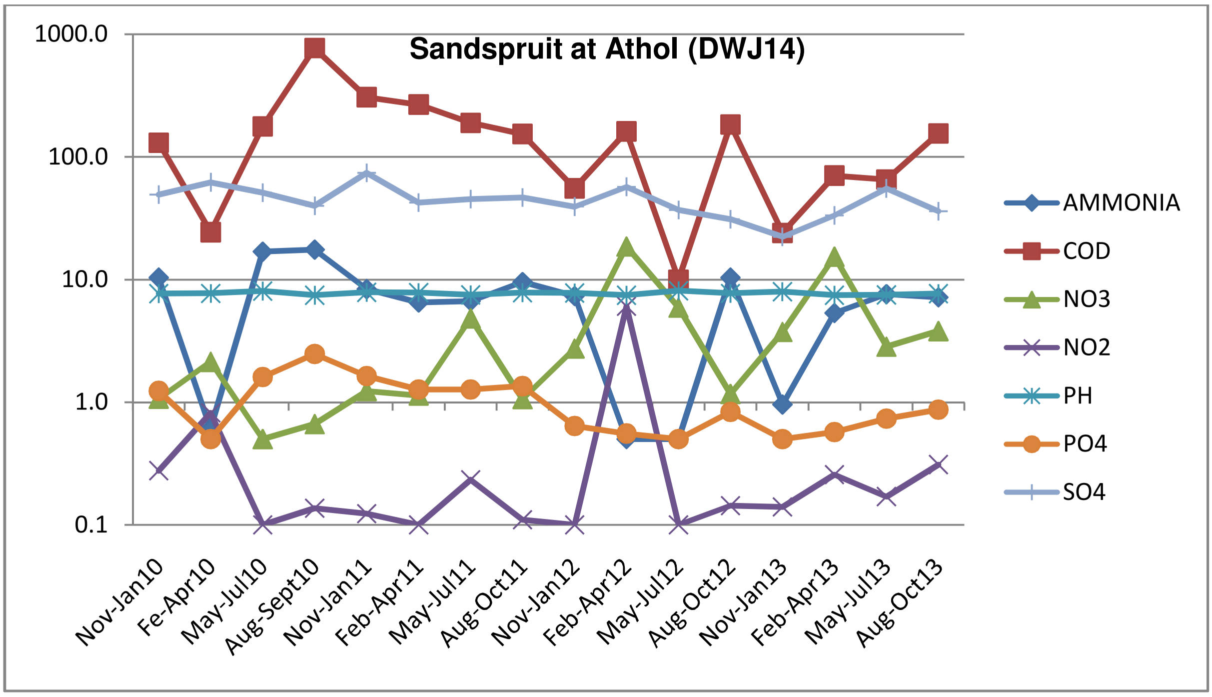

Figure 3.8Log plots of quarterly Physico-chemical data at DWJ14

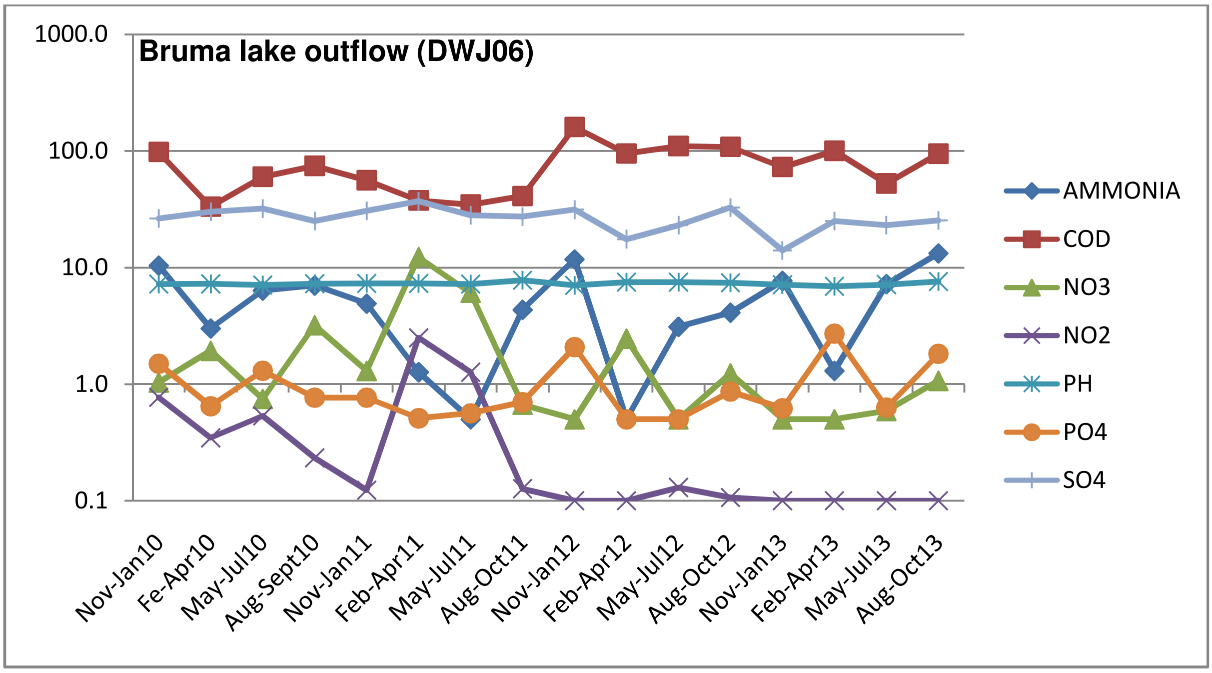

Figure 3.9 Log plots of quarterly Physico-chemical data at DWJ06

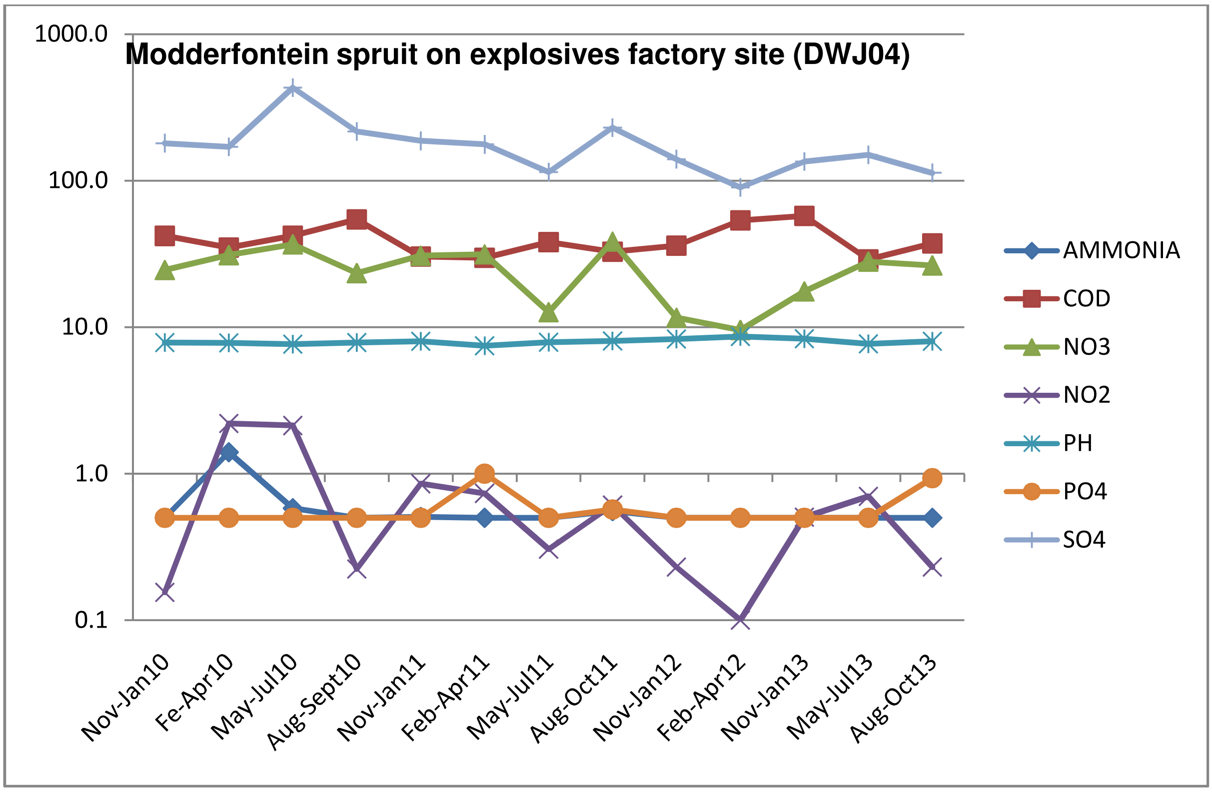

Figure 3.10 Log plots of quarterly Physico-chemical data at DWJ04

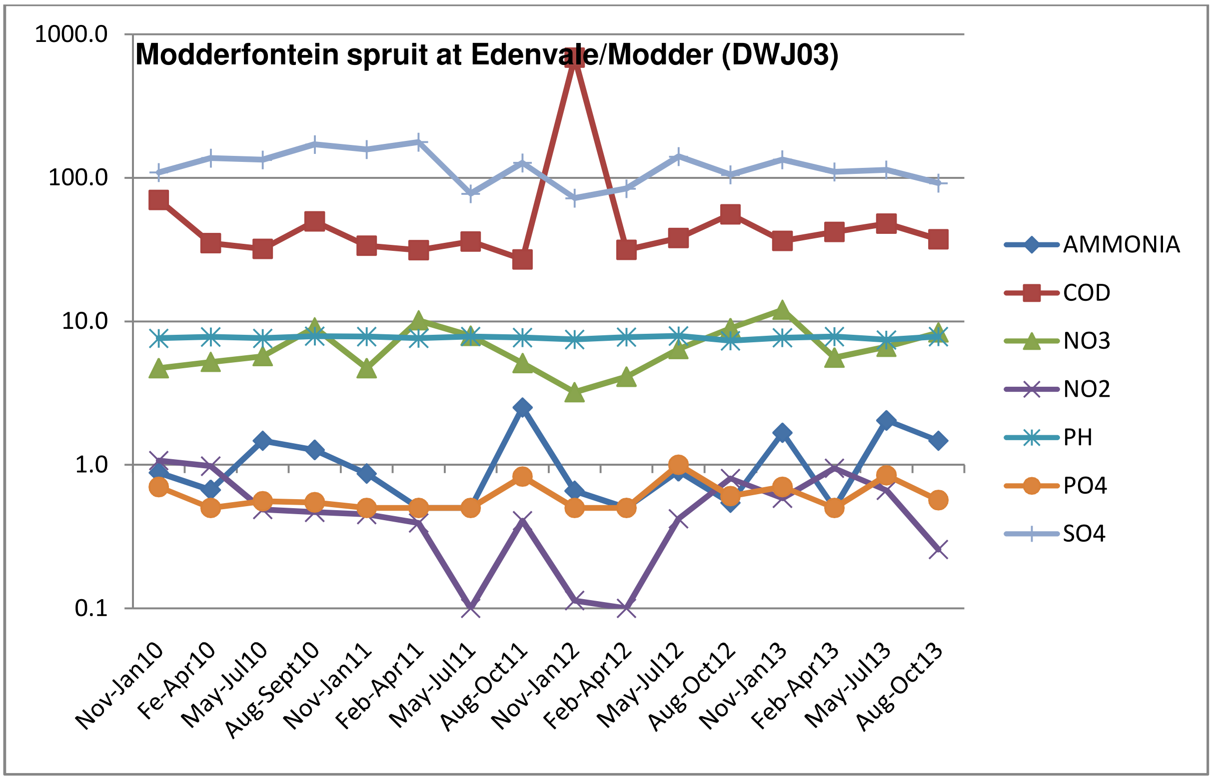

Figure 3.11Log plots of quarterly Physico-chemical data at DWJ03

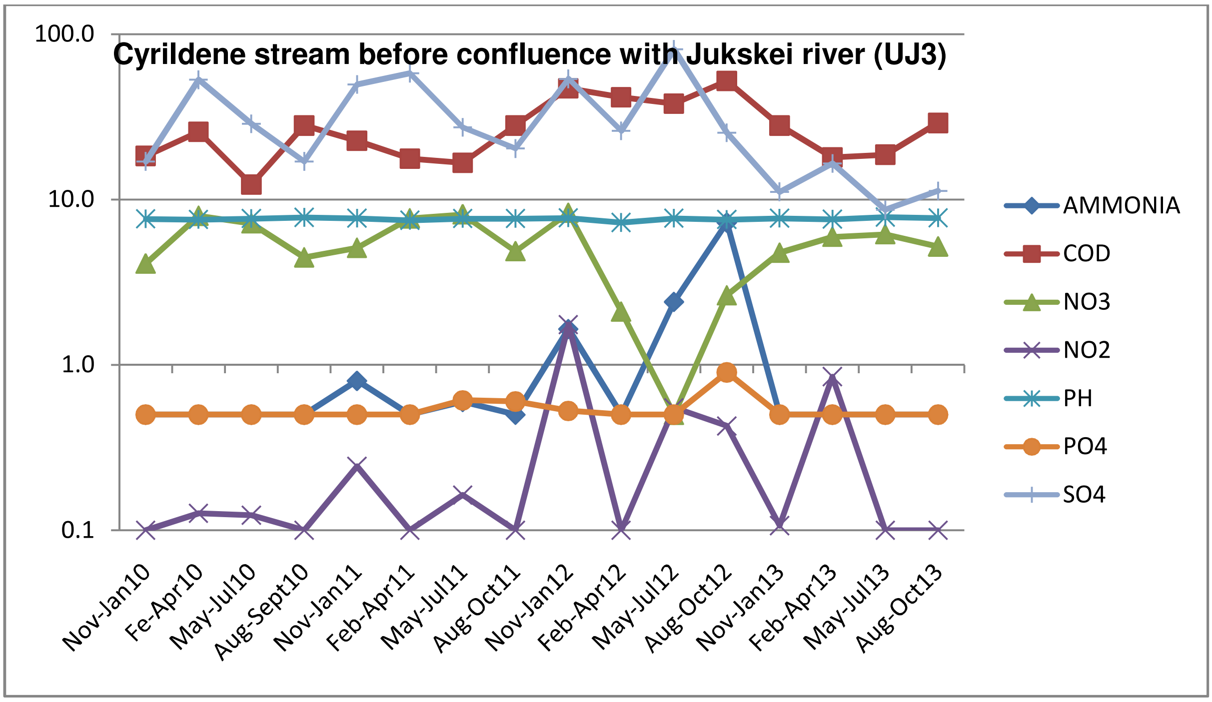

Figure 3.12 Log plots of quarterly Physico-chemical data at UJ3

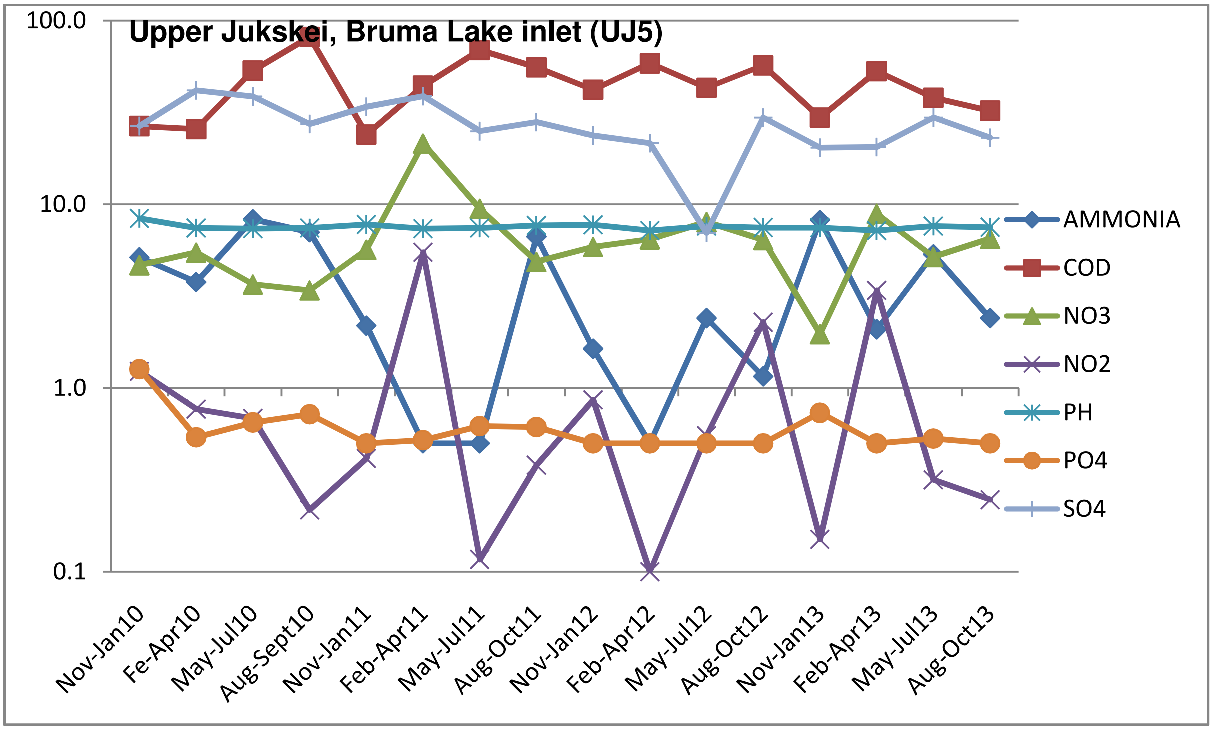

Figure 3.13Log plots of quarterly Physico-chemical data at UJ5

Using the plots above and also monthly plots and actual data values not presented here, the data was assessed and found to be realistic and therefore applicable for WQI determination.

CHAPTER 4 METHODOLOGY

4.1 DETERMINING THE APPROPRIATE WATER QUALITY INDEX

A huge number of water quality indices have been developed such as the National Sanitation Foundation WQI, Canadian Council Environment WQI, Oregon WQI, Weighted Arithmetic WQI and others with various modifications. The Weighted Arithmetic Index method is the simplest, has been found to be effective and has been used widely (Tyagi *et al.*, 2013). In view of this, it was then decided to adopt this method to determine the WQI for Jukskei catchment. This was done in the following four steps as in several other studies (Amad *et al.*, 2010; Mophin-Kania and Murugesan, 2011, Gajendran and Jesumi, 2013).

(a) Selecting the set of water quality variables of concern (parameter selection).

A total of seven water quality parameters (Physico-chemical) whose data was available were used in the determination of index. These are pH, Chemical Oxygen Demand (COD), Nitrate (NO_3^-), Nitrite (NO_2^-), Phosphate (PO_4^{3-}), Sulphate (SO_4^{2-}), and Ammonia (NH_4).

(b) Transformation of the different units and dimensions of water quality variables to a common scale

The quality criteria was segregated into four classes (Ideal, Acceptable, Tolerable and Unacceptable) modified from the National Sanitation Foundation method (Table 4.1). The selection of COJ water quality parameters is to protect the surface water resources for aquatic ecosystems and for recreational purpose. The South African water quality guidelines (DWAF, 1996a) for aquatic ecosystems were used to determine the four classes for fitness of use of water for selected parameters listed in Table 4.2. The Canadian water quality guidelines for protection of aquatic life for NO_3^- and NO_2^- were adopted in the absence of guidelines for these in South Africa while PO_4^{3-} is a standard for surface water resources for South Africa (DWAF, 1988).

Ammonia and pH target water quality range were obtained from DWAF guideline (DWAF, 1996a) for aquatic ecosystems. The COD guideline was determined for Jukskei Catchment (DWAF, 1996b). Sulphate (SO_4^{2-}) obtained from British Columbia Ambient Water Quality Guidelines since DWAF aquatic protection guidelines for SO_4^{2-} are not available. The step also involved the conversion of parameter concentration into a corresponding sub index values using equal and dimensionless numeric scale. Following the classification in Table 4.1, water whose quality equals the guideline value given in Table 4.2 should be acceptable and water with a measured quality better than the guideline should be classified as either good or excellent. In order to achieve this, it was decided to compute the dimensionless water quality value (q_i) using equation 4.1.

$$q_{i} = \left(\frac{C_{i-V_O}}{S_{i-V_O}}\right) X\ 50 \qquad (4.1)$$

Where q_i is the quality rating for the i^{th} parameter, C_i is measured value or concentration of i^{th} parameter, V_o is the ideal value for the i^{th} parameter which is zero for all other parameters except for pH which is considered to be7.0 and S_i is the target water quality range as defined in South African Water Quality Guidelines (DWAF, 1996a) S_i is the recommended standard for the i^{th} parameter obtained from Table 4.2.

According to the classification scheme (Table 4.1), the water quality is acceptable when the rating is 50 and any score less than that means the water quality is polluted. Multiplying by 100 means that the recommendation is for unacceptable water quality as per classification scheme. Therefore instead of using 100 as suggested in most of the literature (Tyagi *et al,* 2013, Amadi *et al.,* 2010; Mophin-Kani and Murugesan, 2011, Gajendran and Jesumi, 2013) the equation was modified whereby the multiplying factor of 50 was used meaning that the recommended water quality class is acceptable.

Table 4.1. Classification scheme for water quality index scores

Water Quality Index Scale			
Standard WQI (Gajendran and Jesumi, 2013)		WQI classification using Jukskei and Klip Rivers Water Quality Classification (www.reservoir.co.za) as obtained from DWAF, 1996a)	
Water Quality rating	Classification	Range	Classification
0-25	Excellent	0 – 25	Ideal
26-50	Good	26 – 50	Acceptable
51-75	Moderately polluted	51 – 70	Tolerable
76-100	Very poor	71 – 100	Unacceptable
Above 100	Unsuitable	Above 100	

Table 4.2. Target Water Quality Range

Target Water Quality Guidelines		
Variables	Water quality guideline	
	Units	
Physical		
pH	pH units	6.5 - 9.0 (7.75)
Organic		
COD	mg/l	15 (DWAF, 1996b)
Macro Elements		
NH_4	mg/l	1.8
NO_3^-/NO_2^-	mg/l	13 (Canadian Council of Ministers of the Environment, 2012)
PO_4^{3-}	mg/l	1
SO_4^{2-}	mg/l	100 (British Columbia Ambient Water Quality Guidelines, 2001)

(c) Weighting of the water quality variables based on their relative importance to overall water quality.

The purpose of weighting is to place greater emphasis on the parameters or variables that are considered more important depending on what WQI is used for (House, 1990). As described in Dzwairo *et al.* (2012) individual water quality parameters can be assigned weighting factors as a barometer to signal the level of harmful effects to human health and aquatic ecosystem in order to simplify the complex parameter interaction. In this study, the seven water quality parameters were assigned weights ranging from 1 – 5, whereby a weight of 1 was considered the least significant and 5 the most significant. This follows similar approaches applied in other studies (Alobaidy *et al.*, 2010; Dzwairo *et al.*, 2012;Nel*et al.*, 2013; Gajendran and Jesumi, 2013).

Table 4.3 shows the weights adopted for each variable based on the understanding of the relative importance of each variable as a pollution indicator and also on the basis of the weights that have been used in other studies. Ammonia and pH were assigned the highest score of 5 due to their severe effects of to the environment and human health (Dzwairo *et al.*, 2012). Nitrate/Nitrite was assigned the score of 4 each as it is closely related to Ammonia and pH and it is also a measurement of nitrogen content in the water (DWAF, 1996a). A score of 4was assigned to COD which like BOD is a measure of organic compounds in the water which indicates the mass of oxygen consumed per litre of water (Alobaidy *et al.*, 2010). COD is a key indicator of the environmental health of a surface water body and it gives indirect information about the bacterial activity, photosynthesis, availability of nutrients, stratification (Patil *et al*., 2012).

pH is very important as it determines the chemical (and thus potential toxicity) of many elements) in water. At pH of above 8, Ammonium ion (NH_4^+) is converted to highly toxic Ammonia (NH_3) and other complex chemical reactions of elements that become either soluble or insoluble. The potential for organic waste to deplete dissolved oxygen is commonly measured as BOD (Biochemical Oxygen Demand) but this is usually measured on Waste Water Treatment Works final effluent. For aquatic ecosystem, COD (Chemical Oxygen Demand) is normally measured as an indication of determines all biological processes in the aquatic environment although normally higher than BOD it provides a meaningful indication of the level of BOD (DWAF, 1996a). Accelerated eutrophication can lead to nuisance algal blooms and fish kills due to diminished reoxygenation of the water body and thus depleted dissolved oxygen levels and increased turbidity (Strobl *et al*., 2006).

Urban river systems are highly polluted by sewage from poorly serviced buildings and frequently blocked and overflowing sewer network, inadequate treated sewage, grey water from informal settlements, and erosion of river banks (Nel *et al*., 2013). Pollution from these sources include oxygen consuming organic matter which impact negatively on pH, sediments and high levels of contaminants and nutrients such as Phosphates, Nitrates/Nitrite and Ammonia (Strobl *et al*., 2006; Bere, 2006; Nel *et al*., 2013).

Table 4.3. Assigned weights and relative weights for selected parameters

Parameter	Assigned weight (w_i)	Relative weight (W_{ri})
Ammonia (NH_4^+))	5	0.2
Chemical Oxygen Demand (COD)	4	0.17
Nitrite (NO_2^-.)	3	0.04
Nitrate (NO_3^-)	3	0.04
pH	5	0.2
Phosphate (PO_4^{3-})	4	0.17
Sulphate (SO_4^{2-})	3	0.13
Sum	**27**	**1.00**

(d) Formulation of overall water quality index.

The sub index for each sampling point for all parameters being monitored over a study period was calculated by multiplying the quality rating (q_i) with relative weight (W_{ri}) linearly using the following expression:

$$WQI = \sum_{i=1}^{n} q_i \;\; w_i \qquad (4.2)$$

Where q_i is the quality of the i^{th} parameter, w_i is the relative weight of the i^{th} parameter while n is the number of the water quality parameters applied.

4.2 STATISTICAL ANALYSIS

Statistical determinations like descriptive summary such as monthly and annual mean, minimum and maximum of WQI, Standard Deviation, were used for data correlation to reveal monthly, seasonal variation, spatial variation and long term water quality trend in the Jukskei catchment. The WQI scores were formulated using MS office excel. Using the time series of surface water quality index values for all monitoring points, trend analysis were applied to determine whether the river water quality has improved or deteriorated during the time period for temporal assessment. Trend analysis was determined by Mann Kendall method on XLSTAT software for the analysis period (2010-2014). To compare the results obtained from Mann Kendall test, linear trend lines are plotted for each monitoring station on MS office excel spreadsheet. The possible reasons why an increasing trend is observed around Kaalspruit, Sand spruit and Upper Jukskei include continuous discharge of grey water and constantly overflowing sewer systems from informal settlements (Kaalspruit), discharge of industrial waste water from Wynberg (Sandspruit).

CHAPTER 5: RESULTS AND ANALYSIS

This chapter first presents the WQI analysis for each of the 8 sub-catchments of the Jukskei catchment as delineated in Figure 3.1. Highly polluted areas are then identified and monthly WQI were determined for these. A summary of the WQI-based water quality analysis forms the next section. The trend analysis of water quality based on the computed WQI values for highly polluted areas is presented as the last Section of the Chapter.

5.1 RESULTS OF WATER QUALITY INDEX ANALYSIS FOR JUKSKEI RIVER CATCHMENT

5.1.1 The Braamfontein spruit

The sub-catchment is drained by the Braamfontein spruit. Water quality monitoring points within this sub-catchment include BS 1, BS 4, DWJ 18, EC 1, EC 5, EDIN, EDOUT, MG5, WDNW, WDW, ZL 1, ZL 3, ZL 4 and ZLW 3.

As seen on Table 5.1, points EDIN and EDOUT(Emmarentia area) indicate a tolerable water quality most of the time. At monitoring points ZL1, ZL3, ZL4, ZL5 and ZLW3 (Johannesburg Zoo and Zoo lake areas), the water quality is predominantly unacceptable. The Westdene area (WDNW and WDW) is indicating unacceptable water quality (Table 5.1 and Figure 5.1).

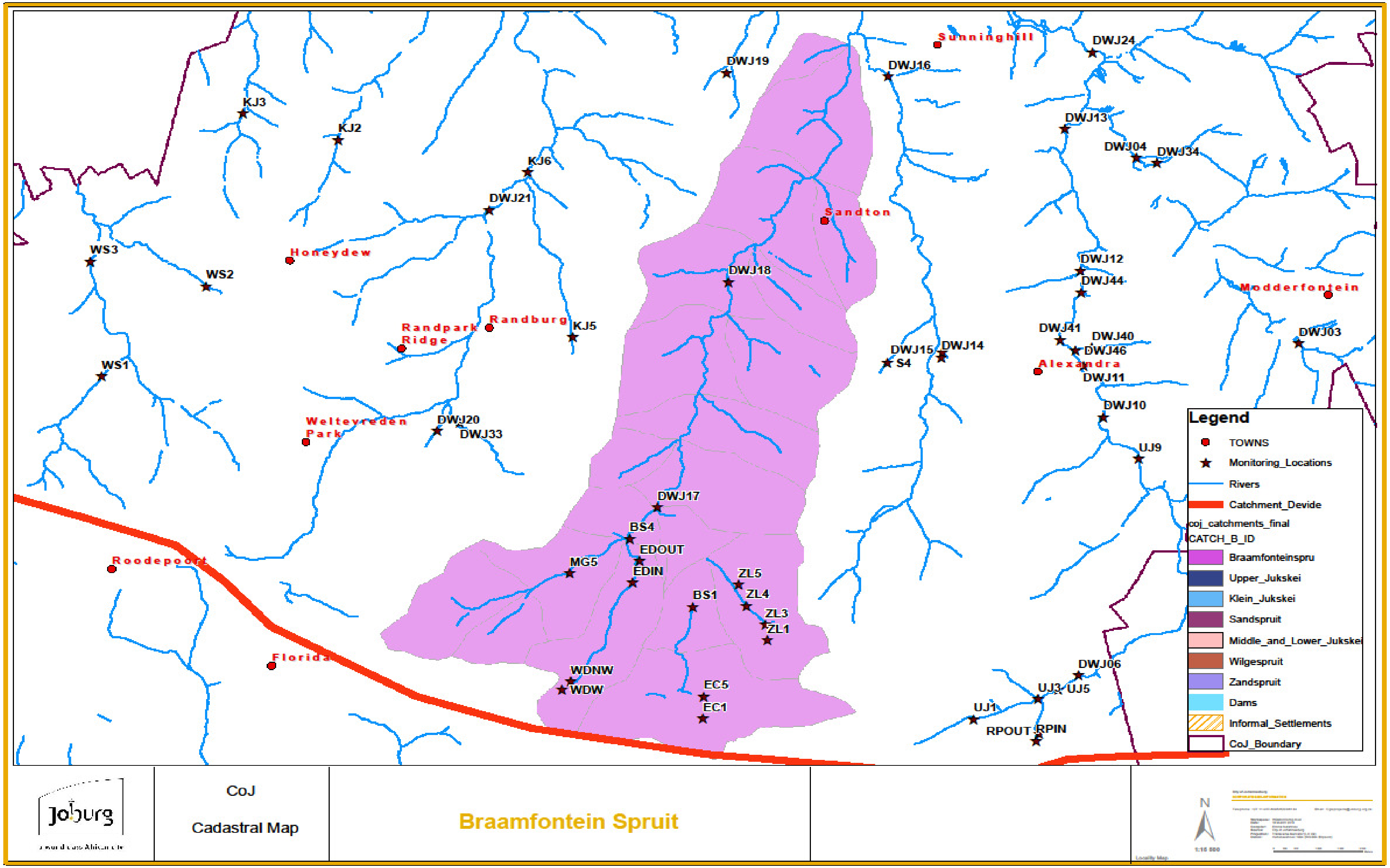

Figure 5.1: Braamfontein sub-catchment

Table 5.1: Braamfontein sub-catchment Water Quality Index

Sub-catchment	Sampling site	2010				2011				2012				2013			
		M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A
Braamfontein spruit	**BS1**	84	56	56	75	55	63	60	59	111	381	54	60	74	58	61	66
	BS4	62	52	56	60	56	66	54	62	63	67	59	58	68	74	53	68
	DWJ18	116	57	58	76	62	96	58	73	63	57	70	70	103	63	72	100
	EC1	167	546	633	227	186	84	57	261	125	74		61	99	136		59
	EC5	58	162	71	85	69	66	63	60	257	93	60	312	74	66	55	70
	EDIN	65	52	81	62	59	62	56	59	60	73	57	58	61	61	55	64
	EDOUT	69	77	68	65	59	69	63	70	66	72	54	61	69	69	59	89
	MG5	66	73	64	104	64	64	66	59	66	67	62	77	70	75	65	108
	WDNW	65	77	77	94	71	76	58	113	83	89	76	72	65	74	64	97
	WDW	61	77	72	96	72	76	69	104	76	102	74	76	65	75	179	107
	ZL 1	81	67	65	60	88	61	60	52	107	73	170	102	92	119	100	161
	ZL 3	106	67	209	138	114	70	67	286	66	93	127	136	112	85	177	146
	ZL 4	79	65	69	64	119	74	63	58	64	76	65	99	126	116	129	146
	ZL 5	76	63	81	75	61	68	67	92	77	85	121	100	101	136	169	147
	ZLW 3	214	66	69	64	57	72	65	111	70	73		90	110	84	170	135

* **Orange** - Tolerable; **Red** - Unacceptable

5.1.2 Wilge spruit

The Wilge spruit sub-catchment (Figure 5.2)shows better conditions when compared to all other sub-catchments with the water quality predominantly in a tolerable range as seen on Table 5.2. There are quarters when the water quality improved to acceptable range especially during 2010 and 2013. May-July quarter indicated a very high WQI due to exceedence of Nitrate, Nitrites and Phosphate which could be influenced by discharge of grey water from Magnum plot 22 informal settlement located upstream of WS3.

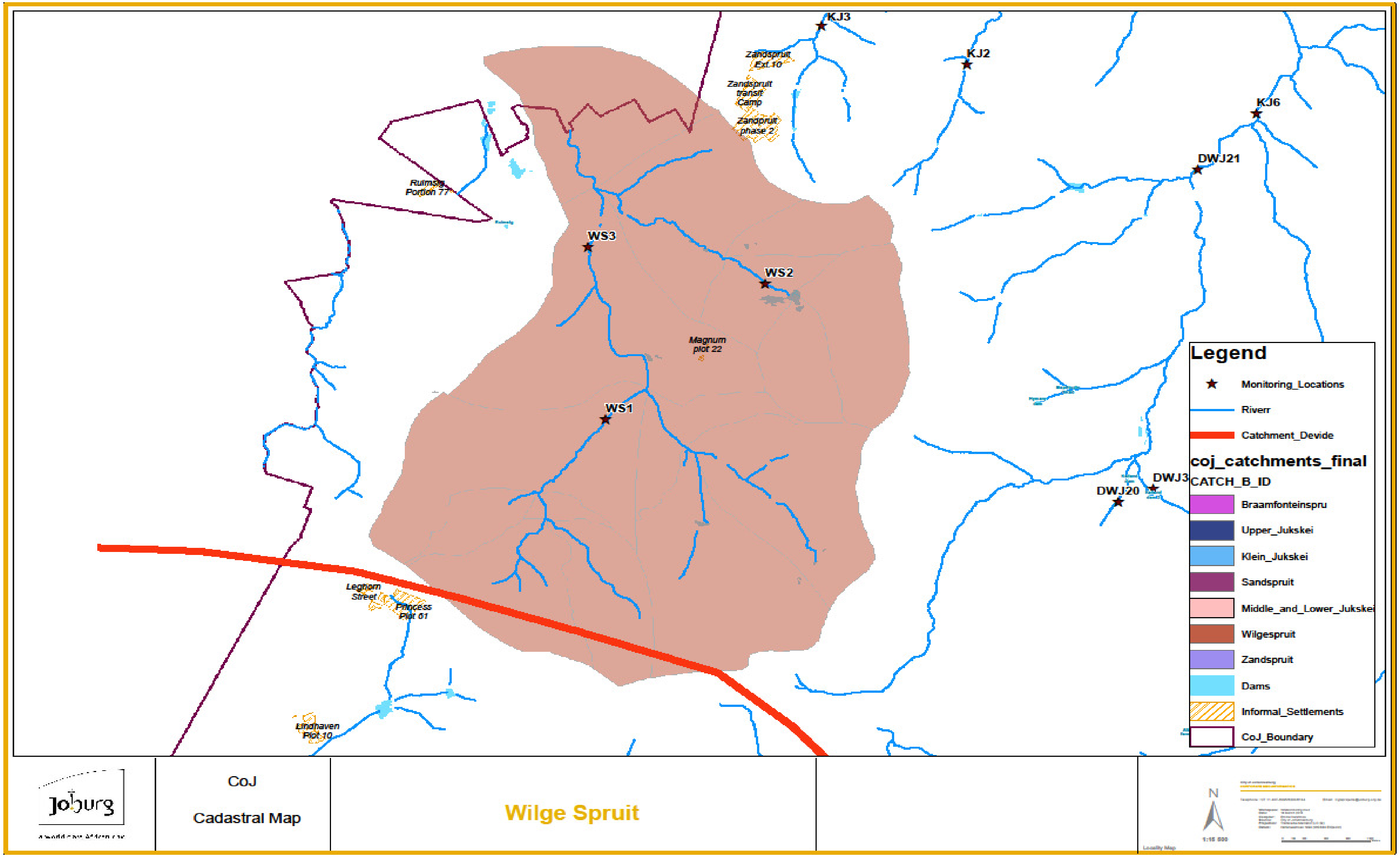

Figure 5.2:Wilgespruit sub-catchment

Table 5.2: Wilge spruit sub-catchment Water Quality Index

Sub-catchment	Sampling site	2010				2011				2012				2013			
		M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A
Wilge spruit	WS 1	50	50	50	53	54	56	52	71	56	52		61	59	49	53	63
	WS 2	48	59	63	52	55	56	57	56	60	129		59	67	48	54	57
	WS 3	53	60	61	57	55	54	56	57	61	94		66	800	61	56	70

* **Green** - Acceptable; **Orange** - Tolerable; **Red** - Unacceptable

5.1.3 Modderfontein spruit

The modderfontein sub-catchment (Figure 5.3)which is also monitored by three sites; DWJ03, DWJ04 and DWJ34 has consistently shown a high level of pollution in all three monitoring sites (Table 5.3). Analysis of quarterly water quality indicates unacceptable WQI throughout the study period. WQI analysis indicates that the sub-catchment is at risk and needs urgent attention.

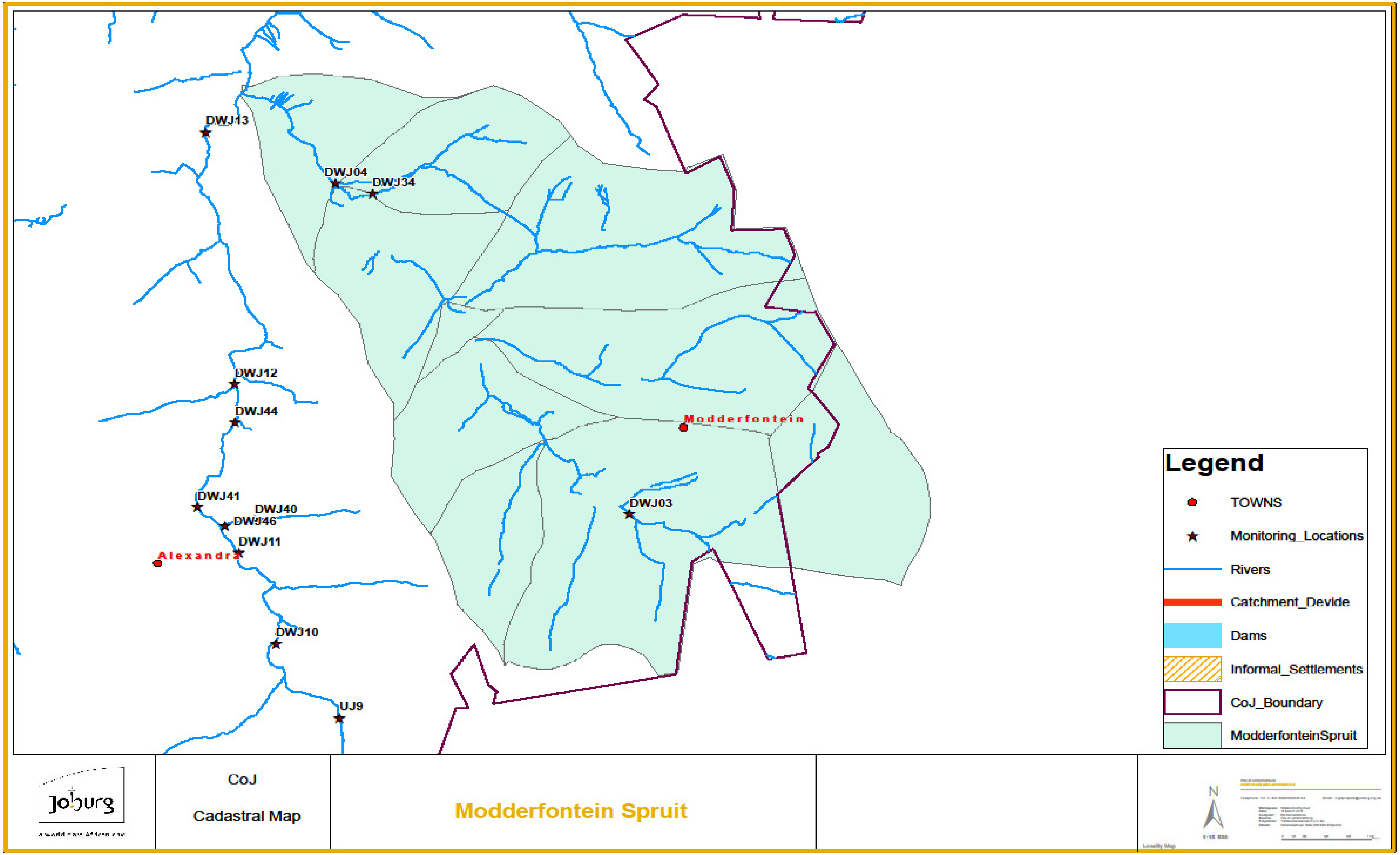

Figure 5.3: Wilgespruit sub-catchment

Table 5.3: Modderfontein sub-catchment Water Quality Index

Sub-catchment	Sampling site	2010				2011				2012				2013			
		M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A
Modderfonte	DWJ03	122	83	124	62	95	71	69	179	444	67	102	77	141	75	159	128
	DWJ04	83	129	105	92	80	76	75	93	81	92			95		72	81
	DWJ34	543	99	327	245	105	69	60	76	81	82			606		102	165

* **Orange** - Tolerable; **Red** - Unacceptable

5.1.4 Upper Jukskei

The upper Jukskei sub-catchment Figure 5.4) has water quality that is predominantly unacceptable (Table 5.4) except for areas such as Cyrildene and Rhode Park (RPIN, RPOUT and UJ9). The main stem (the Jukskei River), which starts near Ellis Park stadium shows unacceptable water quality throughout the study period. This condition could be associated with ongoing sewer blockages in areas such as Bertrams, Johannesburg Central, Doornfontein, Bruma, Observatory and Alexandra. The highest WQIs are associated with monitoring points within Alexandra area which could be as a result of grey water and sewage from informal settlement and old Alexandra extensions.

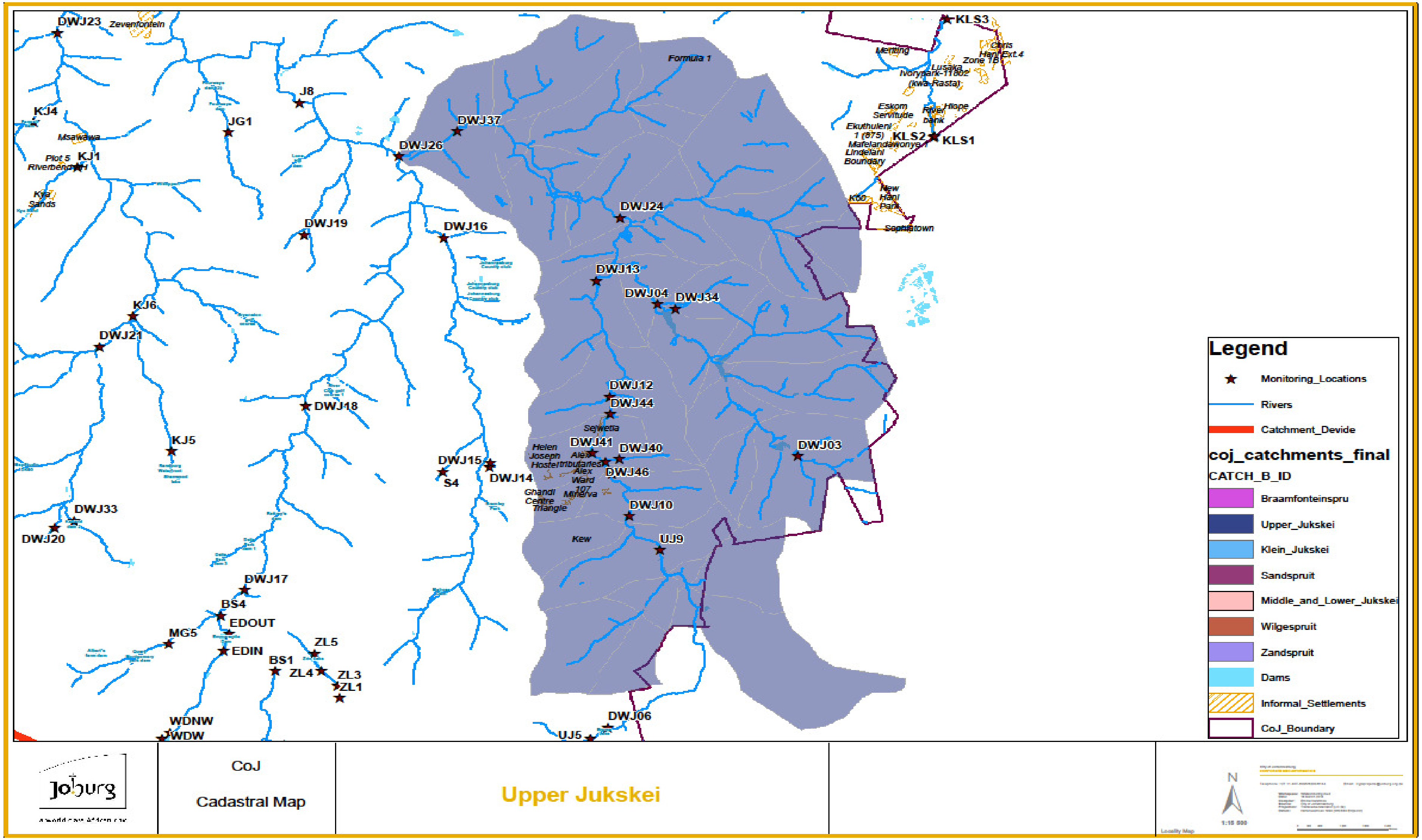

Figure 5.4: Upper Jukskei sub-catchment

Table 5.4: Upper Jukskei sub-catchment Water Quality Index

Sub-catchment	Sampling site	2010				2011				2012				2013			
		M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A
Upper Jukskei	DWJ06	651	196	399	444	317	107	58	281	761	94	247	304	476	152	438	812
	DWJ10	103	74	90	66	63	64	67	114	58	63	63	144	137	63	58	65
	DWJ11	73	29	71	64	67	65	99	67	61	75	65	133	64	62	59	65
	DWJ12	110	117	249	129	109	74	55	145	177	64	259	265	150	97	133	236
	DWJ13	73	62	62	127	120	65	89	165	68	78	143	208	123	95	199	97
	DWJ40	79	60	66	96	85	473	91	88	62	78	60	65	133	58	92	203
	DWJ41	2288	1682	3067	3606	2090	2130	3113	2859	798	2549	1303	2218	3462	440	887	466
	DWJ44	265	812	322	195	209	222	113	367	442	65	530	294	423	137	146	409
	DWJ46	79	94	124	470	92	431	764	168	59	68	87	65	117	58	100	237
	RPIN	50	147	50	54	82	46	52	50	64	53	60	51	62	46	51	57
	RPOUT	59	77	65	58	59	61	64	61	81	75	59	70	72	79	62	70
	UJ1	459	340	703	509	262	73	93	496	223	71	216	132	536	217	696	358
	UJ3	52	59	51	60	39	54	60	60	134	62	174	447	59	52	55	59
	UJ5	331	239	506	449	154	69	80	421	129	70	172	113	487	157	331	97
	UJ9	73	81	63	66	58	63	76	70	68	62	69	119	63	61	72	

* **Green**- Acceptable; **Orange -**Tolerable; **Red**- Unacceptable

5.1.5 Sandspruit

The Sand spruit sub-catchment water quality consistently remained in the unacceptable class during the study period (Figure 5.5). The monitoring site DWJ15 which is located on a tributary of Sand spruit draining Wynberg area consistently indicated an unacceptable water quality with very high WQI values during the study period(Table 5.5). This condition could be attributed to the industrial discharges of waste water into the storm water in Wynberg industrial area.

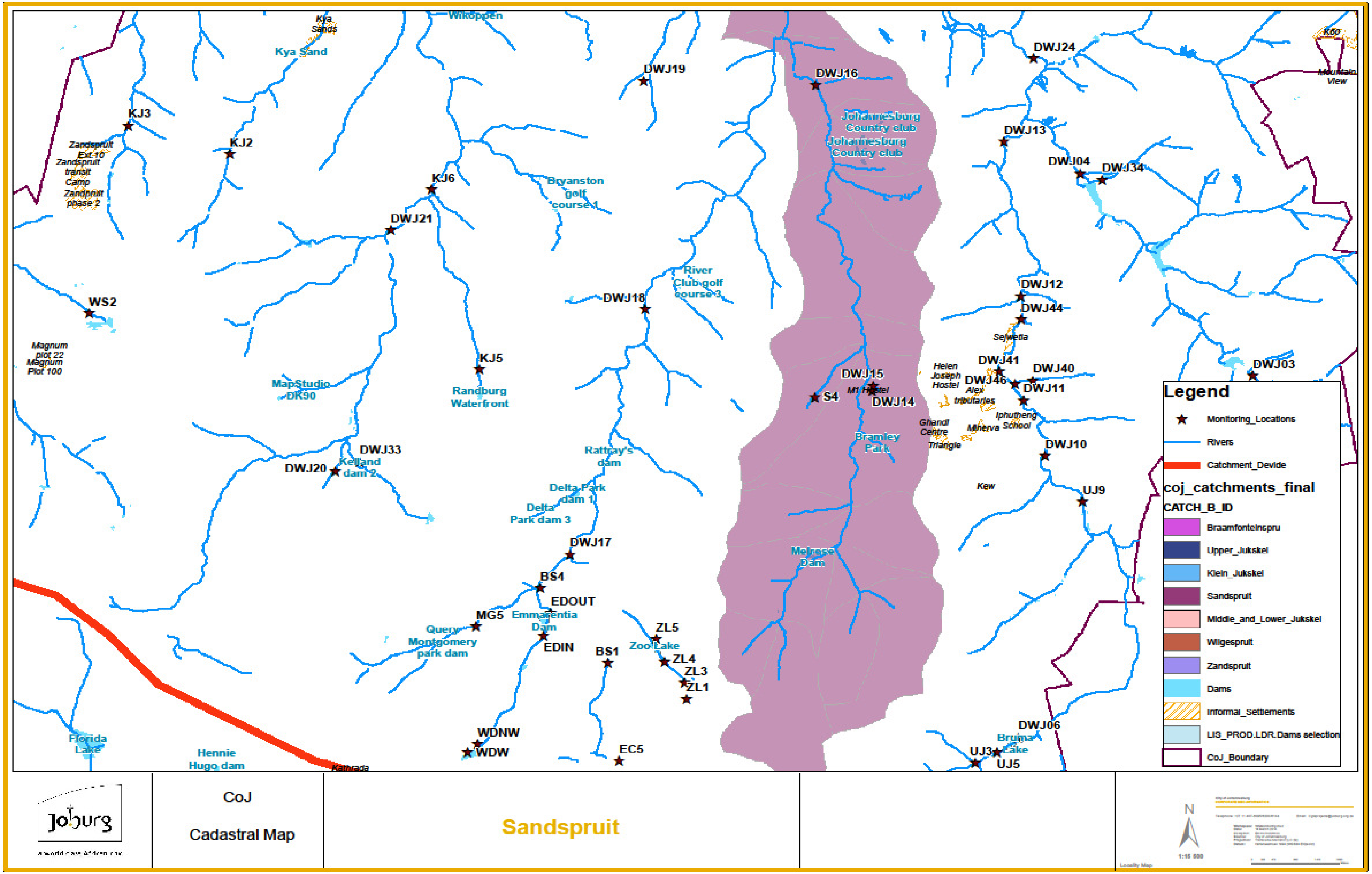

Figure 5.5: Sand spruit sub-catchment

Table 5.5: Sand spruit sub-catchment Water Quality Index

Sub-catchment	Sampling site	2010				2011				2012				2013			
		M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A
Sand spruit	DWJ14	674	65	1069	1438	671	537	501	640	456	138	56	700	87	351	476	508
	DWJ15	638	553	101	140	818	495	2036	1515	388	114	1388	133	1213	320	986	969
	DWJ16	95	61	66	93	74	530	63	119	58	69	68	67	90	57	57	145
	S4	58	54	387	99	57	57	90	62	79	57	63	103	62	62	81	92

* **Orange** - Tolerable**; Red**- Unacceptable

5.1.6 Middle& Lower Juskei River

The sub-catchment (Figure 5.6) shows unacceptable water quality throughout. Most of the monitoring points remained unacceptable during the study period. JG1 which monitors the Glen Austin stream downstream of the confluence of Jukskei and Modderfontein spruit indicated the worst situation(Table 5.6). This condition could be attributed to sewage and grey water from Mayibuye informal settlement.

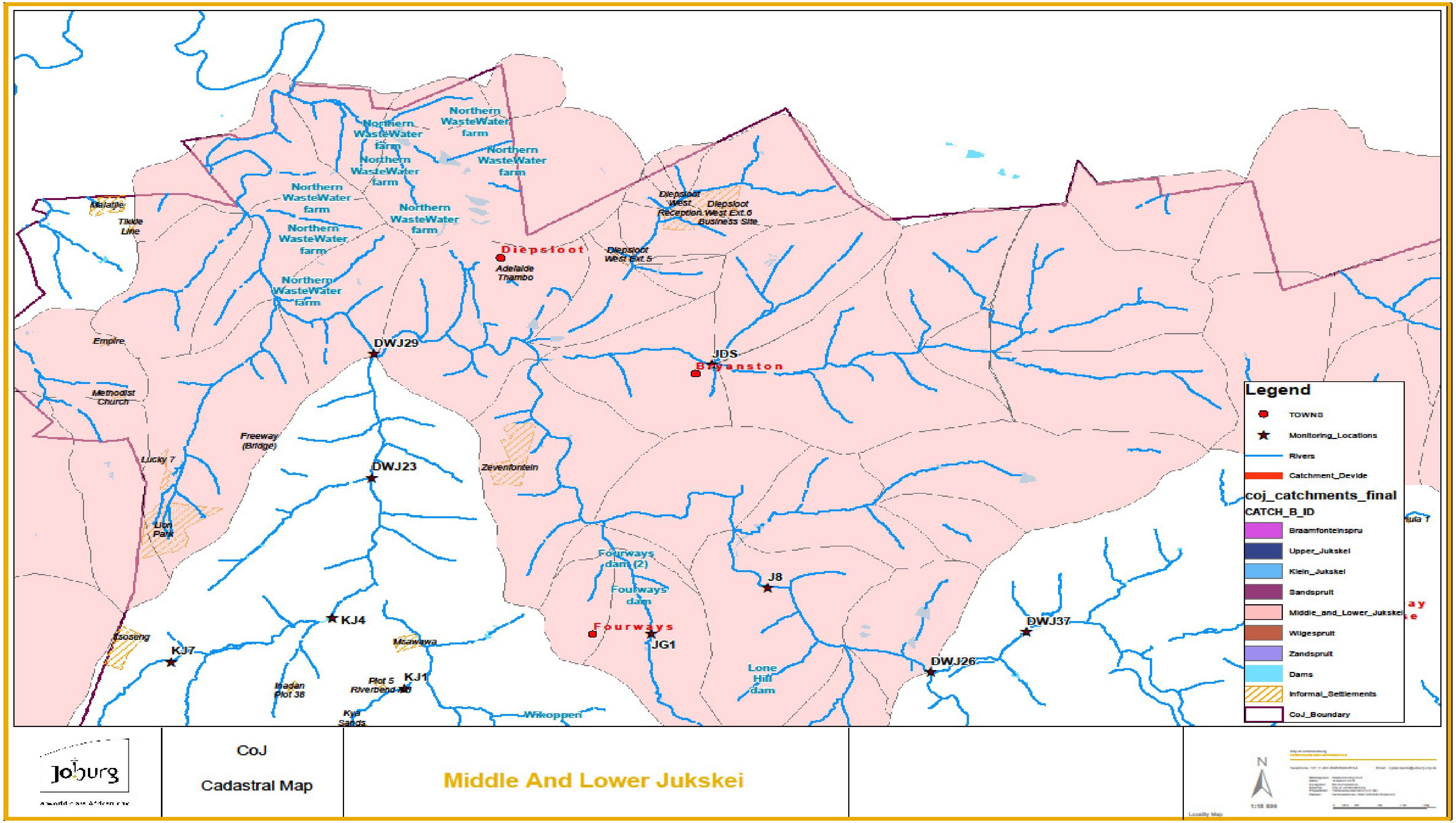

Figure 5.6: Middle & Lower Jukskei sub-catchment

Table 5.6: Middle & Lower Jukskei sub-catchment Water Quality Index

Sub-catchment	Sampling site	2010				2011				2012				2013			
		M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A
Middle & Lower Jukskei River	DWJ17	64	73	60	70	58	64	55	57	69	68	53	57	85	63	63	71
	DWJ19	115	59	65	73	62	65	59	112	74	70	66	85	94	105	70	104
	DWJ24	82	66	62	103	135	70	68	183	66	71	145	187	117	62	64	
	DWJ26	77	92	71	100	89	1478	69	181	70	79	112	85	69	67	107	155
	DWJ29	67	58	74	73	70	68	63	73	72	68	64	185	63	58	84	121
	DWJ37	69	69	62	104	98	71	71	192	59	55	109	139	66	60	103	178
	FG1	159	76	422	85	100	111	74	176	113	95	146	170	86	149	553	67
	J8	66	59	68	81	78	69	68	117	74	76	144	175	65	64	77	76
	JG1	1278	148	483	1301	1029	233	995	1698	729	78	146	801	1160	951	1476	788

* **Orange** - Tolerable**; Red**- Unacceptable

5.1.7 The Klein Jukskei

The quarterly WQI indicated that the Klein Jukskei (Figure 5.7) is characterised by tolerable water quality although in some instances the WQI was in an unacceptable range for some monitoring points (Table 5.7). Some of the areas within this sub-catchment that may be responsible for the deterioration of water quality include Kya sands industrial, Cosmo city township, Lion Park and informal settlements such as Msawawa, Zandspruit, Riverbend and Kya sand.

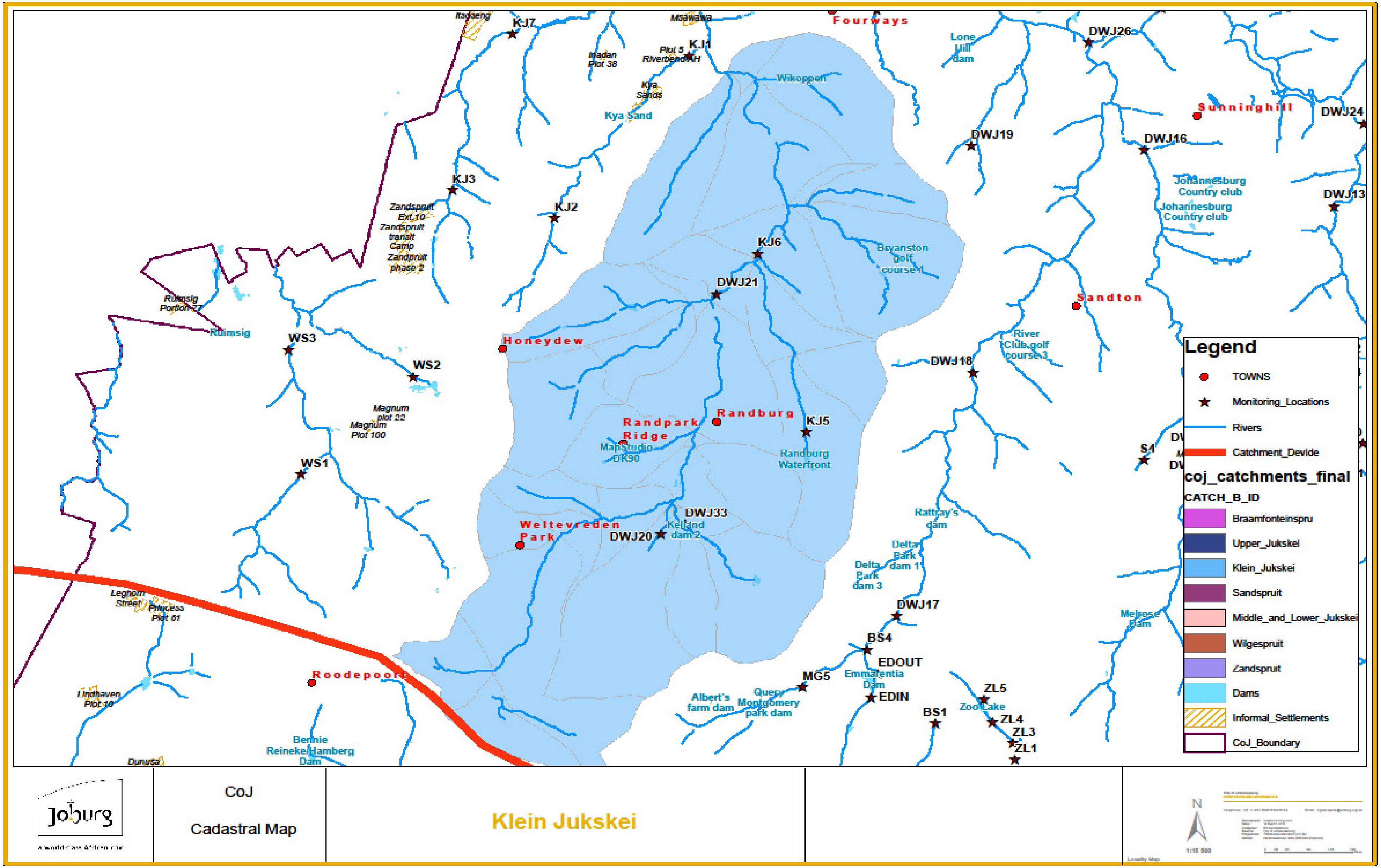

Figure 5.7: Klein Jukskei sub-catchment

Table 5.7: Klein Jukskei sub-catchment Water Quality Index

Sub-catchment	Sampling site	2010				2011				2012				2013			
		M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A
Klein Jukskei	DWJ20	62	55	73	84	57	61	61	62	63	58	59	133	73	61	55	67
	DWJ21	70	60	58	69	60	67	59	67	59	66		94	66	58	61	76
	DWJ33	54	63	99	60	56	67	72	92	76	60	61	133	69	64	59	65
	KJ1	71	63	490	91	118	67	66	238	80	73	68	78	583	64	271	1198
	KJ2	52	51	62	59	61	53	58	62	56	79		89	131	69	107	172
	KJ3	64	64	175	233	87	69	63	311	72	69	-	173	60	68	97	89
	KJ4	362	58	83	141	104	70	83	68	115	64	85	75	67	67	464	263
	KJ5	60	63	56	80	66	60	55	83	61	69	57	287	69	63	66	64
	KJ6	61	58	63	70	70	68	66	68	69	63	75	74	71	-	-	-
	KJ7	56	59	69	92	59	63	63	300	68	61	-	75	77	62	-	-
	KJ8	171	57	621	-	-	-	-	-	-	-	-	-	293	-	-	308

* **Orange**- Tolerable**; Red** - Unacceptable

5.1.8 Kaal spruit

The Kaal spruit sub-catchment (Figure 5.8), which encompasses areas such as Ivory Park, Midrand, Kanana and Olifantsfontein indicated the worst water quality within the Jukskei catchment. The WQI remained unacceptable for the whole of analysis period during all quarters in all the three monitoring sites (Table 5.8). The Kaal spruit River forms the boundary between COJ and Ekurhuleni Metropolitan Municipality (Thembisa) before flowing into City of Tshwane. The level of pollution in this area can be attributed to the high number of informal settlements along the river.

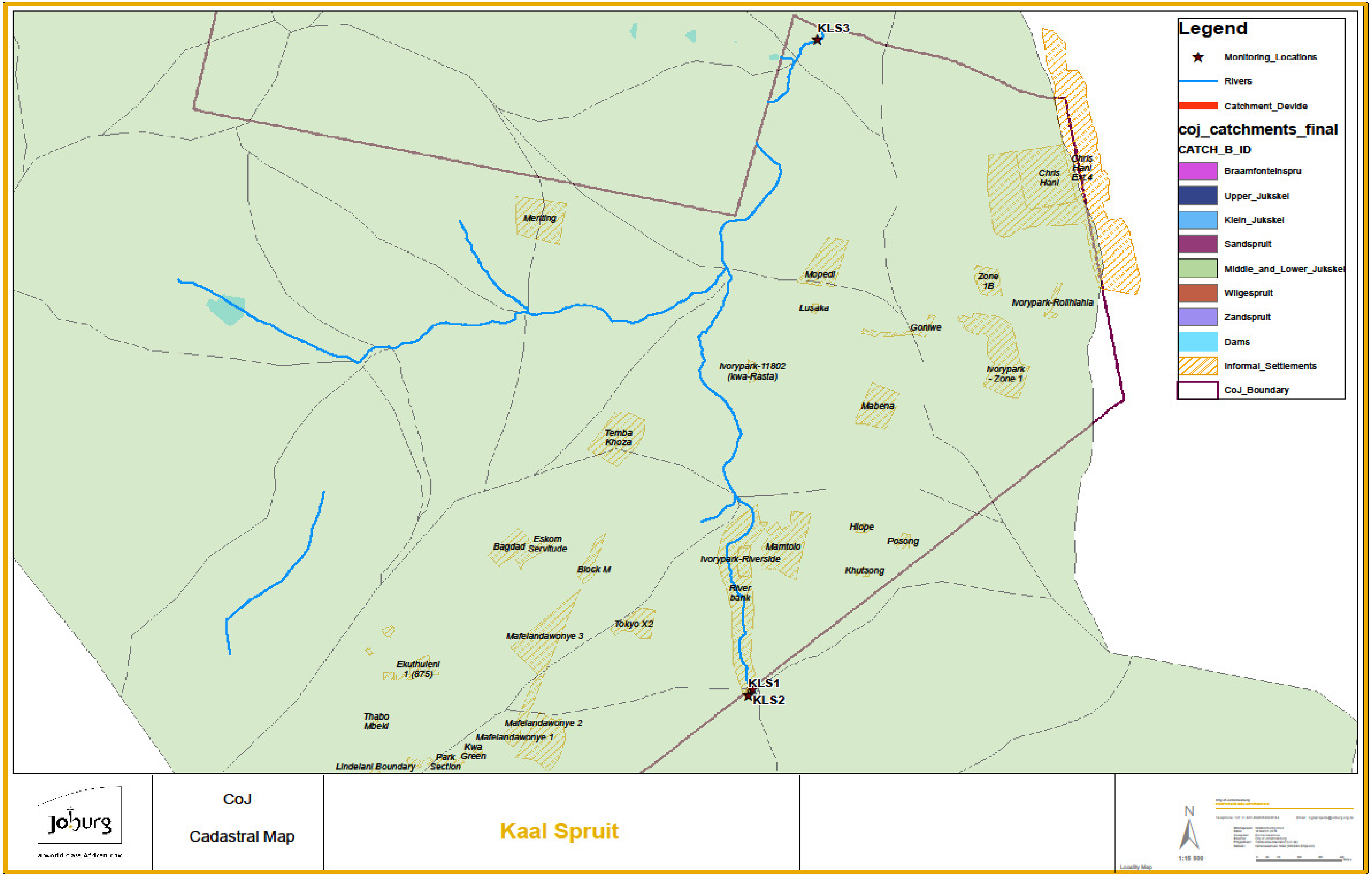

Figure 5.8: Kaalspruit sub-catchment

Table 5.8: Kaalspruit sub-catchment Water Quality Index

Sub-catchment	Sampling site	2010				2011				2012				2013			
		M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A	M-J	A-O	N-J	F-A
Kaal spruit	KLS1	2070	809	744	2353	1259	286	926	1279	1360	189	522	1985	1761	1298	1814	766
	KLS2	638	1339	818	1513	1748	1011	1574	2108	874	1060	959	699	1730	994	1082	720
	KLS3	1065	345	674	1142	608	389	437	1039	782	97	636	823	1614	668	1221	1063

* **Red** - Unacceptable

5.2 MONTHLY WATER QUALITY INDEX FOR THE HIGHLY POLLUTED CATCHMENTS

From quarterly WQI it became clear that the Upper Jukskei sub-catchment, Kaal spruit, Modderfontein, Sand spruit, Middle & Lower Jukskei were highly polluted. The sampling points which consistently indicated unacceptable WQI were selected and monthly WQI were determined for the recent data (2013). Tables 5.9through to Table 5.13and Figures 5.9through to 5.13 indicate the monthly WQI and fluctuations throughout the year 2013.

5.2.1 Modderfonteinspruit

Analysis of 2013 monthly WQI revealed that the Modderfontein sub-catchment is highly polluted especially the upper reaches of the sub-catchment which indicated unacceptable WQI (Table 5.9 and Figure 5.9). The elevated levels of Nitrates/Nitrites in these monitoring points are the reason for high levels of WQI. No data was available for DWJ04 and DWJ34 from January to June months.

Table 5.9: Modderfontein Monthly Water Quality Index

	Monitoring points		
MONTHS	DWJ03	DWJ04	DWJ34
JAN	103	-	-
FEB	83	-	-
MAR	76	-	-
APR	65	-	-
MAY	109	-	-
JUN	140	-	-
JUL	101	72	102
AUG	89	79	168
SEPT	223	89	197
OCT	64	78	124
NOV	235	89	1047
DEC	78	99	164

* **Orange** - Tolerable; **Red** - Unacceptable

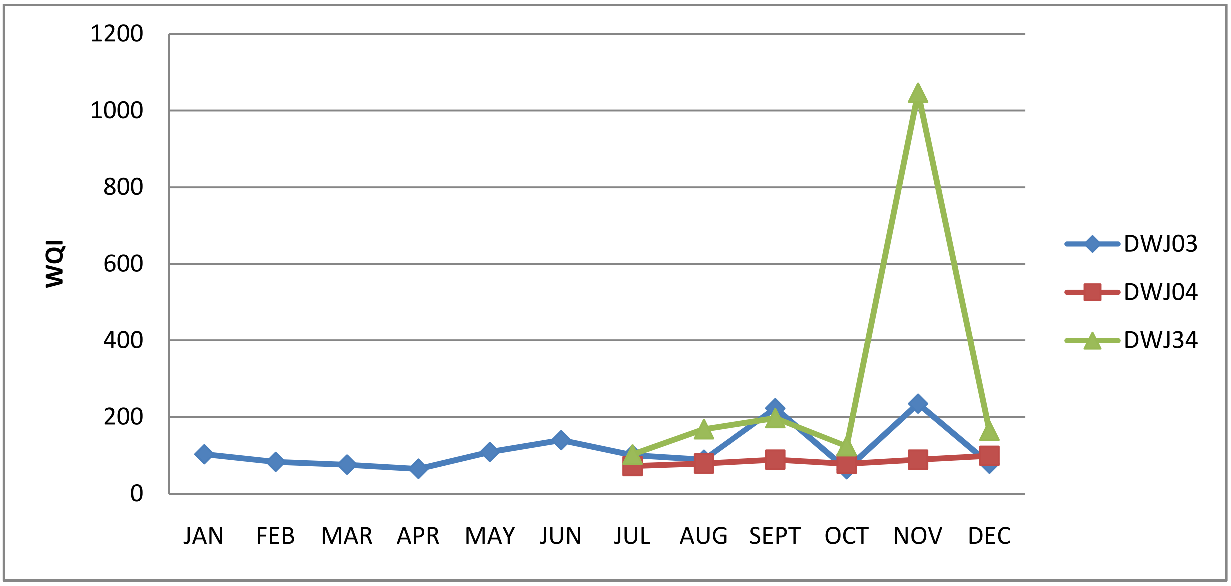

Figure 5.9: Graphical plots of variation of WQI in Modderfontein sub-catchment during 2013

5.2.2 Upper Jukskei

The Upper Jukskei exhibit exceedingly very high WQI showing unacceptable water quality conditions especially around Alexandra and Bruma areas. The drivers behind the high levels of WQI include the high levels of COD, PO_4 and NH_4 which are associated with sewage pollution (Table 5.10 and Figure 5.10).

Table 5.10: Upper Jukskei Monthly Water Quality Index

	Monitoring points								
MONTHS	UJ1	UJ5	DWJ06	DWJ12	DWJ13	DWJ40	DWJ41	DWJ44	DWJ46
JAN	103	164	437	190	103	194	2692	780	191
FEB	83	-	-	89	71	69	77	92	68
MAR	76	72	-	55	68	56	83	57	51
APR	65	240	152	153	142	52	1161	268	53
MAY	109	302	612	109	184	-	238	126	-
JUN	140	253	341	165	-	113	2123	213	119
JUL	101	444	363	117	59	74	308	97	83
AUG	89	126	203	257	164	163	594	529	179
SEPT	223	135	568	246	-	258	731	644	248
OCT	64	234	1665	203	229	189	68	61	285
NOV	235	864	558	122	166	57	246	245	64
DEC	78	432	430	142	98	142	4447	246	89

* **Orange** - Tolerable; **Red** - Unacceptable

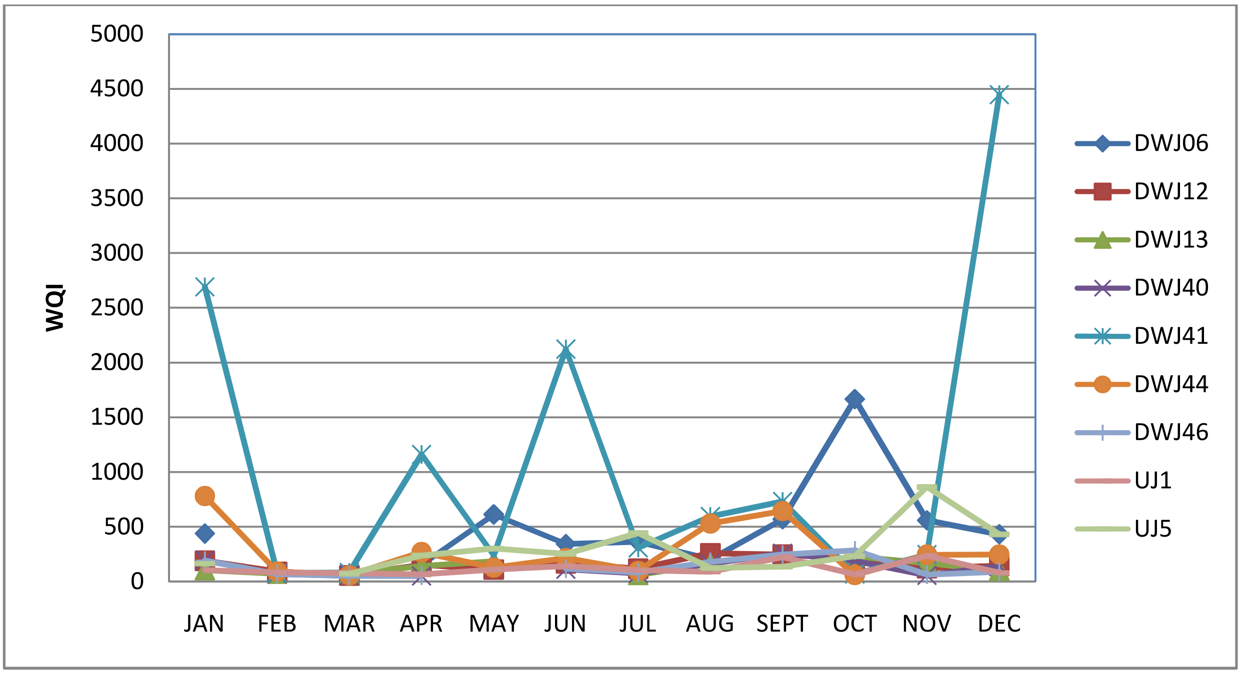

Figure 5.10: Graphical plots of variation of WQI in Upper Jukskei sub-catchment during 2013

5.2.3 Kaal spruit

The Kaal spruit sub-catchment indicated the worst WQI throughout the whole Jukskei catchment whereby the water quality remained unacceptable throughout 2013 in all monitoring points (Table 5.11 and Figure 5.11). Except for pH, the target water quality ranges for all other six parameters are exceeded resulting in high WQI values.

Table 5.11: Kaalspruit Monthly Water Quality Index

	Monitoring points		
MONTHS	KLS1	KLS2	KLS3
JAN	2773	1544	2437
FEB	2089	1792	536
MAR	1432	908	829
APR	380	282	636
MAY	1479	631	1333
JUN	2174	2141	1333
JUL	1795	479	997
AUG	1273	1026	1582
SEPT	902	929	1395
OCT	128	202	210
NOV	838	2124	1381
DEC	1678	1519	1021

* **Red** - Unacceptable

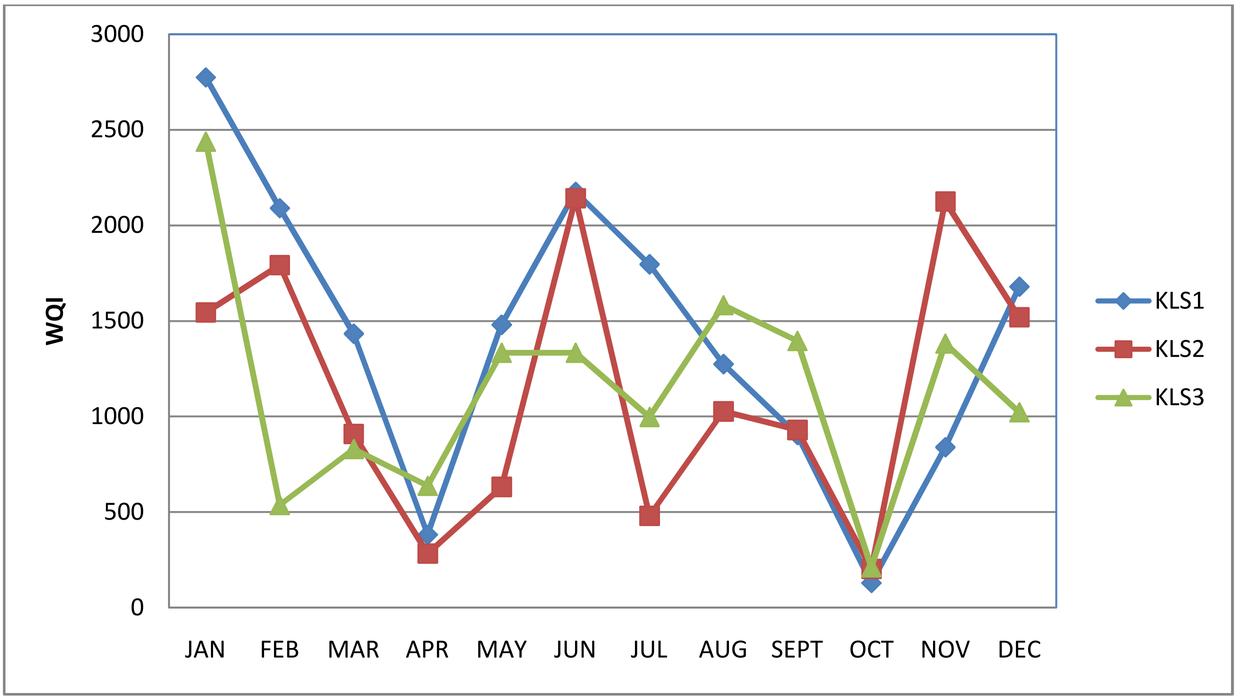

Figure 5.11: Graphical plots of variation of WQI in Kaal spruit sub-catchment during 2013

5.2.4 Sand spruit

The monthly WQI indicated very poor water quality within the Sand spruit sub-catchment with both monitoring points predominantly recording unacceptable WQI during 2013 (Table 5.12 and Figure 5.12).

Table 5.12: Sand spruit monthly Water Quality Index

	Sampling points	
MONTHS	DWJ14	DWJ15
JAN	69	944
FEB	941	54
MAR	57	517
APR	58	382
MAY	1270	54
JUN	57	1498
JUL	101	1408
AUG	135	1255
SEPT	1290	77
OCT	89	1577
NOV	68	1526
DEC	119	1162

* **Orange** - Tolerable; **Red** - Unacceptable

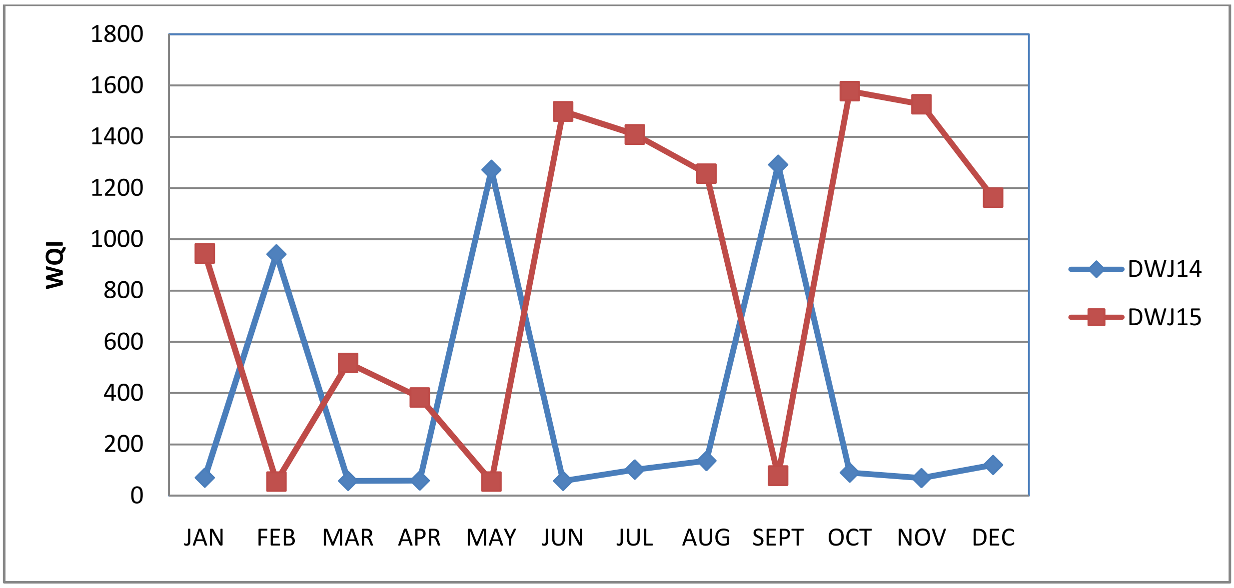

Figure 5.12: Graphical plots of variation of WQI in Sand spruit sub-catchment during 2013

5.2.5 Middle and Lower Jukskei

While the water quality remained unacceptable at JG1 with very high WQI values throughout the year, FG1 was mostly tolerable (Table 5.13 and Figure 5.13).

Table 5.13: Middle and Lower Jukskei Monthly Water Quality Index

	Sampling points			
MONTHS	DWJ26	FG1	JG1	DWJ26
JAN	63	61	982	63
FEB	61	59		61
MAR	68	56	917	68
APR	72	329	983	72
MAY	129	1081	1204	129
JUN	70	64	1767	70
JUL	116	515	1463	116
AUG	179	71	1122	179
SEPT	215	67	1085	215
OCT	70	63	150	70
NOV	69	133	1189	69
DEC	76	56	1316	76

* **Orange** - Tolerable; **Red** - Unacceptable

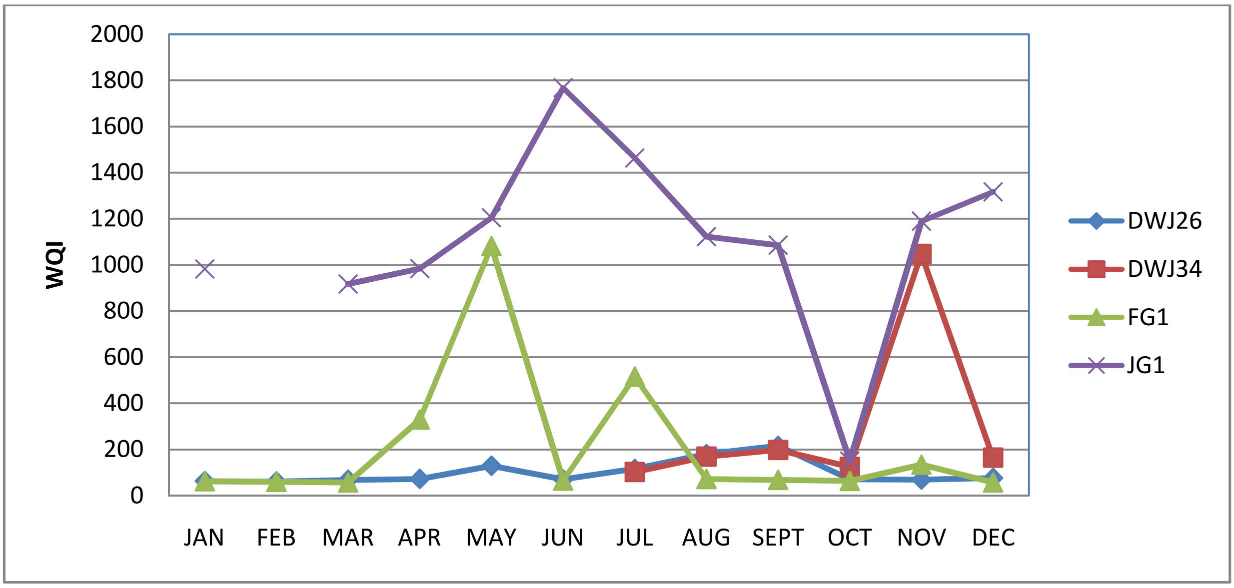

Figure 5.13: Graphical plots of variation of WQI in Sand spruit sub-catchment during 2013

5.3 SUMMARY OF THE WATER QUALITY ANALYSIS

Although Jukskei river catchment water quality is mostly unacceptable in most sub-catchments, the Wilge spruit sub-catchment is still in a better state as the WQI range from tolerable to acceptable during the analysis period. The kaal spruit sub-catchment is the worst in all three monitoring points (KLS1, KLS2, and KLS3) with very high WQI values in excess of 1000 in some cases. Based on the results of the quarterly WQI analysis, the

Modderfontein, Sand spruit, Upper Jukskei, Kaal spruit as well as Middle and Lower Jukskei indicated extreme WQI and hence are regarded as highly polluted areas. Monthly WQI analysis indicated that DWJ04, DWJ34 for Modderfontein, Upper Jukskei (DWJ06, UJ5, and DWJ44), Kaal spruit (KLS1, KLS2 and KLS3), Sand spruit (DWJ15) as well as Middle and Lower Jukskei (JG1) remained unacceptable for the rest of 2013. Table 5.14 presents the summary of the Jukskei sub-catchments WQI and possible causes.

Table 5.14: Summary of Water Quality Index and conditions in the Jukskei sub-catchments

Sub-catchment	Water quality monitoring points	Possible drivers/causes
Braamfontein spruit,	The Braamfontein catchment is predominantly ranging from tolerable to unacceptable WQI. The Westdene and Zoo Lake being the problematic areas. The high WQI are as a result of exceedingly very high levels of NH_4^+, COD and in some instances NO_3^-/NO_2^-.	Animal watering and related activities at the Johannesburg Zoo could be the source of high levels of NH_4^+, COD and NO_3^-/NO_2^-.
Wilge spruit,	This is the only sub-catchment throughout the Jukskei which indicates the WQI ranging from Acceptable to Tolerable. The tolerable WQI is as a result of slight exceedance of NH_4^+ and COD.	Wilge spruit is characterised by light industries and predominantly a residential area comprising of small holdings and plots. Agricultural activities in the area as well as occasional sewer blockages could be the source of NH_4^+, and oxygen consuming substances.
Modderfontein spruit,	Stations DWJ03, DWJ04 and DWJ34 located in the Modderfontein area are also indicating very high levels of Nitrates/Nitrites which are influencing the WQI values. Huizenga and Harmse (2005) also found that the Modderfontein water quality was poor.	In this sub-catchment although dominated by residential areas, there are two significant industrial activities which could be the source of high Nitrates/Nitrites including the Kelvin Power station and AECI explosives in Modderfontein (Huizenga and Harmse, 2005). Nitrate and Nitrite are naturally occurring ions that are part of nitrogen cycle. Nitrate ion in water is undesirable. This is because it can cause methaemoglobinaemia in infants less than 6 months old (Yisa and Jimoh, 2010). Harmse and Huizenga (2005) also noticed

Sub-catchment	Water quality monitoring points	Possible drivers/causes
		that the pH was acidic during some of the month.
Upper Jukskei,	The high WQI values in the Alexandra area reveal an increasing pollution possibly from grey water flowing from storm water drains and along the streets of Alexandra into Jukskei River. COD, PO_4^{3-} and Nitrate/Nitrite were very high in most of the monitoring points.	Landie (2011) observed that access to running water is a luxury for many households in Alexandra, so these houses have no fitted drains and residents resort to throwing their used water into the streets. Sewage drains overflow onto the roads and pose a serious health risk to residents, particularly children and the elderly. Poor water infrastructure maintenance also has a negative effect on the roads and causes huge cracks and potholes.
Sand spruit,	The high WQI values are attributed to high levels of phosphates, Sulphates and Nitrate. High concentrations of phosphates can indicate the presence of pollution and are largely responsible for eutrophic conditions.	Monitoring sites DWJ14 and DWJ15 are located within the stream that drains the Wynberg industrial area in Alexandra which could be the source of PO_4^{3-}, SO_4^{2-} and NO_3^-/NO_2^-.
Middle and Lower Jukskei,	Jukskei River is the largest phosphate contributor to the Hartbeespoort Dam, which has a severe euthrophication problem and it also implies that the present eutrophication problem in the Hartbeespoort Dam is related to high phosphate input from the	The sub-catchment is predominantly residential areas and the high WQI could be as a result of domestic waste-waters (sewage and grey water particularly those containing detergents) from upstream as well as the Northen Waste Water Treatment Works located near Diepsloot (Infromal settlement also linked to Lower Jukskei by small unnamed

Sub-catchment	Water quality monitoring points	Possible drivers/causes
	Jukskei River (Huizenga and Harmse, 2005).	tributary of Jukskei).
Klein Jukskei, Kaal spruit	The high WQI values at Klein Jukskei catchment are attributed to elevated levels of Ammonium, Nitrate and Phosphates during the study period. Huizenga and Harmse (2005) found that the water quality of Klein Jukskei improved and was better as compared to the Jukskei main system.	Kya Sands industrial area, Cosmo city sewer network constantly blocked and overflowing, three informal settlements discharging grey water are some of the problems within the sub-catchment that could be linked with the high levels of WQI. Stations
Upper Jukskei.	The Upper Jukskei sub-catchment exhibit unacceptable WQI as a result of very high WQI. The situation is caused by COD, PO_4^{3-}, NH_4^+, andNO_3^-/NO_2^- which remained very high during the analysis period throughout all the monitoring points within the sub-catchment.	DWJ06, UJ1, UJ5 and UJ9 are monitoring the impact from Doornfontein, Johannesburg CBD, Cyrildene, Bruma, Yeoville and Bezuidenhout valley. The impacts from these areas range from poorly serviced and overcrowded buildings, constantly overflowing sewage from superimposed storm water/sewer network.
Kaal spruit	The monitoring sites KLS1, KLS2 and KLS3 are all located within the Kaalspruit sub-catchment. The levels of Nitrates/Nitrites, Phosphates, Sulphates, Ammonium and COD are extremely high at all three sites and are therefore influencing the WQI.	The sub-catchment is dominated by informal settlements which continually discharge grey water, solid waste and sewage to the river. Sewer manholes are constantly blocked and overflowing within Thembisa, Ivory Park, Kanana and Kaalfontein areas.

5.4 WATER QUALITY INDEX TREND ANALYSIS

Although there are those stations already on the threshold of becoming unacceptable, the trend analysis exercise was limited to those that are currently on an unacceptable level to elevate matters of concern and exposure of the surrounding communities to waterborne diseases. Decision makers can therefore prioritise these areas for immediate actions necessary to alleviate pollution sources. It was decided to confine the trend analysis to monitoring results in the sub-catchments that were found to be highly polluted.

5.4.1 Mann Kendall Trend Analysis

The trend is said to be decreasing if Mann Kendall test statistic (S) is negative and the computed probability is greater than the level of significance. The trend is said to be increasing if the S is positive and the computed probability is greater than the level of significance (Karmeshu, 2012). In this study, the significance level (alpha) was determined at 5% or 0.05 on averaged quarterly water quality time series data (2010 to 2013) for selected sampling points persub-catchments showing high levels of WQI. The high level of confidence is considered appropriate for analysis of this nature to ensure highest confidence on the results (Drapela and Drapelova, 2011). The two tailed test was performed. According to this test, the null hypothesis H_0 assumes that there is no trend and this is tested against the alternative hypothesis H_1 which assumes that there is a trend (Onoz and Bayazit, 2012).All the graphs have been made to start the y-axis with 0 and not any higher values to avoid misleading the reader about the extent of the trends.

5.4.2 ModderfonteinSpruit

Mann Kendall trend test did not show any form of significant trend in the status of water quality of Modderfontein sub-catchment. The computed p values at all the three sites were found to be higher than the significant value (0.05).While this condition is favourable particularly since the WQI is not increasing, the water quality remains in an unacceptable class which means that the sub-catchment is highly polluted (Table 5.15 and Figures 5.14, 5.15and 5.16). Although the visual inspection indicate an increasing trend in all monitoring points within the sub-catchment, statistically it is considered insignificant.

Table 5.15:Modderfonteinspruit trends

Sub-catchment	Sampling site	Kendall' tau	S	Var(S)	p-value (Two-tailed)	Sen's slope	Interpretation
Modderfonteinspruit	DWJ03	0.091	6.000	0.000	0.737	1.563	No trend
	DWJ04	0.690	10.000	27.333	0.085	5	No trend
	DWJ34	0.333	5.000	0.000	0.469	20	No trend

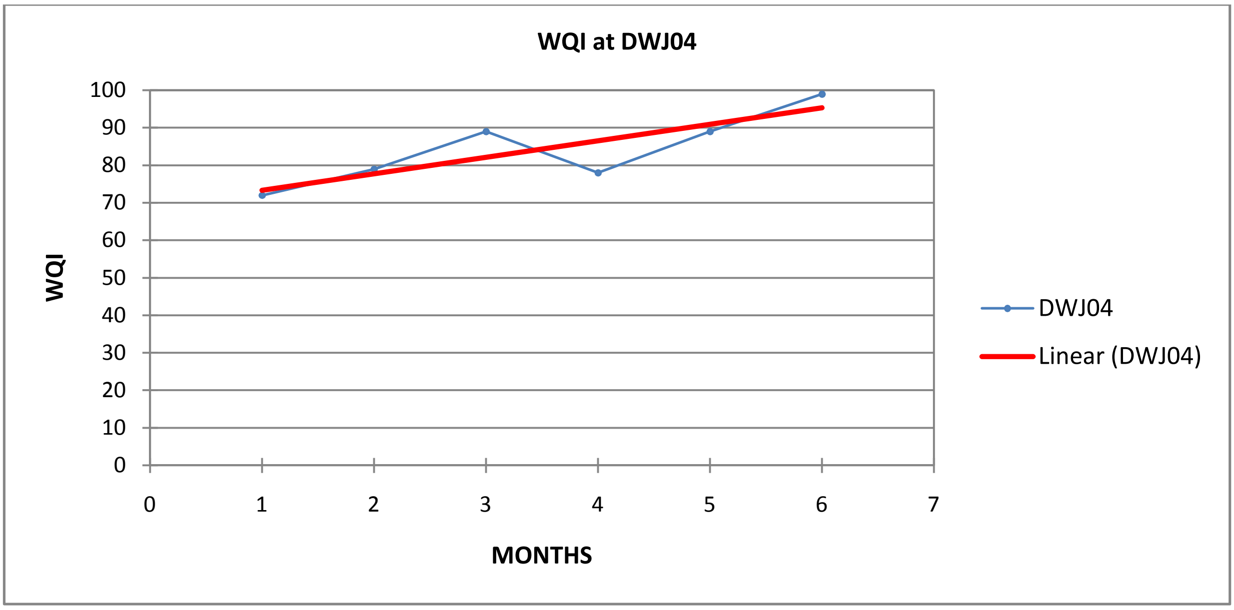

Figure 5.14: Graphical plots WQI trends at DWJ04 during 2013

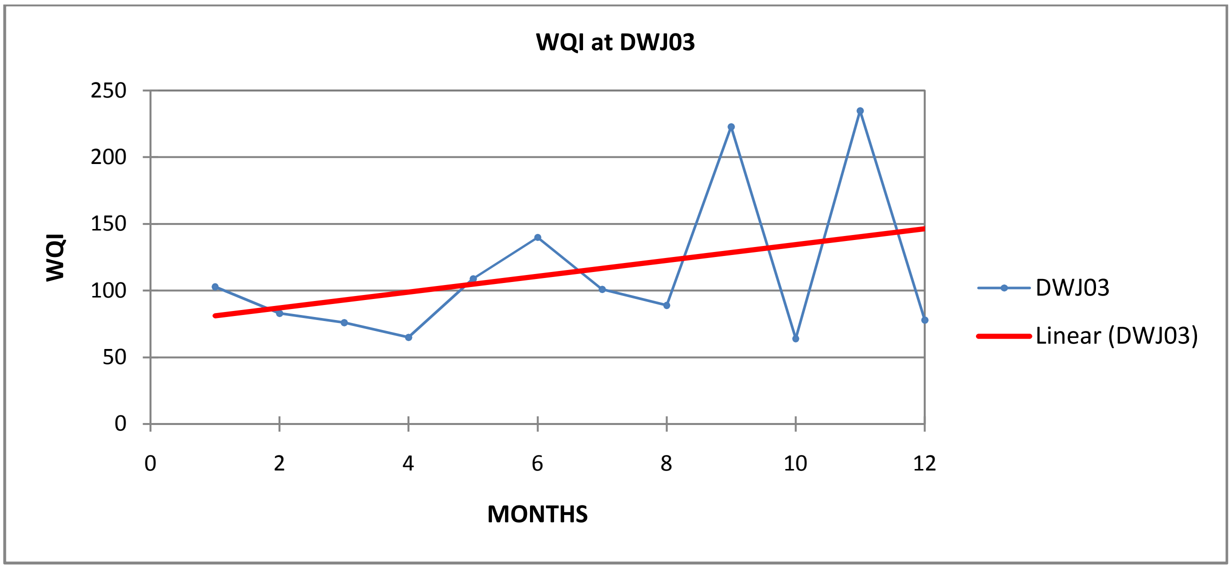

Figure 5.15: Graphical plots of WQI trends at DWJ03 during 2013

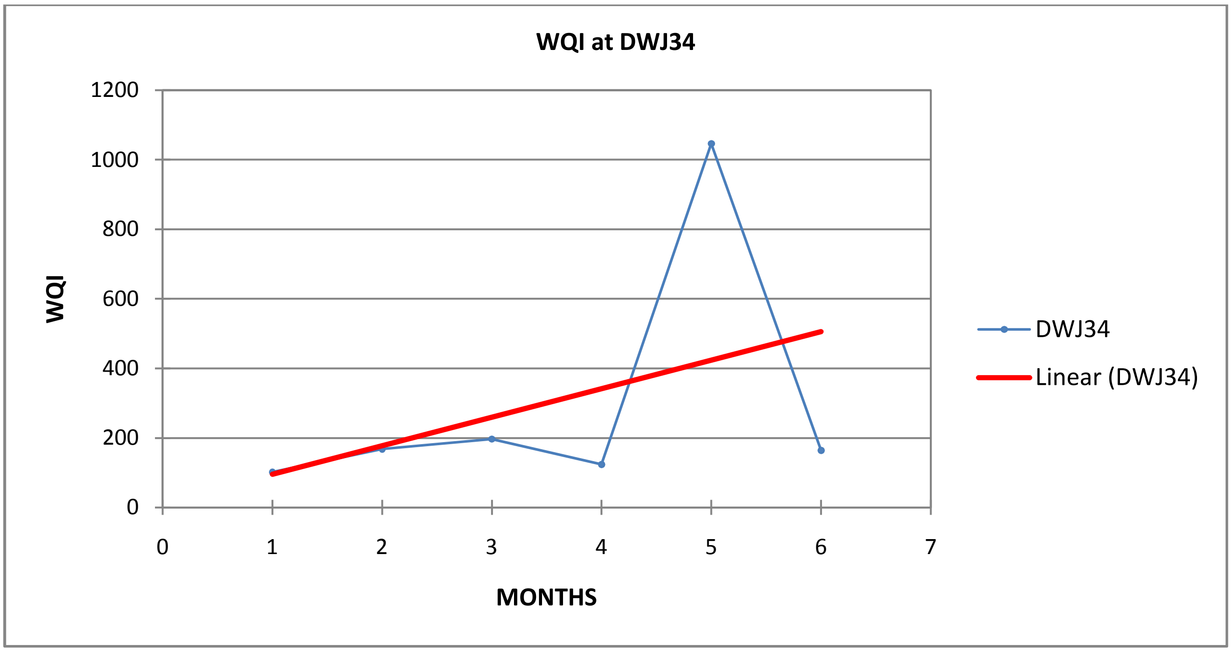

Figure 5.16: Graphical plots of WQI trends at DWJ34 during 2013

5.4.3 Upper Jukskei

All the analysed water quality monitoring sites throughout the Upper Jukskei sub-catchment did not show any sign of significant trend over the study period. Inspections of trend graphs indicate an increasing trend for all the monitoring points analysed except for DWJ44 which is showing a decreasing trend (Table 5.16 and Figures 5.17through to Figure 5.25.statistically the trend is insignificant. An increasing trend is more obvious at DWJ06, DWJ41 and UJ5 although Mann Kendall indicates otherwise. This could be as a result of smaller samples which in this case included four quarterly WQI values. However the minimum population to test for a trend in Mann Kendall analysis is 4 (Helsel and Hirsch, 2002).The possible reasons why an increasing trend is observed around Upper Jukskei include continuous discharge of grey water and constantly overflowing sewer systems from underground sewer systems.

Table 5.16: Upper Jukskei trends

Sub-catchment	Sampling site	Kendall' tau	S	Var(S)	p-value (Two-tailed)	Sen's slope	Interpretation
Upper Jukskei	DWJ06	0.200	9.000	0.000	0.484	21.833	No trend
	DWJ12	0.242	16.000	0.000	0.311	5.45	No trend
	DWJ13	0.244	11.000	0.000	0.381	7.875	No trend
	DWJ40	0.164	9.000	0.000	0.542	6	No trend
	DWJ41	0.091	6.000	0.000	0.737	19.576	No trend
	DWJ44	0.091	6.000	0.000	0.737	3.25	No trend
	DWJ46	0.236	13.000	0.000	0.359	4.75	No trend
	UJ1	0.091	6.000	0.000	0.737	1.563	No trend
	UJ5	0.345	19.000	0.000	0.165	26.8	No trend

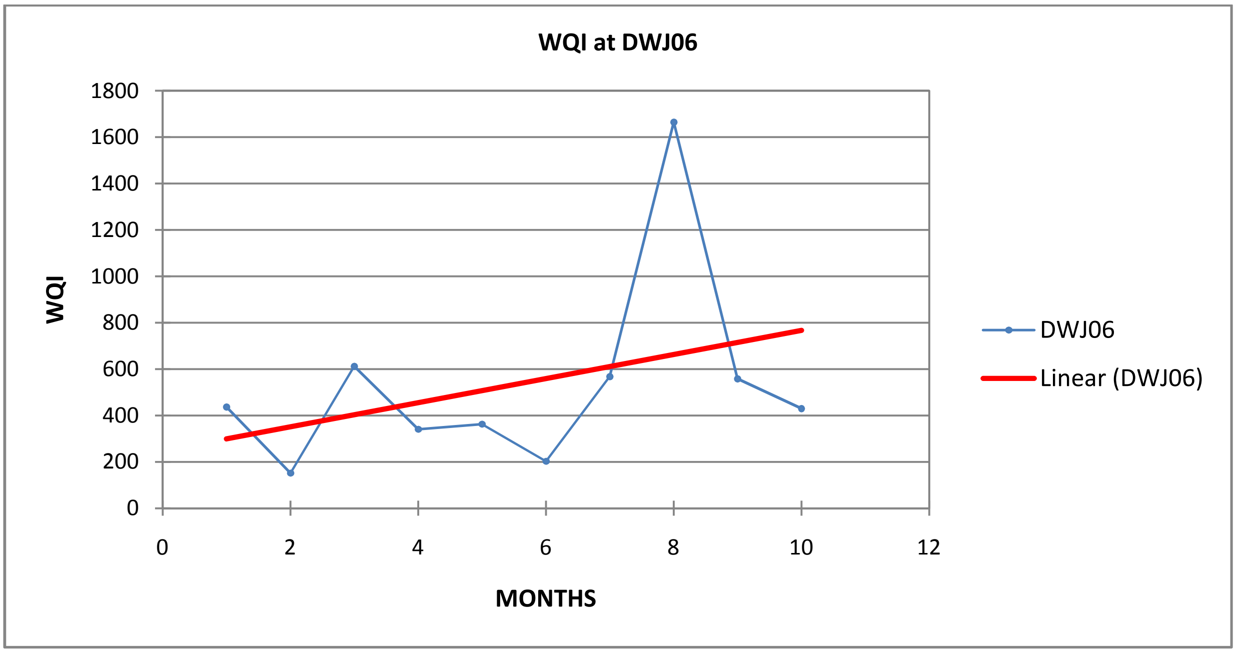

Figure 5.17: Graphical plots of WQI trends at DWJ06 during 2013

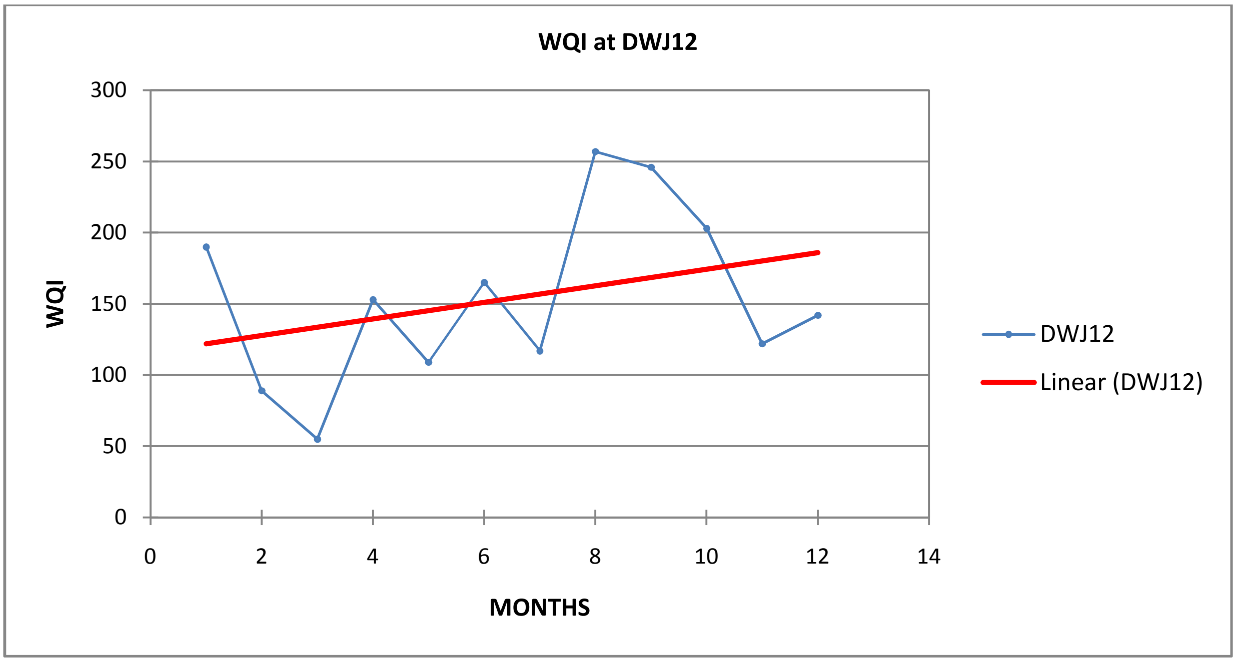

Figure 5.18: Graphical plots of WQI trends at DWJ12 during 2013

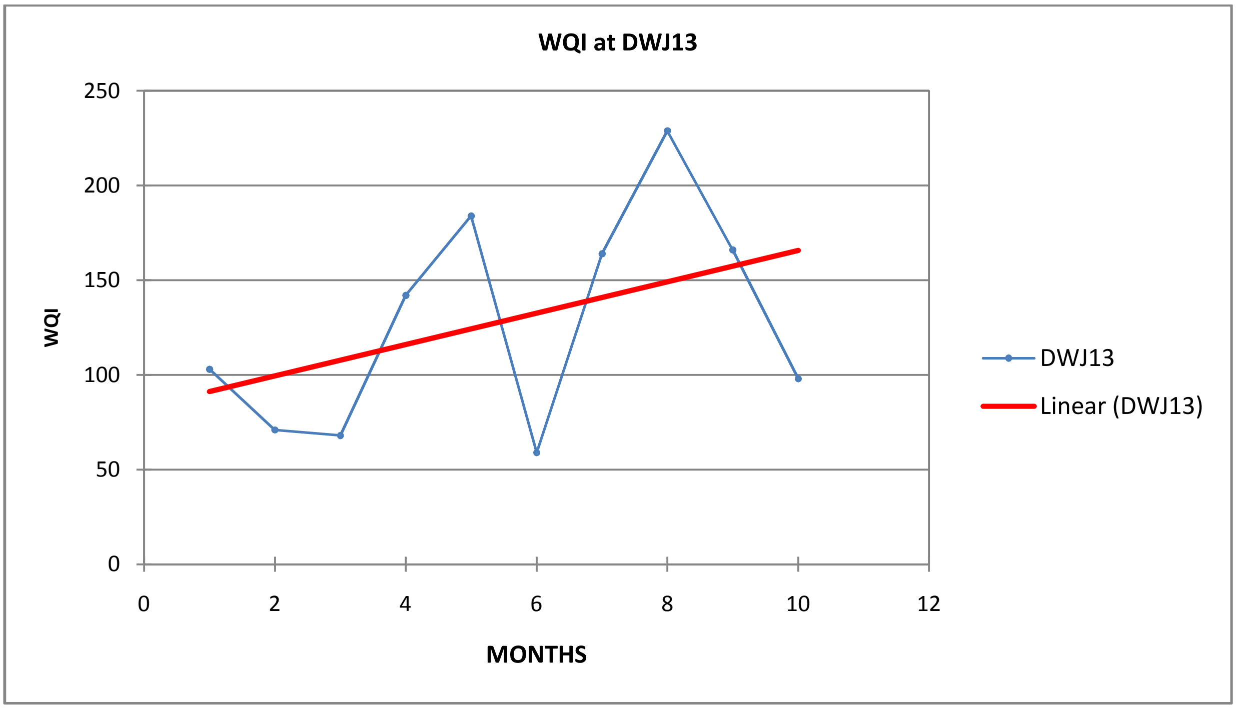

Figure 5.19: Graphical plots of WQI trends at DWJ13 during 2013

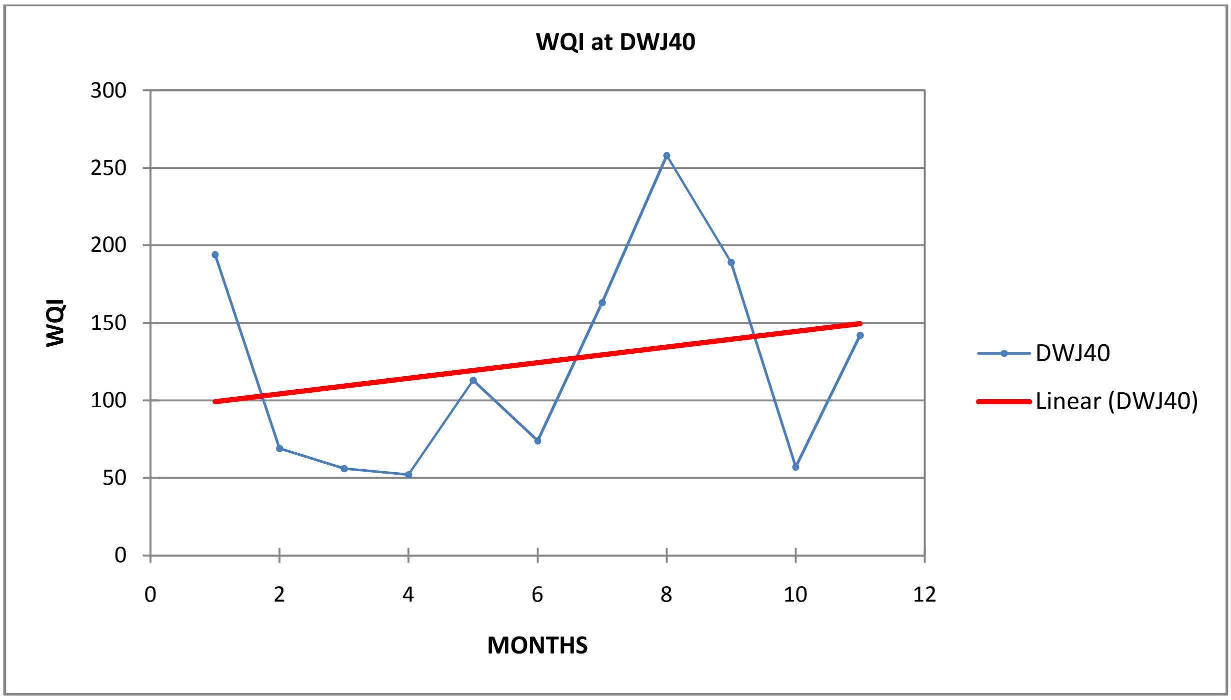

Figure 5.20: Graphical plots of WQI trends at DWJ40 during 2013

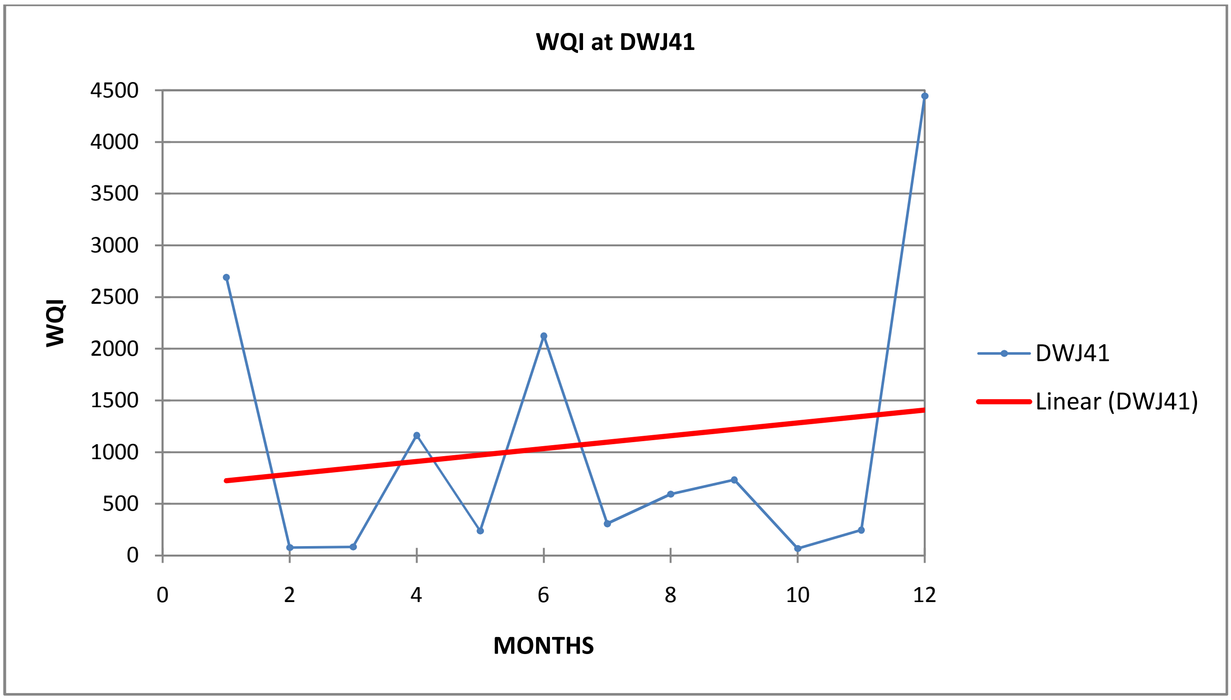

Figure 5.21: Graphical plots WQI trends at DWJ41during 2013

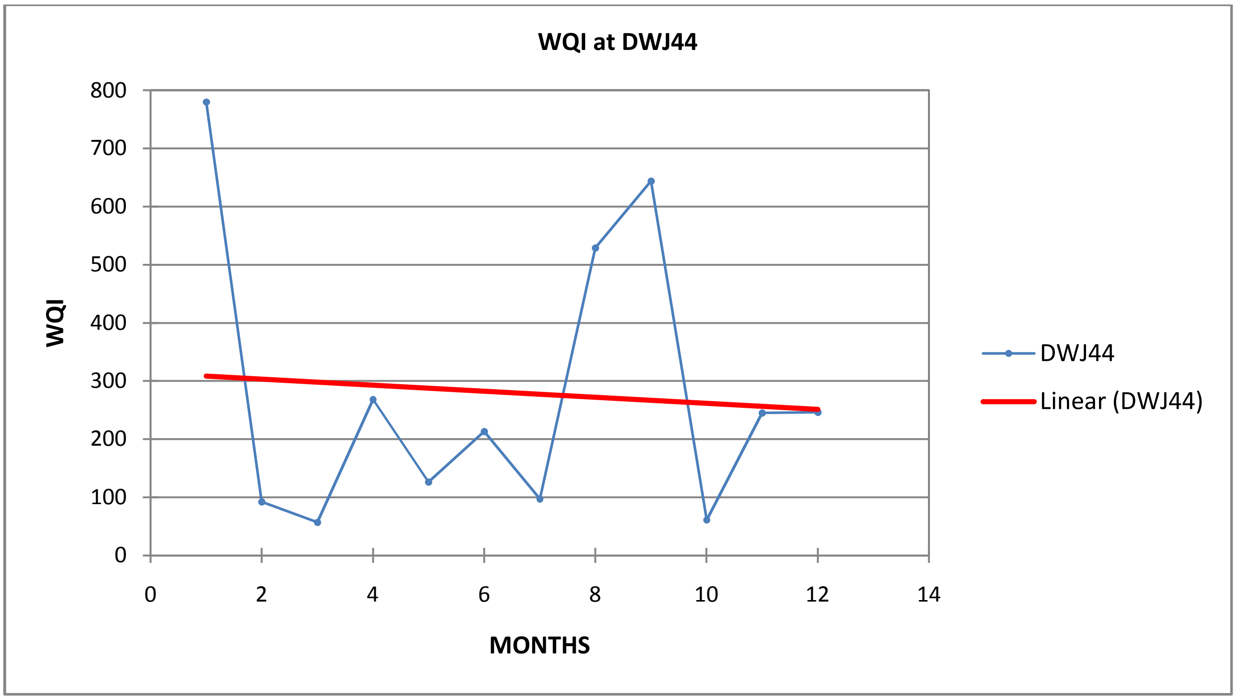

Figure 5.22: Graphical plots of WQI trends at DWJ44 during 2013

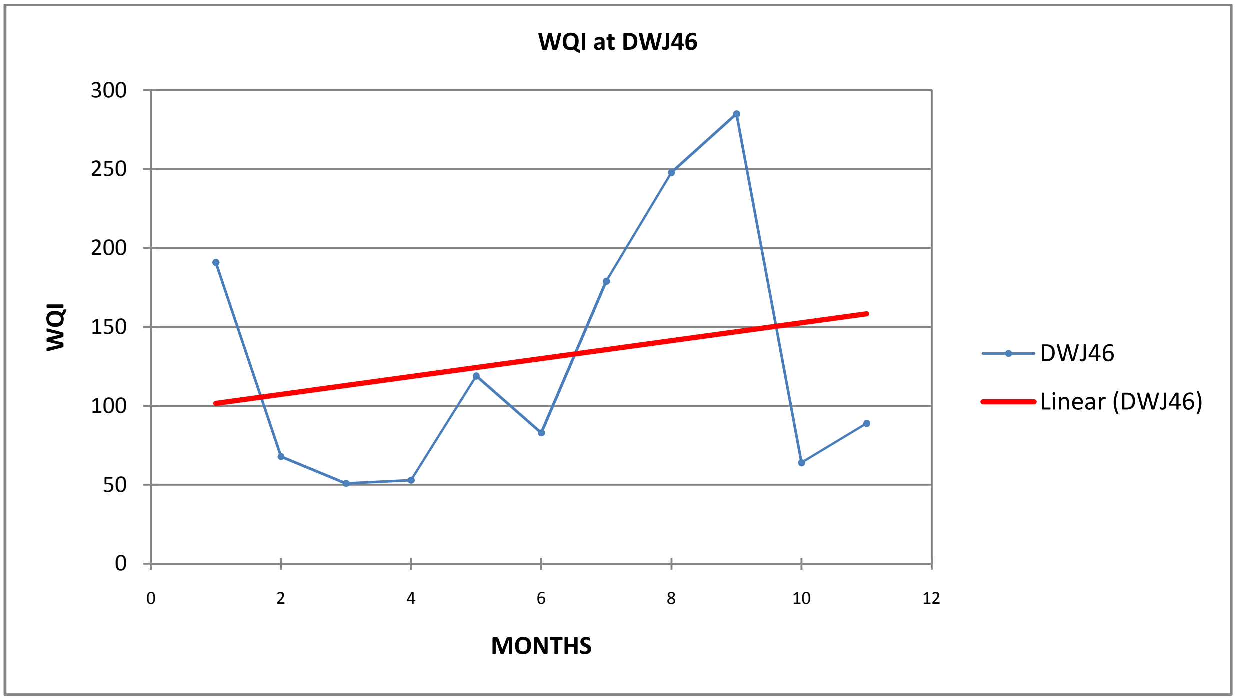

Figure 5.23: Graphical plots WQI trends at DWJ46 during 2013

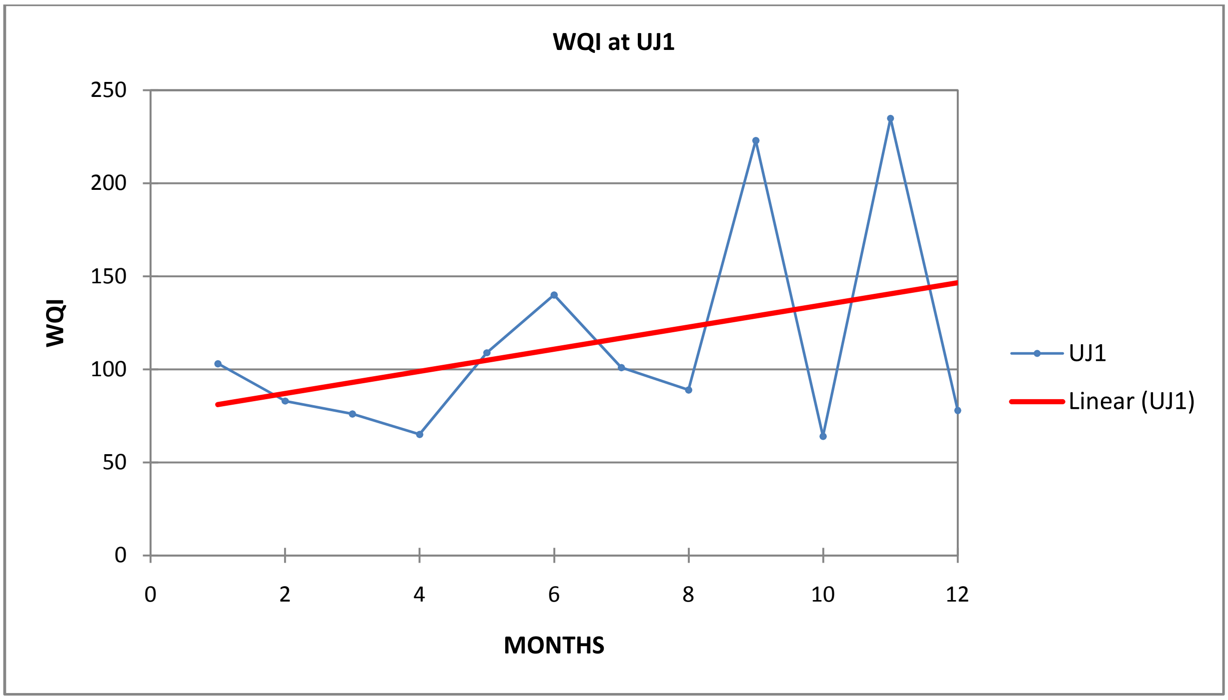

Figure 5.24: Graphical plots of WQI trends at UJ1during 2013

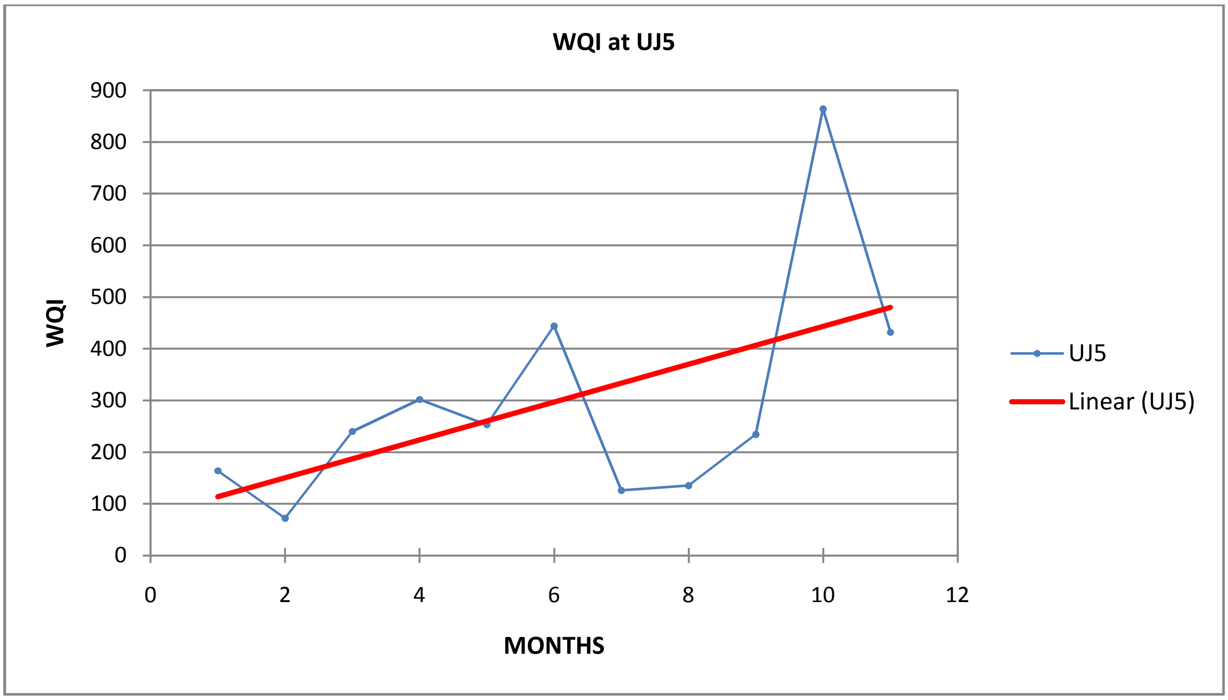

Figure 5.25: Graphical plots of WQI trends at UJ5 during 2013

5.4.4 Sand Spruit

The two monitoring points within the Sand spruit catchment including DWJ14 and DWJ15 indicated no significant trend during the analysis period. On plotting the linear trend line the DWJ14 indicated a decreasing trend while DWJ15 indicated a steady increasing trend (Table 5.17and Figures 5.26 and 5.27). Statistically these trends are considered insignificant. The discharge of industrial waste water from Wynberg could be the reason for this condition at DWJ15.

Table 5.17: Sand spruit trends

Sub-catchment	Sampling site	Kendall' tau	S	Var(S)	p-value (Two-tailed)	Sen's slope	Interpretation
Sand spruit	DWJ14	0.137	9.000	211.667	0.582	2.211	No trend
	DWJ15	0.321	21.000	211.667	0.169	71	No trend

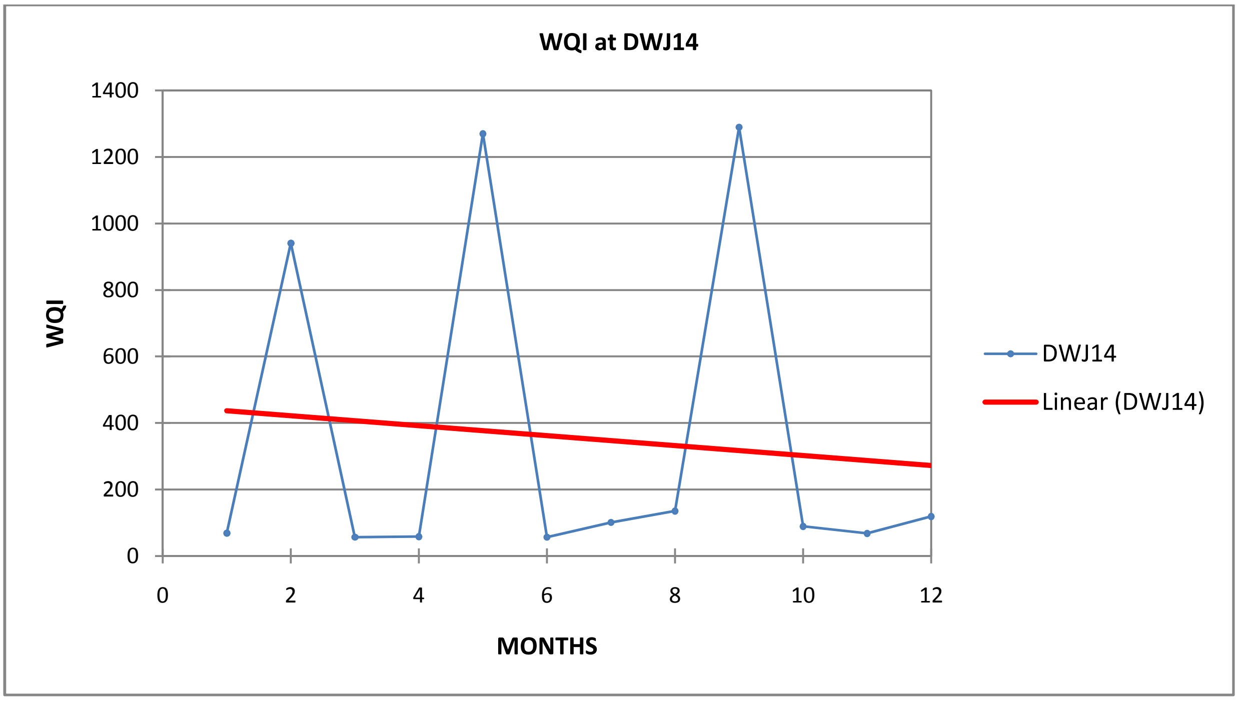

Figure 5.26: Graphical plots of WQI trends in at DWJ14 during 2013

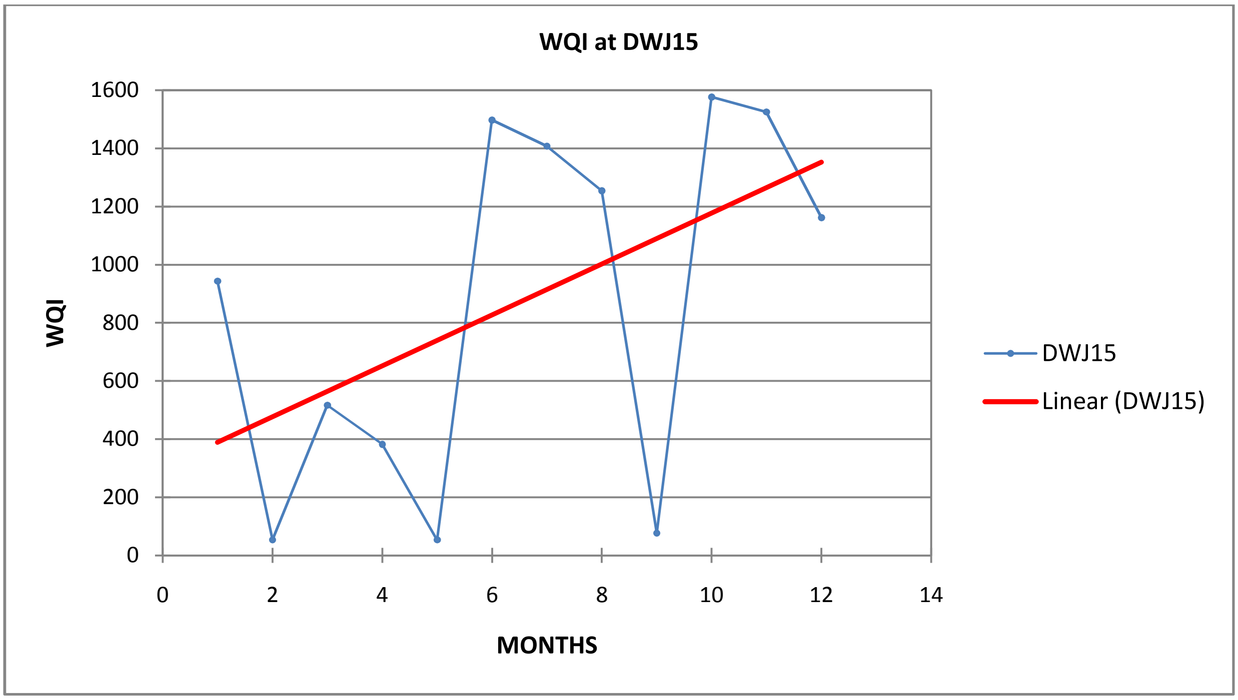

Figure 5.27: Graphical plots of WQI trends at DWJ15 during 2013

5.4.5 Middle and Lower Jukskei

The Middle/Lower Jukskei sub-catchment remained stable with all three monitoring points indicating no significant trend during 2013.The graphical plots of the WQI indicated an increasing trend at DWJ26 while JG1 and FG1 indicated a slight decrease (Table 5.18 and Figures 5.28, 5.29and 5.30). Statistically, the trends are however considered insignificant.

Table 5.18: Middle and Lower Jukskei trends

Sub-catchment	Sampling site	Kendall' tau	S	Var(S)	p-value (Two-tailed)	Sen's slope	Interpretation
Middle & Lower Jukskei	DWJ26	0.382	25.000	211.667	0.099	1.45	No trend
	FG1	0.015	1.000	211.667	1.000	0.111	No trend
	JG1	0.200	11.000	0.000	0.445	23	No trend

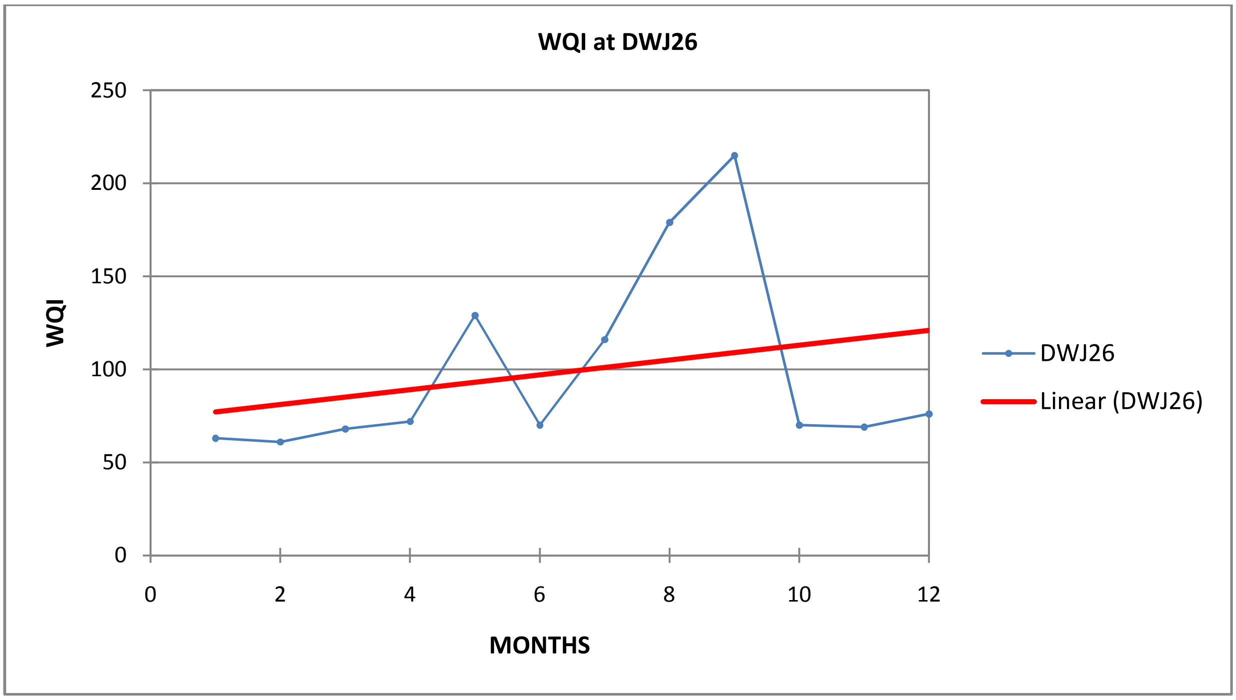

Figure 5.28: Graphical plots of WQI trends at DWJ26 during 2013

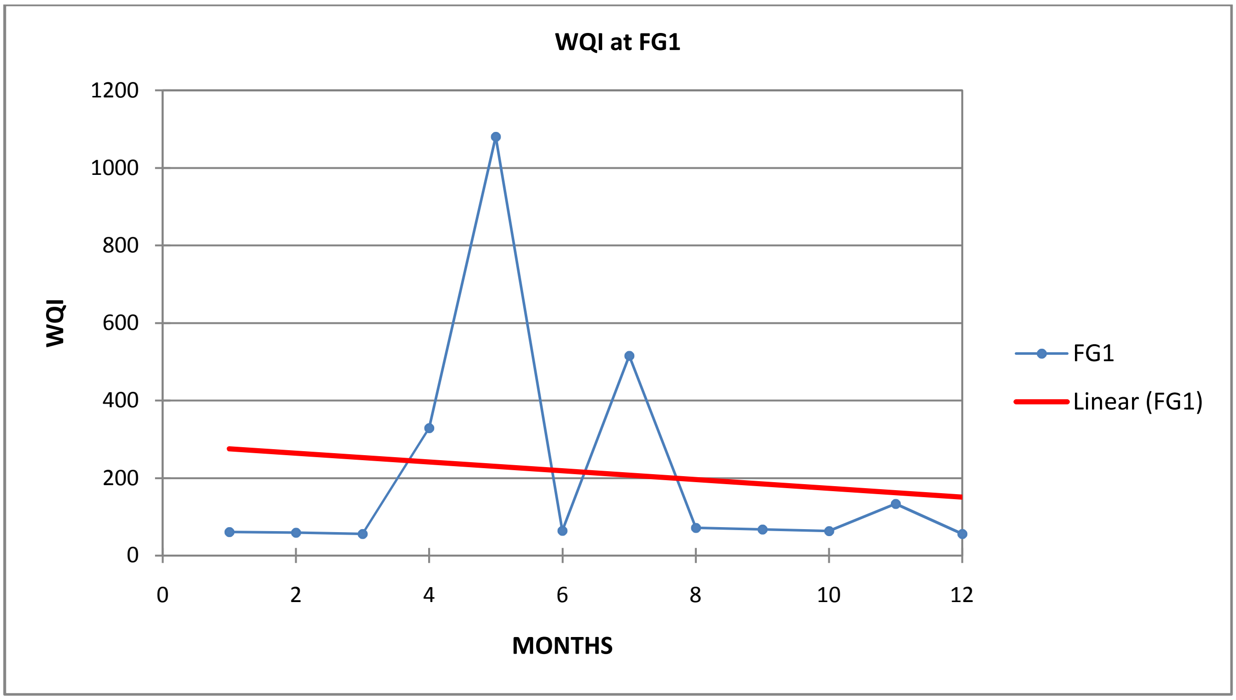

Figure 5.29: Graphical plots of WQI trends at FG1during 2013

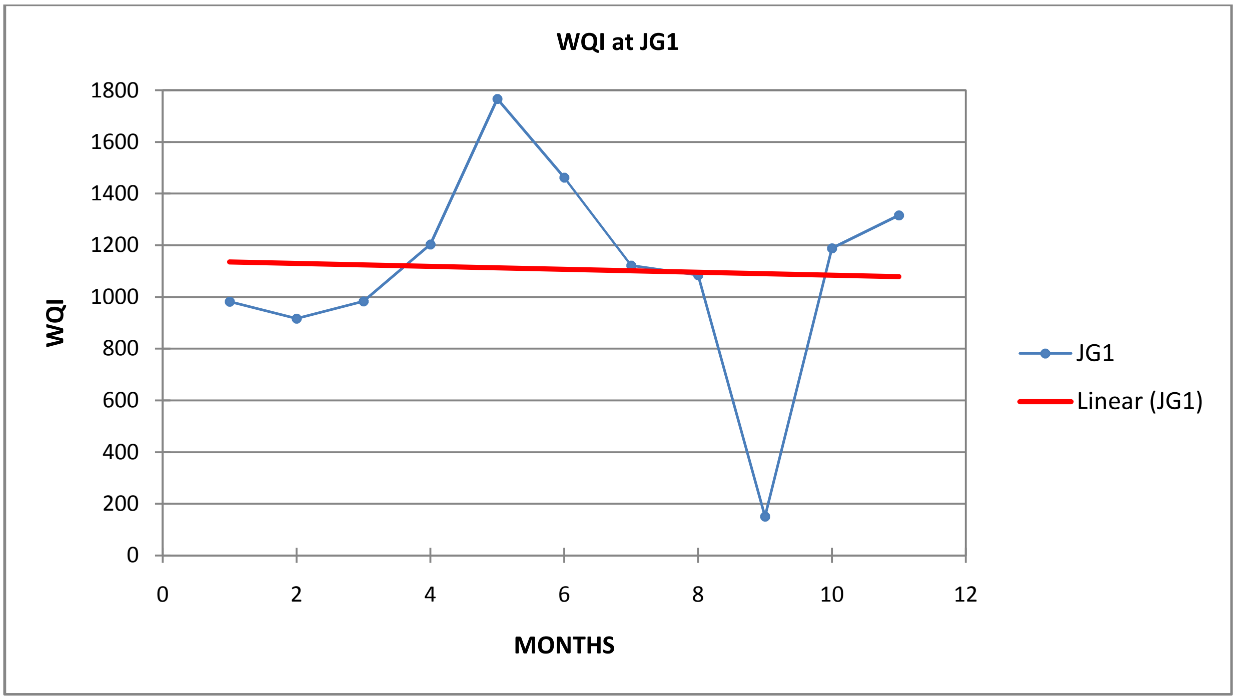

Figure 5.30: Graphical plots of WQI trends at JG1during 2013

5.4.6 Kaal spruit

The Kaal spruit water quality condition is worse although no trend was detected during the study period. The p values for three monitoring sites were quite high as compared to the significant value of 0.05 and hence no trend was detected. Visual inspection indicates a downward trend in all three monitoring points but statistically it is considered insignificant. The WQI plots indicate a decreasing trend at KLS1 and KLS3 while KLS2 is steadily increasing (Table 5.19 and Figures 5.31, 5.33 and 5.33).

Table 5.19: Kaal spruit trends

Sub-catchment	**Sampling site**	**Kendall' tau**	**S**	**Var(S)**	**p-value (Two-tailed)**	**Sen's slope**	**Interpretation**
Kaalspruit	**KLS1**	-0.394	-26.000	0.000	0.086	-127.9	No trend
	KLS2	-0.030	-2.000	0.000	0.947	-2.836	No trend
	KLS3	0.076	5.000	211.667	0.783	8.8	No trend

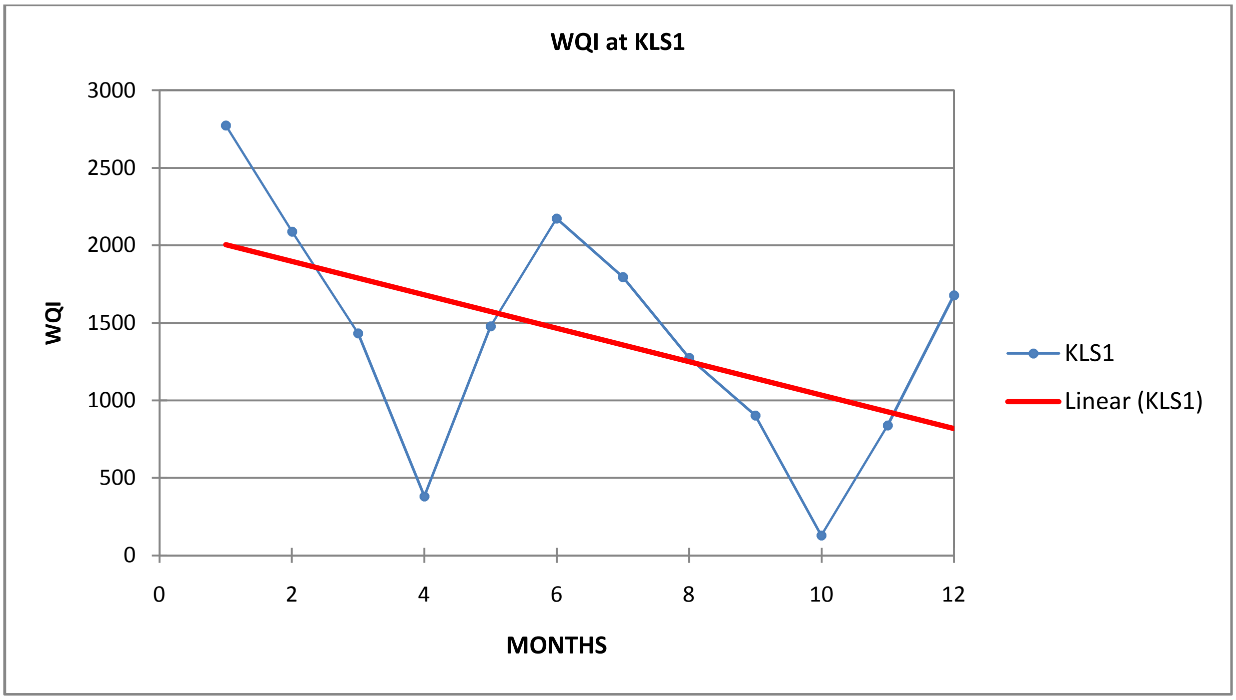

Figure 5.31: Graphical plots of WQI trends at KLS1during 2013

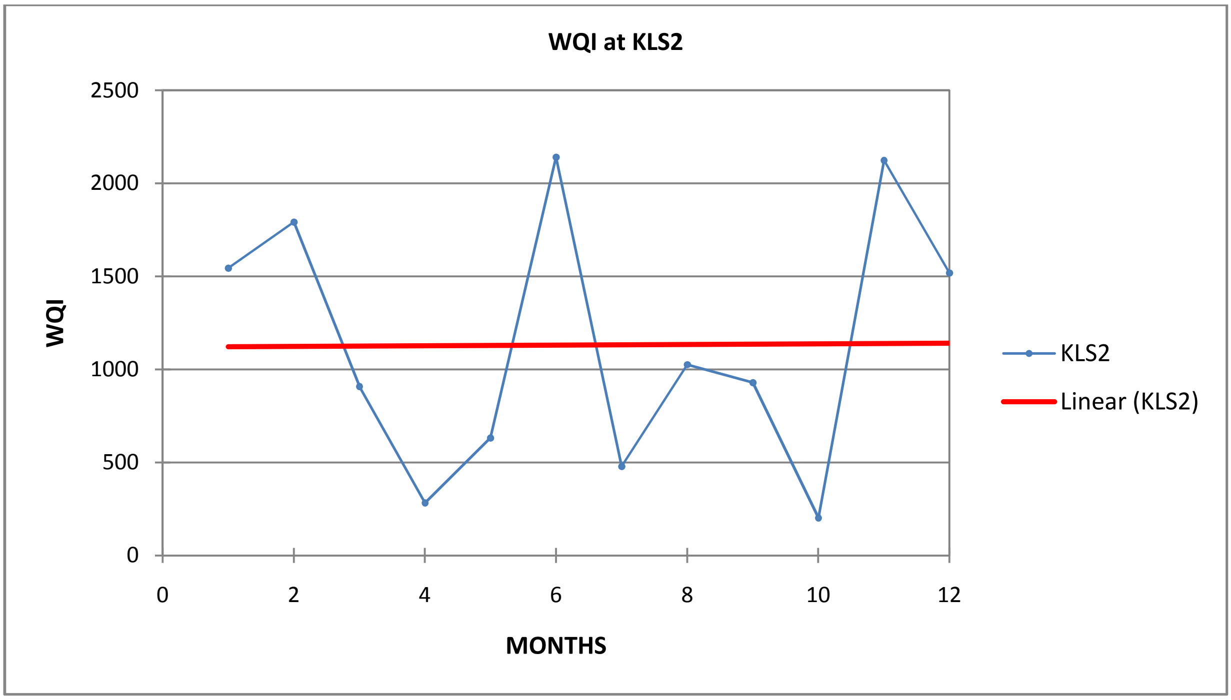

Figure 5.32: Graphical plots of WQI trends at KLS2 during 2013

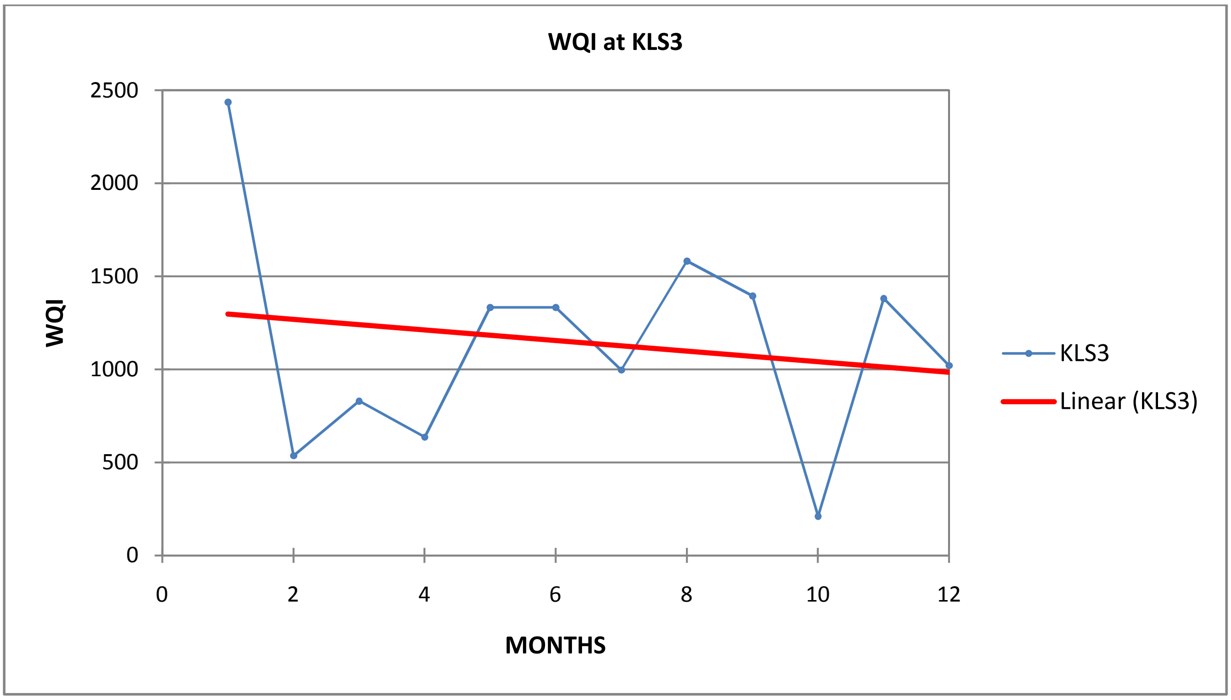

Figure 5.33: Graphical plots of WQI trends at KLS3 during 2013

5.4.7 Summary of Trend Analysis

The Mann Kendall trend test did not reveal any significant trend in all sampling points assessed for 2013 monthly data. The p values computed at all monitoring points were found to be less than the significant value (p= 0.5 or 5%). The trend lines of WQI plots at most of the monitoring points at Upper Jukskei, Kaal spruit, Sand spruit sub-catchments indicated WQI plots indicated some an increasing trend while few particularly in the Sand spruit and Kaal spruit and Upper Jukskei indicated a decreasing trend.

Table 5.20: Possible causes of trends in the Jukskei sub-catchments

Sub-catchment	**Observed trends**	**Possible drivers/causes**
Modderfontein spruit,	Statistical analysis indicate no trend but visual inspection indicate an increasing trend on all three monitoring points including DWJ03, DWJ04 and DWJ34	Inspection of the data indicated elevated levels of Nitrates/Nitrites, pH, COD and Sulphates. Possible sources include the Kelvin Power station, AECI, continuously blocked sewer systems and a small wastewater treatment works operated by ERWAT.
Upper Jukskei,	In this sub-catchment, the trend analysis indicated that the trend is insignificant and therefore no trend results for all nine monitoring points. However, the graphs indicate an increasing trend on all nine monitoring points, particularly the ones located around Alexandra township (DWJ40, DWJ41, DWJ44 and DWJ46).	Sewage drains around the whole of Alexandra overflow onto the roads on a daily basis. The water quality data indicated that Jukskei river already contains excessive levels of Nitrates, Sulphates, COD even before it reaches Alexandra township. Raw sewage leaks into the storm water drains which are superimposed with sewage drains in the inner city. Raw sewage also flows from poorly serviced and overcrowded buildings in Doornfontein, Johannesburg CBD, Cyrildene, Bruma, Yeoville and Bezuidenhout valley.
Sand spruit,	The graphs indicated a decreasing trend on DWJ14 and an increasing trend on DWJ15, however the trend was statistically insignificant during the study period.	The monitoring point DWJ14 is located upstream of the confluence of Sand spruit and the stream draining the Wynberg industrial area while DWJ15 is located immediately after the confluence. The flow on the stream consist of raw sewage containing waste water from different factories in

Sub-catchment	Observed trends	Possible drivers/causes
		Wynberg contain elevated levels of PO_4^{3-}, SO_4^{2-} and NO_3^-/NO_2^-.
Middle and Lower Jukskei,	The trend analysis graphs reveal an increasing trend on monitoring point DWJ26 while FG1 and JG1 indicate decreasing trend.	The water quality data for DWJ26 reveal excessive levels of SO_4^{2-} and NO_3^-/NO_2^-, Although FG1 and JG1 show a decreasing WQI trend, NH_4, COD, SO_4^{2-} are exceedingly high. The source of these pollutants include Northern Waste Water Treatment Works located just upstream of DWJ26, Diepsloot and Mayibuye informal settlements.
Kaal spruit	Trend analysis graphs indicated a pronounced decreasing trend at KLS1 and KLS3 while KLS2 does not reveal any trend.	The water quality data reveal high concentration of sewage related constituents including PO_4^{3-}, SO_4^{2-} and NO_3^-/NO_2^-,COD and NH_4in all three monitoring points.

5.5 SUMMARY OF RESULTS AND ANALYSIS

While the WQI is able to paint the picture of the water quality conditions of the Jukskei river catchment within Johannesburg borders, it was also possible to single out the areas which are more problematic for further assessment. This exercise revealed the Modderfontein spruit, Upper Jukskei, Kaal spruit, Middle and Lower Jukskei and Sand spruit sub-catchments as being highly polluted with continually unacceptable WQI.

All three monitoring points in the Modderfontein spruit sub-catchment including DWJ03, DWJ04 and DWJ34 indicated unacceptable WQI throughout the study period (2010-2013).It has been observed however that the WQI values are higher during dry seasons throughout the study period indicating that the dilution factor is playing a role during wet season while reduced flows during dry period increases the concentration of pollutants. Of more concern is that the trend analysis graphs indicate an increasing trend of WQI in all three monitoring points although the trend is statistically insignificant (Figures 5.14 to 5.16).

The more problematic monitoring points in the Upper Jukskei sub-catchment included DWJ06, DWJ12, DWJ41, DWJ44, DWJ46, UJ1 and UJ5 which consistently recorded unacceptable WQI during successive years (2010 to 2013). Pollution levels in this sub-catchment are increasing as revealed in trend analysis graphs (Figures 5.17 to 5.25)

The WQI analysis in the Sand spruit indicates that DWJ14 and DWJ15 are more problematic in this sub-catchment. The calculated WQI values were classified unacceptable throughout the study period. The wet season WQIs were lower than those recorded during dry seasons (February-April and May-July). Trend analysis figures indicate an increasing trend at DWJ15 and a decreasing trend at DWJ14. The increasing trend at DWJ15, although statistically insignificant is a matter of concern as it indicates more and more pollutants being discharged into the Wynberg stream (a tributary of Sand spruit) (Figures 5.26 and 5.27).

Monitoring points of concern in the Middle and Lower Jukskei sub-catchment include JG1, FG1 and DWJ26 which indicated continuous unacceptable WQI. The highest WQI were calculated for dry seasons while the wet seasons indicated lower WQI indicating the impact of rainfall in diluting the pollutants. An increasing trend at DWJ26 on the trend analysis

(Figure 5.28) is a problem that could be associated with the Northern Waste Water Treatment Works and Diepsloot informal settlement.

The Kaal spruit indicate the worst WQI across the City of Johannesburg borders. The WQI calculated for the three monitoring points during the study period are classified unacceptable. The WQI are highest during dry season (May-July and February-April) and lower during wet season (August-October and November-January).

The WQI determination exercise also made it possible to reveal those areas that are still in good conditions with rivers that are near natural conditions within the City of Johannesburg borders. Rivers which are still in good conditions include Wilge spruit and Klein Jukskei, Braamfontein sub-catchments. The Wilge spruit is the only sub-catchment which shows more natural conditions with WQI seldom exceeding 60 (tolerable). No trend analysis was determined for this sub-catchment since it is not under severe water quality threat.

At the Klein Jukskei the WQI at KJ1 and KJ4 becomes unacceptable during dry seasons (February-April and May-June) throughout the study period. The Klein Jukskei is one of the sub-catchments which are at the critical state which needs an immediate intervention before it becomes worse. The WQI in most of the monitoring points is tolerable. Trend analysis was not performed for this sub-catchment but steps need to be undertaken to improve its water quality.

The Braamfontein spruit like Klein Jukskei is at a critical stage with a fair share of monitoring points recording unacceptable WQI more frequently, particularly recently (from 2012). This is more apparent on the Zoo Lake monitoring points including ZL1, ZL3, ZL4, ZL5 and ZLW3. The Westdene monitoring points (WDNW and WDW) have consistently recorded unacceptable WQIs, EC1 has also shown a consistent unacceptable WQI. Trend analysis was also not performed for this sub-catchment but steps need to be undertaken to improve its water quality.

CHAPTER 6: DISCUSSION

The chapter starts by providing an insight into the current practice with respect to water quality data analysis and reporting methods being employed by the City of Johannesburg and shortcomings thereof. The advantages of employing the WQI to resolve these problems are also discussed. This is discussed in the light of the Department of Water Affairs' project called Waste Discharge Charge System to be piloted in the catchment.

6.1 SHORTCOMINGS OF THE CURRENT CITY OF JOHANNESBURG DATA ANALYSIS METHODS AND REPORTING

As shown in section 2.8.1.2, City of Johannesburg (COJ)possesses very credible water quality data which is continually being generated from their comprehensive monitoring programme. Section 2.2 indicates the background with regard to collecting water quality monitoring data in a manner which COJ like any other institution does to understand the nature of their water resources and to identify and address water pollution. Section 2.8.1.2 further reveals the shortcomings with respect to water quality data analysis, interpretation and reporting to comply with the level of reporting required by various stakeholders and decision makers in various structures of the municipal administration.

The analysis of each of the parameters from the monthly or averaged quarterly values by comparing it to target water quality range for aquatic ecosystem is a tedious exercise susceptible to errors and misjudgement since there are no guidelines to combine different classifications (ideal, acceptable, tolerable or unacceptable) in cases where different parameters fall within different classes. The reports are often characterised by figures, values and classifications for various parameters for each of the monitoring points considered problematic. This does not provide the decision makers the concise information they need to make decisions such as declaring a specific monitoring point a water quality hotspot. This failure contributes to perpetuation of water pollution.

6.2 THE ADVANTAGE OF USING WATER QUALITY INDEX

The WQI simplifies the complex water quality data comprised of a variety of parameters into a single value which was used to classify the water quality of COJ rivers. The WQI for all sampling points was determined using quarterly water quality data. This is in accordance to the reporting of COJ water quality results. Tables 5.1 to 5.8 indicated the quarterly WQI determined for each sub-catchment of the Jukskei catchment for specific water quality monitoring points. It can be noticed from these tables as the WQI changes substantially during the four quarters of the year. Different problem areas were identified using the WQI data including the Upper Jukskei, Modderfontein spruit, Sand spruit and Kaal spruit. Monitoring points indicating the worst pollution within these areas (constant unacceptable WQI throughout from 2010 to 2013) were further analysed by using the monthly data to determine the monthly WQI. Unlike comparing each of the measured value against the guideline limit, the WQI readily provides a combined figure to screen the problem areas. Focussed and detailed analysis of individual sampling point and parameters can then follow if detailed information is needed or to understand causes of high WQI.

The WQI generated can also be used to determine the trend over a specified period which is then useful in the current process of determining water quality hotspots for specific interventions. Currently this is not an easy exercise since it involves the analysis of large quantities of data (3-4 years) to decide if the sampling point qualifies to be considered a water quality hot spot.

The calculated WQI indicated that all the COJ Rivers and streams are experiencing continuous pollution and deterioration of water quality. Each of the eight sub-catchments indicated very high levels of WQI. In general, except for Wilge sub-catchment, most of monitoring points, especially in sub-catchments such as Kaal spruit, Sand spruit and Modderfontein, the WQI indicated that the water quality is in an unacceptable class.

The trend analysis of the WQI values did not indicate any significant trend (increasing or decreasing) using a two-tailed Mann Kendall analysis with a 95% confidence level. Linear fits of the WQIs however indicated there were many trends of worsening water quality. The high significance level adopted (95%) could be the possible reason why the Mann Kendall test did not suggest any trends, although this is in accordance with international practice in determining the trend using non parametric methods such as Mann Kendall.

6.3 IMPLICATIONS OF THE IMPLEMENTATION OF THE PROPOSED WASTE DISCHARGE CHARGE SYSTEM

The Waste Discharge Charge System (WDCS) of the Department of Water Affairs and Forestry (now Department of Water and Sanitation) (DWAF, 2003) is a pollution control mechanism conceptualised from the principle of polluter pays embodied within the National Water Act of 1998 (DWAF, 2003).The WDCS works in a manner such that the Department of Water and Sanitation set the Resource Quality Objectives for any particular resource and or a catchment. Any water user as described under section 21 of National Water Act of 1998 who discharges a specified load of pollutants to a water resource will pay a specified amount based on the load of pollutants discharged. The overall objective of the WDCS is to solve the problem of excessive water pollution. In attaining this objective several other objectives would be achieved, namely; efficient resource utilisation, cost recovery for activities related to pollution abatement and damage reparations, discouraging of excessive pollution and promotion of sustainable water use (Venter and Maré, 2010). The WDCS is focused on reducing discharge load in order to achieve or maintain RQOs in a catchment. Where RQOs are being met, the WDCS is not applied. Where RWQOs are exceeded or in threat of being exceeded, the WDCS may be applied as part of water quality management in the catchment (DWAF, 2012). A properly implemented and managed WDCS would encourage desirable activities from waste dischargers, namely abatement of pollution at source, recycling of waste streams and wastewater, re-use of water, water conservation and return of water to its source. However, this is totally reliant on effective monitoring and enforcement.

Compliance is also strongly dependent on the relationship between the economic benefits of breaking the regulations and the economic consequences of any sanctions that might be applied if non-compliance is detected. The likelihood of non-compliance being detected and acted on is an important part of people complying with regulation. As a result, water resources regulation in South Africa is currently very weak. This can be seen through the high levels of illegal water use, and deteriorating water quality. There are a number of reasons for this, including major issues of capacity. COJ will have to build this into their own regulatory tools including bylaws. The WDCS must be preceded by various other processed through the process being led by Department of Water Affairs and Sanitation including classification of water resources and setting of Resource Quality Objectives (RQOs).

The success of this important pollution control measure rests on the determination of RQOs. The concept of the RQO as a measure of acceptable environmental, social and economic impact. The setting of RQOs is catchment specific and reflects societal sanction of activities in the catchment. The purpose of establishing acceptable RQOs is to balance the need to protect and sustain water resources with the need to develop and use them. The Jukskei catchment is part of the pilot area which the Department of Water Affairs will be rolling out later in 2014/2015. It is therefore an opportunity for municipalities such as Johannesburg to externalise all pollution emanating from other users within their borders.

The proposed WDCS pilot (DWAF, 2007) will be based on parameters that are also found to be the major pollutants in this study including Salinity (electrical conductivity, chloride, sodium and sulphate), Nutrients (soluble phosphorous, nitrate, ammonium), Heavy metals (arsenic, cadmium, chromium, copper, mercury, lead, nickel and zinc), Organics (Biochemical oxygen demand or chemical oxygen demand) and pH (Pegram, *et al*., 2014).

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

This study aimed to assess the current water quality data analysis, interpretation and reporting by the City of Johannesburg (COJ) and to find an appropriate Water Quality Index (WQI) that could be used by COJ to improve their analysis of the water quality data. The study also aimed at utilising the developed WQI to analyse the current water quality data, to demonstrate the significance of using the WQI to simplify water quality analysis and presentation, and to identify water quality hotspots.

The study successfully examined the current water quality monitoring data analysis in use at COJ and found the shortcomings related to information generation. The study has revealed that there is a weakness in the City of Johannesburg with respect to the water quality data analysis, interpretation and reporting methodologies. Comparison of the target water quality range as specified in DWAF water quality guidelines does not provide very comprehensive information of the status of water quality within the COJ.

As the data base enlarges, it becomes more problematic to analyse long-term data for each parameter. It becomes very tedious and produces a lot of figures and tables which tend to be very complicated for the officials who must use this information to identify problem areas, identify projects, motivate for funding, implement and monitor projects. The information required by the officials of the COJ is an identification of problem areas, causes of pollution and an indication whether the pollution is getting worse or better. .

The WQI used in this study successfully revealed the status of the water quality within the Jukskei catchment of COJ. The WQI values were determined for each monitoring site for each of the study years grouped into four quarters. Although the status of water quality is already within the unacceptable class in all the sampling sites, the WQI values reveal the severity of the pollution problem over time. Application of trend analysis did not reveal any significant trend.

The study reveals that WQI as a simple and practical tool in analysing and interpreting the water quality data to generate useful information from the data and to communicate the information to policy makers, managers and the general public. This study has indicated that COJ can benefit from using this tool in addition to detailed analyses that need to be conducted from time to time where problem sites are identified. WQI can therefore be used to identify these sites followed by detailed statistical analysis to help identifythe root cause of the problem.

It is recommended that COJ adopts the WQI to improve the water quality data analysis and interpretation and to improve the understanding of water quality status of the COJ. The WQI formulae can be integrated into the Laboratory Information Management System at Cydna Laboratory which analyse COJ water samples for the system to perform the analysis as soon as the data is uploaded.

Bylaw enforcement is also a problem as there is no coordination due to various stakeholders responsible with no clear roles (Memeza, 2000). While the enforcement activities are more pronounced on road traffic violations, there is still a major problem in the environmental management related bylaw enforcement. This also is likely to improve once the Department of Water Affairs starts rolling out the Waste Discharge Charge System and other related projects including determination of Resource Quality Objectives and the classification of water resources.

During the study, it was discovered that COJ had discontinued analysing for Turbidity since December 2012. The reason was because of limited budget being allocated to run the water quality monitoring programme. While the issue of budget constraint is unavoidable, it is important to determine the impacts of discontinuing monitoring of parameters that are crucial in water quality assessments. Choice must be made with regard to discontinuing analysing for a specific parameter vis-à-vis discontinuing a specific monitoring site to optimize on values of data while save costs.

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