Chapter

uMngeni Basin Water Quality Trend Analysis for River Health and Treatability Fitness

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Abstract

One of the main challenges facing the potable water production industry is deterioration of the quality of raw water. Drinking water that does not meet quality standards is unfit for consumption. Yet, this quality is a function of various factors, key among them being quality of the raw water from which it is processed. This is because costs related to potable water treatment are related to the nature of raw water pollutants and the degree of pollution. Additionally, survival of aquatic species depends on self-purification of the water bodies through attenuation of pollutants, therefore, if this process is not efficient it might result in dwindling of the aquatic life. Hence, this chapter presents spatial and temporal water quality trends along uMngeni Basin, a critical raw water source for KwaZulu-Natal Province, in South Africa. As at 2014 the basin served about 3.8 million people with potable water. Results from this study are discussed in relation to uMngeni River's health status and fitness for production of potable water treatment. Time-series and box plots of 11 water quality variables that were monitored at six stations over a period of eight years (2005 to 2012), were drawn and analysed. The Mann Kendall Trend Test and the Sen's Slope Estimator were employed to test and quantify the magnitude of the quality trends, respectively. Findings showed that raw water (untreated) along uMngeni River was unfit for drinking purposes mainly because of high levels of *Escherichia coli*. However, the observed monthly average dissolved oxygen of 7 mg/L, that was observed on all stations, suggests that the raw water still met acceptable guidelines for freshwater ecosystems. It was noted that algae and turbidity levels peaked during the wet season (November to April), and these values directly relate to chlorine and polymer dosages during potable water treatment.

Keywords: water quality trend, uMngeni, river health, treatability, spatio temporal, water quality, monitoring

1. Introduction

Water is an integral natural component of any ecosystem as well as a social and economic good [1, 2]. However, utilisation of this resource is highly influenced by its quantity and quality. For example, due to limited capacity and the prohibitive cost of treatment chemicals, water treatment utilities and municipalities, especially in developing countries, struggle to provide water for domestic use. This is particularly severe in rapidly growing informal settlements and peri-urban areas. A key factor affecting the production of adequate potable water has been deterioration of the quality of raw water sources [3–5]. This has mainly been attributed to anthropogenic factors [6] such as rapid urbanisation, industrial waste [7], population growth, and climate change among others. The protection of drinking water sources is thus a critical step in ensuring the production of drinking water at a reasonable price. This is also made possible through the participation of various stakeholders with varying knowledge on water science. The research sector has lately been playing a pivotal role in ensuring that water treatment utilities are updated regarding the state of river basins. Hence, failure to incorporate water quality data in water resource management and infrastructure planning challenges the ability of decision makers to respond to the increasing economic and social demands of associated use and consumption of poor-quality water.

The management of water quality is a complex process because of the diversity of polluting parameters as well as their interaction and resultant characteristics within a polluted environment [2]. An important aspect of water quality assessments for drinking water source protection is identifying changes in water quality trends and specific pollution sources, which are an integral process during appraisals of decisions related to environmental protection [8, 9]. To assist with these appraisals, long-term water quality data are employed as they are useful for detecting the spatial and temporal changes in the state of aquatic environments, when interpreting effectiveness of measures aimed at [10]. Water quality monitoring can thus assist to reveal the history of a water body and further give a reflection of the current status. Water quality trends analysis present a simple method of determining the long-term fitness of a catchment for a given use. The chosen technique is expected to assist with identifying how the concentration of a given water parameter changed over a period of time. With this method, one can determine the long-term fitness of a water body for specific uses such as potable production and protection of aquatic biodiversity. The success of a trend analysis depends on the main principles (1) acquisition of water quality data from a properly-designed monitoring program, (2) application of appropriate statistical methods for trend detection, and (3) a good understanding of relevant water quality parameter correlations [11].

It is known that rivers are often the ultimate sinks of effluent and other forms of pollution [12, 13]. Various processes, for example, soil erosion, disposal of waste from urban-industrial and domestic activities including fertiliser run off from agricultural activities, cause the deterioration of water quality [2]. Specifically, polluted water is a threat to flora and fauna and is unsuitable for any human need [14]. Thus, consumption of water that is polluted results in ill health which, in extreme cases, can cause death [4]. Pathogens present in drinking water including many bacterial, viral and protozoan agents have been reported in various research articles to cause illness and death to various degrees and in different year timelines [15–17]. Some specific health and water-related problems have statistically was grouped by Khan, Tareen [18] as follows: hepatitis A (32%–38%), gastroenteritis (40%–50%), hepatitis B (16%–19%), hepatitis C (6-7%), dysentery (28–35%), and diarrhea (47%–59%).

Each water quality variable (parameter) also has an effect, either beneficial or detrimental on aquatic organisms. The effect depends on whether they act synergistically or antagonistically [12]. To aquatic organisms, this effect is influenced by the tolerance limit of that organism. However, the fundamental principle of pollution prevention is to stop or minimise anthropogenic activities, which result in the contamination of water systems. In determining pollution prevention strategies, it is important to firstly identify the key pollutants of concern [19]. South Africa is not exceptional to the current worldwide deterioration of the quality of river waters. It is perceived as one of the major impediments to South Africa's capability to provide sufficient water of appropriate quality to meet its current needs and to ensure sustainable water provision for the future [20]. The quality of water directly affects its use, such that poor quality water is less available for various uses. An understanding of the temporal and spatial changes in the water quality of rivers is critical for water resource protection and management.

During the production of potable water, several chemicals, for example, disinfectants, coagulants and oxidants, are added at various stages of the process [21], the objective being to produce water that is biologically, chemically and aesthetically acceptable. The cost of chemicals is a major component of operating a potable water production plant [22, 23] although the types and quantities vary depending on a range of factors such as incoming raw water quality and the treatment technology [21]. Because water treatment costs determine the pricing of potable water, it means that ultimately cost presents a barrier regarding access to safe and adequate water for drinking and sanitation purposes, especially for poor communities [5, 24]. Additionally, the measured water quality variables, for example, turbidity and pH, have either a direct or indirect effect on the dosage and performance of the treatment chemicals. One condition is when there is high pH water, which will require a comparably lower coagulant dosage since coagulant optimisation is at high pH values. On the other hand, an elevated turbidity level increases coagulant dosage. Coagulant is a chemical that conglomerates dissolved pollutants into flocs that can then be removed using filtration and sedimentation [25]. Thus, the cost of potable water treatment due to diminished water quality represents an important component of the societal costs of water pollution [24, 26]. Therefore, finding timely, cost-effective, and appropriate solutions that address water pollution and its resulting challenges is critical.

Hence, the main objective of this chapter was to highlight water quality trends in uMngeni Basin for the period 2005 to 2012. The focus was on (1) how water quality variability impacted chemical dosage during potable water production at Durban Heights and Wiggins Water Treatment Plant and (2) determining how the quality variability affected the overall freshwater ecosystem health within the basin, using specific parameters. The following sections describe uMngeni Basin, provide the methods employed during analysis as well as results and conclusions drawn.

2. Study area

uMngeni River (232 km) and its basin (4432 km^2) are the primary source of raw water that is then treated to potable use for a population of almost 6.7 million people [27] within and around Durban Metro as well as Pietermaritzburg City, in KwaZulu-Natal (KZN) Province, South Africa (**Figure 1**) uMgeni Water, a State-Owned Entity, is the biggest 'user' of raw water in the uMngeni Basin as it produces 472 million cubic meters of potable water per year for commercial, industrial and domestic use along the basin and its adjacent coastal areas [27]. The catchment receives an annual precipitation of 410–1450 mm, mean annual runoff which varies from 72 mm to 680 mm and a mean annual evaporation of 1360–2040 mm (CSIR., 2011).

uMngeni Basin supports a diverse range of livelihood activities which contribute approximately 16% to the gross national product of South Africa [28]. Although the province covers a small portion of the country's land area, the province contributes almost 30% to the national agricultural output and, therefore, significantly bridges food security in South Africa. A consequence of this development has been high levels of pollutants entering the water resources system and getting flushed out to sea.

The basin's main river rises close to the uMgeni Vlei, near Fort Nottingham at an altitude of 2071 m (**Figure 2**). The land surrounding the headwaters is mainly used for forestry plantation and agriculture [29]. Most of the farmers practice dairy, piggery and maize production [29]. As a result of many economic activities, damage to the

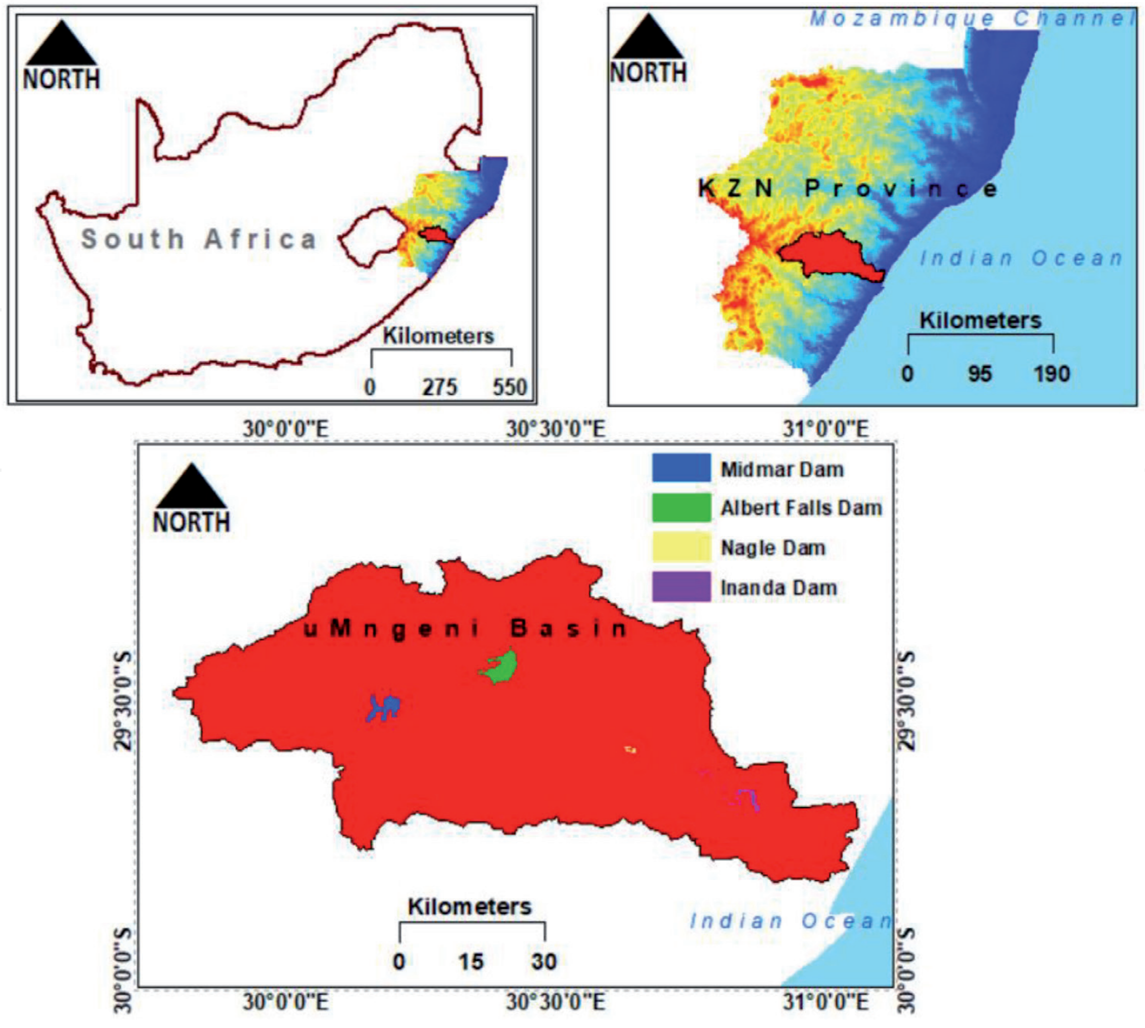

Figure 1.
South Africa, KwaZulu-Natal Province and uMngeni Basin plus four dams.

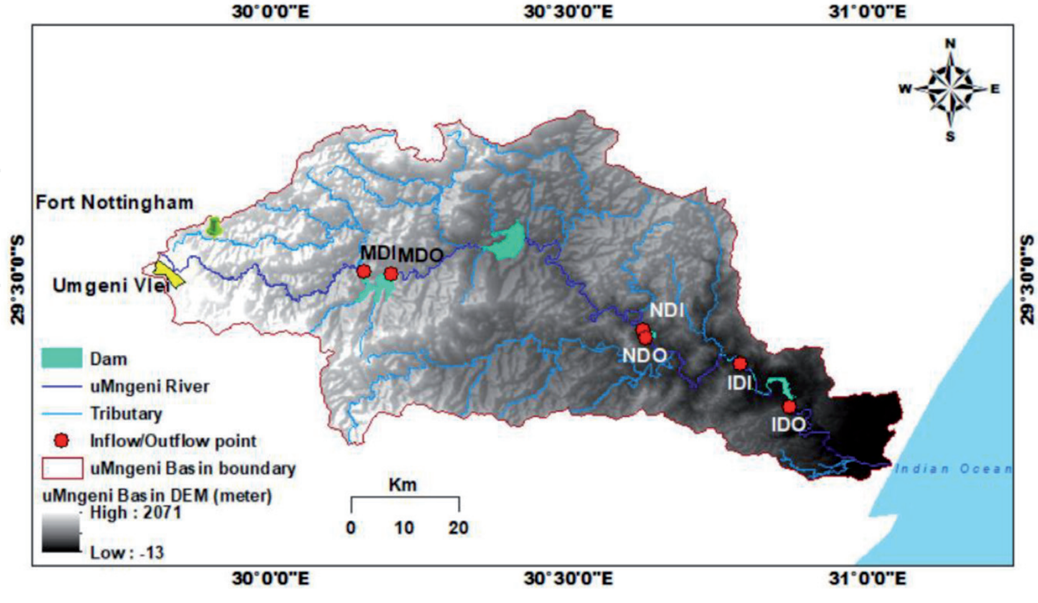

Figure 2.
uMngeni River and dams along its course, showing dam inflows and outflows.

headwater wetlands has been reported [30]. The removal of riparian vegetation and invasion by exotic flora has also contributed to erosion of the riverbank throughout the upper uMngeni River. Four major dams namely; Midmar, Albert Falls, Nagle and

Inanda are located along the river course as it flows towards the Indian Ocean. Except for Albert Falls, raw water is abstracted from the other three dams by Umgeni Water Amanzi, for the purpose of producing potable water. Because Umgeni Water Amanzi's primary business depends on the quality of raw water, the treatment utility works in conjunction with the Department of Water and Sanitation (DWS) to monitor and manage the dams. The monitoring program has generating a vast amount of data that could be used to improve management of the basin, overall. This chapter is based on the analysis of historical data, which was obtained from uMgeni Water (2013).

Station 1: Midmar Dam Inflow (MDI): The station is located at the mouth of Midmar Dam. It measures the quality of inflow that helps to reflect the polluting activities upstream the river. Literature has cited agricultural activities runoffs and sewage bursts from low-cost settlements such as Mpophomeni, as significant polluting activities in the upstream of this dam [31]. Intensive livestock production and its related activities like cattle grazing, poorly managed dairies and piggeries, are the dominant sources of faecal pollution in Midmar and Albert falls dam catchments.

Station 2: Midmar Dam Outflow (MDO): The station is located where the dam re-joins river. It measures the quality of water before being discharged into uMngeni River. This helps reflect the natural purification efficiency of the dam. Since treatment plants generally abstract water of the best quality, this station should indicate the quality expected at Midmar Water treatment plant.

Station 3: Nagle Dam Inflow (NDI): The station is located downstream of Albert Falls Dam, which acts as reservoir for the former. Since it is located at the mouth of Nagle Dam, it measures the inflow from the river and thus helps reflect the pollution activities and river health status between Albert Falls and Nagle dams.

Station 4: Nagle Dam Outflow (NDO): The station is located where Nagle Dam re-joins uMngeni River. The quality of water at this station is expected to give an overview of the raw water being abstracted for treatment at Durban Heights.

Station 5: Inanda Dam Inflow (IDI): The station is located at the mouth of Inanda. It basically reflects the pollution activities from Nagle Dam to Inanda Dam. It gives information on the pollution activities arising due to activities by the rural community in the Valley of Thousand hills. Inanda Dam has been reported to experience some periods of elevated algal counts.

Station 6: Inanda Dam Outflow (IDO): The station is located at the outflow of Inanda into uMngeni River. When compared with its subsequent inflow station, it helps reflect the capacity of the dam to naturally purify water due to retention. Since treatment plants generally abstract from the best quality point, this station is expected to show the treatability of water at Wiggins treatment plant.

Catchment water quality monitoring involves the analysis of various parameters such as biological pathogens (e.g. *E. coli*), physical parameters (e.g. conductivity), metals, organic pollutants, turbidity, total suspended solids and pH [32]. These parameters should fall within specified guideline values for the raw water to be deemed safe for use. Studies have reported that statistic analysis of water quality data, is mainly affected by the nature of the data-sets, which are often non-monotonic trends, non-linearity, non-normally distributed, exhibit seasonal variations and have time spacing that is uneven [9, 33, 34]. This approach informed on the methods and materials for this study.

3. Material and methods

Eight-year data-sets (2005 to 2012) for the six stations as indicated in **Figure 2**, were acquired from the then uMgeni Water (2013) and analysed. Eleven (11) parameters namely alkalinity, pH, electrical conductivity (EC), nitrate, phosphorus, temperature, turbidity, total algae count, *E. coli*, dissolved oxygen and ammonia were finally considered for spatial and temporal trend analysis. These parameters were selected for trend analysis in this study based on the following three criteria; (1) literature citing the parameter as significant to aquatic biodiversity health, (2) the availability of data and (3) the parameter being of interest mainly due to pollution activities in the study area. In addition to raw water quality, potable water quality data-sets for Durban Heights and Wiggins treatment plant for the period 2005 to 2012 were also obtained for comparative analysis. Both graphical (time-series and box-plot) and statistical SK test methods were employed.

3.1 Time-Series Plot

A time series is a set of observations obtained by measuring a single variable regularly over a given period. The main characteristics of a time series analysis are that the data are not independently sampled, their dispersion varies in time, and they are often governed by a trend and cyclic components. In this study, time-series line plots were produced for all parameters in order to depict the variable patterns. Even though they graphically provided an easy and quick method of assessing the pollution patterns, their inability to display the crucial data characteristics, specifically mean, mode and median, was a major drawback. While considering the importance of these characteristics for describing water quality of the basin, box-plots were also done to augment the graphical trending [35]. Since effective trend analysis requires a fairly long sequence of data for a given sampling site, it was considered to use a five-year monthly data-set at a minimum, for monotonic trend analysis. However, for a step-trend, at least two years monthly data before and after treatment would be required [36]. These time frames are only guidelines as the longer the periods of record, the greater would be the sensitivity to detect smaller changes, based on the minimum guideline for monotonic and step.

3.2 Box-plot

One of the main advantages of a box-plot, also known as box and whisker, is its ability to summarise the distribution of data-sets in a way that allows for spatial comparison. This technique gives a visual summary of; (1) the centre of the data (the median = the centre line of the box), (2) the variation or spread (inter-quartile range = the box height), (3) the skewness (quartile skew = the relative size of box halves) and (4) presence or absence of unusual values 'outliers' [35, 37]. In this study the box plot was used to visually capture spatial variation among the study area stations. By allowing a comparison of data without making any statistical assumption, a box-plot presented a greater advantage compared to other observational techniques. However, the main limitation of observational methods was inability to quantify the magnitude of the observed trend [35, 37]. While considering the importance of determining the magnitude of trend especially when forecasting, statistical methods were also employed in this study.

When a study depends on secondary data, it is reasonable to consider a statistical method that accommodates outliers, missing values and censored-values which are common in water quality data-sets. The Seasonal Kendall test (SK test), which is a special case of the Mann Kendall Trend Test, is such a non-parametric test that can handle non-normal distributed data even with outliers, missing values or censored-values [35]. It is used to test for a monotonic trend of a parameter of interest when the data collected over time are expected to change in the same direction (up or down) for one or more seasons, e.g., months. The following assumptions underlie the SK test: (1) When no trend is present the observations are not serially correlated over time, (2) the observations obtained over time are representative of the true conditions at sampling times, (3) the sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time, (4) any monotonic trends present are all in the same direction (up or down). If the trend is up in some seasons and down in other seasons, the SK test will be misleading, (5) the standard normal distribution may be used to evaluate if the computed SK test statistic indicates the existence of a monotonic trend over time [33].

A positive SK value indicates an increasing trend whilst a negative value shows a decrease. A trend is considered statistically significant if the calculated P - value is less than 0.05 [36]. In this study, for situations where a significant trend was obtained, the Sen's Slope test was then employed to determine the magnitude of the trend. More detailed descriptions of the SK are found in Hirsch, Slack [38], Darken [39] and Helsel and Hirsch [35]. Both the SK and Sen's slope were calculated using XLSTAT 2014 software. The software runs in Excel and does not require prior programming knowledge, making it simple and user-friendly.

4. Results and discussion

4.1 Turbidity

The time series graph depicted in **Figure 3** shows that turbidity exhibited seasonal variation with regular peaks in the wet season (October to March). The most plausible explanation for the peaks is the increased soil and other particulates runoff due to rain. The mean and median values (**Table 1**) for all stations studied shows that turbidity was above the South Africa expected limit for drinking water, which is 0–1 NTU [40]. The SK test presented in **Table 1** shows a decreasing turbidity trend from Nagle Dam inflow station to Inanda Dam outflow. The most plausible explanations for the improvement of quality especially at Inanda Outflow station could be the retention effect which could have occurred as the flow decreased. Midmar Inflow (306 NTU) recorded the highest turbidity level, which could be attributed to intensive farming activities upstream this station.

Chlorination of highly turbid waters tends to increase the level of trihalomethane (THM) which has been reported as carcinogenic [41, 42]. Excessive turbidity in drinking water is aesthetically unappealing and is of health concern as the suspended particles can provide food and shelter for pathogens [43]. If not removed, turbidity can promote regrowth of pathogens in the distribution system and this could lead to waterborne disease outbreaks. The South African guideline requires

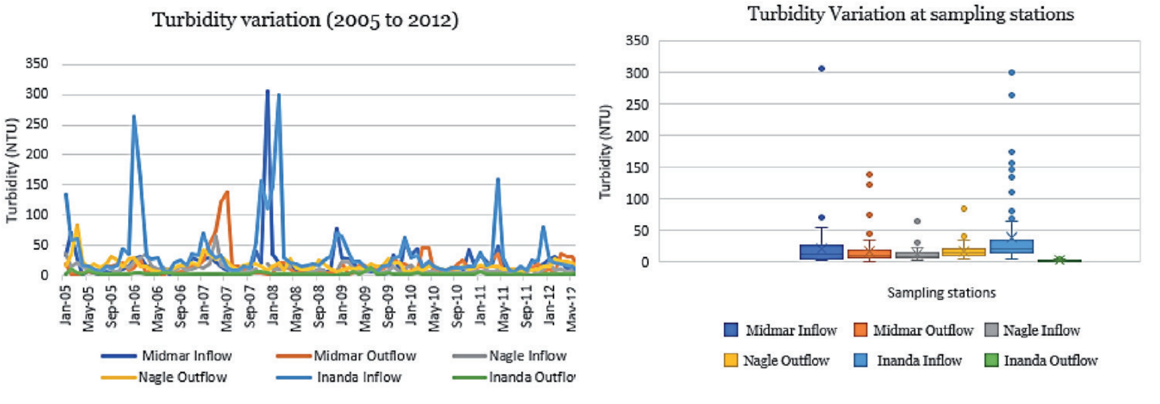

Figure 3.
Turbidity time series and box -plot.

Sample	Minimum	Maximum	Median	Mean	S-K (P)	Sen's slope	Decision
Midmar inflow	2.850	306.000	12.900	20.361	0.385	0.028	No trend
Midmar outflow	0.360	139.000	11.500	16.577	0.211	0.059	No trend
Nagle inflow	3.250	72.740	9.405	12.160	<0.0001	−0.078	Decrease
Nagle outflow	4.910	84.000	14.650	17.286	0.0495	−0.052	Decrease
Inanda inflow	5.635	299.700	21.563	38.729	0.0351	−0.075	Decrease
Inanda outflow	1.040	12.400	2.060	2.683	< 0.0001	−0.012	Decrease

Table 1.
Descriptive statistics for turbidity.

that turbidity level for drinking water be below 5 NTU [21, 44]. Kuutondokwa [45] reported of viable coliform counts in water with turbidity higher than 3 NTU, even in the presence of free residual chlorine. Dearmont, McCarl [26] reported that a 1% increase in turbidity tends to increase chemical costs by one fourth of a percent. Pernitsky and Edzwald [46] further reported that coagulant doses were generally higher when raw water turbidity was high, although the relationship was not linear. To aquatic life, higher than normal turbidity decreases the percentage of light transmitted, which results in decreased photosynthesis [45]. Additionally, excessive turbidity tends to demand an increase in the dosage of disinfectant in order to cater for envisaged pathogens that could be harbouring on the surfaces of the particles. Further, treating water with elevated levels of turbidity naturally results in excess sludge [45], which is undesirable for the environment.

On the other hand, a relatively low turbidity level observed at Inanda Dam Outflow station was desirable for the Wiggins Potable Water Treatment Plant since it meant using minimal quantities of chlorine and polymer. Dennison and Lyne [23], however, while studying factors causing high treatment cost at DV Harris Water Treatment Plant, observed that in contrary, low turbidity levels at Midmar Dam resulted in high treatment cost. The cost was attributed to use of bentonite, a coagulation enhancer that tends to facilitate the coagulation process for rather difficult to 'clean' (less turbid) raw water. The cost of bentonite tends to counteract the reduction of polymer dosage, making it rather expensive to treat water of with turbidity lower than optimal for efficient treatment to potable water quality.

4.2 Algae

For quantifying algae, only dam outflow station data-sets were used. Results for the three stations show that algae is a major problem along uMngeni Basin. As expected, algae exhibited peaks during the wet seasons [47] (**Figure 4**). The mean range of 1900 to 7055 cell/mL indicates that algae were dominant along the basin (**Table 2**). By comparing the mean observations of the three stations it is noted that Nagle Outflow recorded the highest mean concentration among all the three stations.

However, a comparison of the median values (**Table 2**) clearly shows that Inanda is the most deteriorated among the three stations. The latter results conform to earlier studies [29, 48]. During potable water treatment algae is known to have a direct relationship to polymer and chlorine dosage. The high level observed using water from Nagle Outflow suggests that more polymer and chlorine is required to treat water from Nagle compared to that from Inanda Outflow.

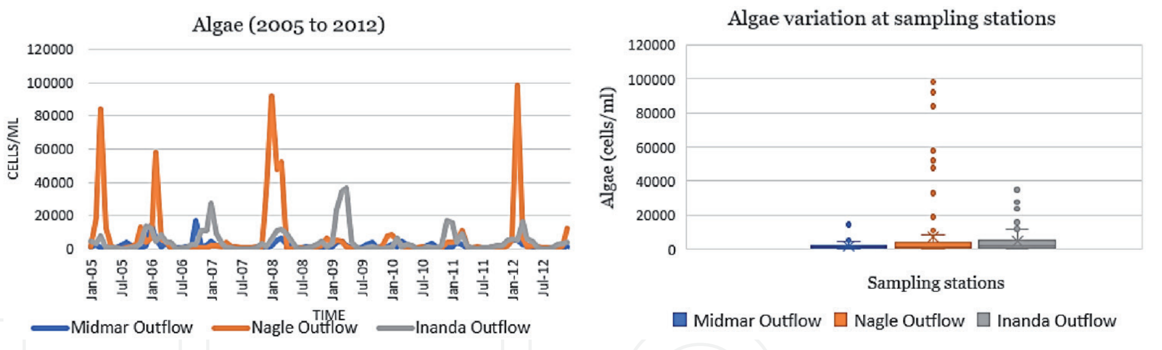

Figure 4.
Algae time series and the box -plot.

Sample station	Minimum	Maximum	Median	Mean	SK (p value)	Sen's	Decision
Midmar outflow	159.500	16760.500	1210.000	1900.600	0.125	−4.64	No trend
Nagle outflow	124.667	98224.400	1155.585	7055.885	0.497	−2.968	No trend
Inanda outflow	105.750	36352.330	1998.750	4499.085	0.748	−1.766	No trend

Table 2.
Descriptive statistics for Algae.

4.3 pH

The time-series plot (**Figure 5**) illustrates that pH variation is not a major problem along uMngeni Basin. Except for Inanda Inflow, the results for the SK test (**Table 3**) reveal no significant temporal variation of pH among the six stations. The observed minimum to maximum ranges were within the general national and international limits for no human risk (6.0 to 9.0 pH) and the survival of fresh water biodiversity [40, 49]. Growth and reproduction of freshwater aquatic species such as fish are found to be ideal within a pH range of 6.5 to 8.5 while pH below 4 or above 10 tends to be lethal to most aquatic animals [21, 50]. The pH values observed would not ideally promote toxicity of dissolved metal ions and protonated species, resulting in aesthetically pleasing water. Additionally, consumption of the water would not cause significant adverse health effects.

The pH of an aquatic system determines the concentration, accumulation and bioavailability of various species, which could be advantageous if required but a disadvantage if this process results in release of pollutants [51]. For example, a

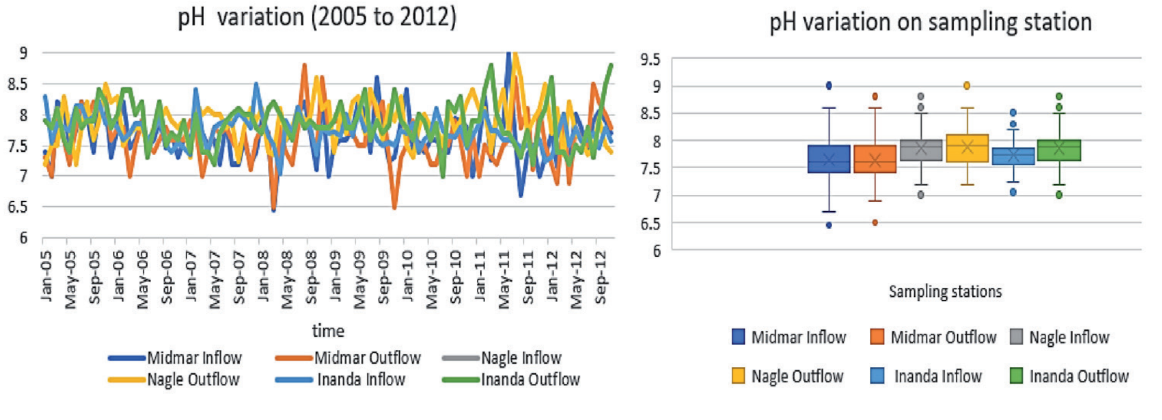

Figure 5.
pH time series and the box-plot.

Sample	Minimum	Maximum	Median	Mean	S-K (P)	Sen's slope	Decision
Midmar inflow	6.450	9.000	7.600	7.646	0.745	0	No trend
Midmar outflow	6.500	8.800	7.600	7.641	0.491	0	No trend
Nagle inflow	7.000	8.800	7.875	7.857	0.77	0	No trend
Nagle outflow	7.200	9.000	7.900	7.880	0.77	0	No trend
Inanda inflow	7.050	8.500	7.742	7.732	0.002	−0.003	Decrease
Inanda outflow	7.000	8.800	7.875	7.857	0.77	0	No trend

Table 3.
Descriptive statistics for pH.

decrease in pH increases the corrosivity of water, and increasing the pH increases the tendency to precipitate mineral scales such as calcium carbonate ($CaCO_3$). Another example relates to ammonia, which is more toxic in alkaline water than in acidic because free (NH_3) at high pH values (pH >8.5) is more toxic to aquatic biota than when in its oxidised form, NH_4^+. Additionally, reduction of pH enhances solubility and speciation of some metals, which elevates their toxicity [52]. On the other hand, alkaline conditions promote precipitation of some cations when they complex with other dissolved ligands [53]. Thus, overall, mobilisation of the species might be beneficial or undesirable, depending on the receiving environment and the concentrations resulting [51].

4.4 Total alkalinity

Alkalinity ranged from a minimum value of 14.6 mg/L at Inanda Inflow to a maximum value of 83.5 mg/L at Inanda Outflow (**Figure 6**) This indicates that uMngeni Basin still had the ability to resist pH change to some degree. Regarding river health, the observed high mean range (27.974 mg/L - 62.842 mg/L) (**Table 4**) suggests that uMngeni River still had the potential to resist pH, resulting in protection of the aquatic animals. This is in agreement with Dallas and Day [54], who reported that South Africa's rivers are naturally alkaline. The SK test results presented in (**Table 4**) show that alkalinity was generally stable during the period 2005 to 2012. A comparison of the mean and median values illustrates that both the inflow and outflow stations showed a moderate spatial increase towards downstream of the uMngeni River. Inanda Inflow station recorded a monthly mean value of 55.840 mg/L which was approximately twice that of Midmar Inflow (28.11 mg/L) (**Table 4**).

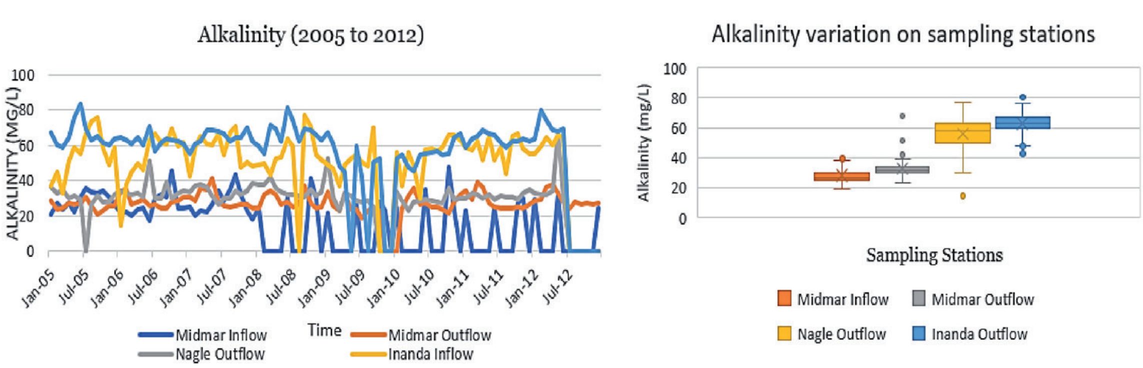

Figure 6.
Total alkalinity time series and the box-plot.

Sample	Minimum	Maximum	Median	Mean	S-K	Sen's slope	Decision
Midmar inflow	17.530	47.500	26.850	28.110	0.492	0.026	No trend
Midmar outflow	19.160	41.400	26.650	27.974	1	0.004	No
Nagle outflow	23.280	67.900	31.815	32.657	0.461	−0.018	No
Inanda inflow	14.600	77.270	57.695	55.840	0.363	0.077	No
Inanda outflow	42.970	83.500	62.995	62.842	0.633	−0.015	No

Table 4.
Descriptive statistics for Total alkalinity.

Regarding potable water production, the observed high alkalinity level at Inanda Dam stations reflects its ability to resist pH change as a result of coagulation. This could explain the low lime dosage used at Wiggins Treatment Plant compared to Durban Heights Treatment Plant.

4.5 Temperature

As expected with South African seasons [47], temperature showed seasonal variation with fluctuations (7.2–12°C) in winter (May – August) and high temperatures (24.7–29.9°C) in summer (September to March) (**Figure 7**) The small variation at the stations at each given time of the year could be explained by the differences in sampling time. The SK and Sen's slope results in **Table 5** show that water temperature decreased slightly towards downstream along uMngeni Basin except at Midmar Outflow.

High temperatures observed in summer coincided with algae bloom. Graham [48] used a data range from 1990 to 1999 to explain that algae bloom was a significant driver for potable water treatment costs along uMngeni Basin. Low temperatures have been reported to result in the formation of small flocs, which are vulnerable to disintegration due to fluid shear force [55]. On the other hand, Veenstra and Schnoor [56] explained that high chemical dosages for potable water treatment during summer were meant to compensate for losses caused by the sun's radiation, making it more expensive to treat water in summer. Even then, since very little can be done operationally to remedy temperature variation, a treatment plant should have strategies in place to counter the effect of low temperature in winter, especially for coagulation and flocculation processes.

Additionally, temperature tends to influence the metabolic rates of aquatic organisms, which influence the quality of the raw water. In warm waters respiration rate tends to increase, leading to increased oxygen consumption and decomposition of organic matter. The concentration of oxygen in water is also affected by temperature,

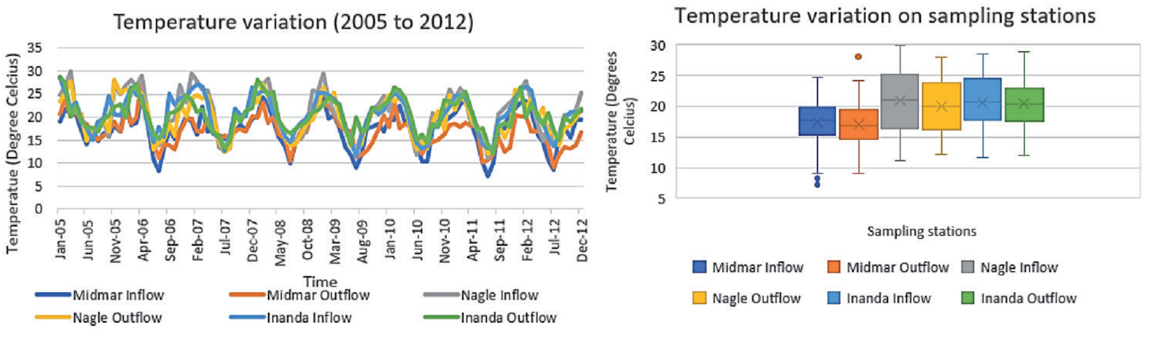

Figure 7.
Temperature time series and the box-plot.

Sample	Minimum	Maximum	Median	Mean	S-K	Sen's slope	Decision
Midmar inflow	7.200	24.700	17.700	17.397	0.83	−0.003	No
Midmar outflow	9.100	28.100	16.900	17.029	< 0.0001	−0.038	Decrease
Nagle inflow	11.200	29.900	21.000	20.908	0.0455	−0.029	Decrease
Nagle outflow	12.100	28.000	19.975	19.964	0.001	−0.031	Decrease
Inanda inflow	11.633	28.450	20.750	20.587	0.002997	−0.026	Decrease
Inanda outflow	12.000	28.800	20.400	20.419	0.0379	−0.013	Decrease

Table 5.
Descriptive statistics for Temperature.

with increasing temperature encouraging escape of the gas from water. The rate of biodegradation of organic compounds increases with increased temperature and this further adds to the reduction of dissolved oxygen as well as nutrient accumulation [57]. Metals and compounds behave differently in low and high temperature environments. For example, $CaCO_3$ precipitates out in hot water to form scaling, which can cause clogging in hot water pipes [58]. Therefore, overall, temperature affects the quality of raw water that feeds into a potable water treatment plant.

4.6 Dissolved oxygen

Dissolved oxygen levels varied between 4.2 mg/L and 11.80 mg/L as depicted in **Figure 8**. Except for Inanda Outflow, the SK test results depicted in the table show that dissolved oxygen remained fairly stable among the stations studied between 2005 and 2012. The high mean (7.926 mg/L - 9.385 mg/L) and median (8.100 mg/L - 9.500 mg/L) (**Table 6**) range shows that dissolved oxygen along uMngeni Basin was within the 80–100% assuming 8.0 mg/L as saturation level [59]. Dissolved oxygen concentrations in unpolluted water normally range between 8 and 10 mg/L [60].

The minimum values observed at Midmar Dam, which are below 5 mg/L (**Table 6**) is worrisome when considering fitness for the survival of aquatic biodiversity. Low dissolved oxygen concentrations are known to adversely affect

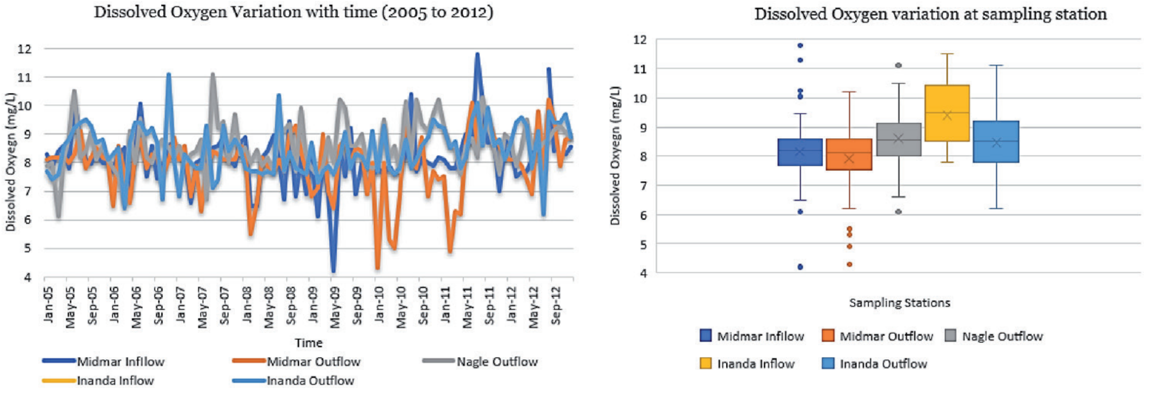

Figure 8.
Dissolved oxygen time series and the box-plot.

Sample	Minimum	Maximum	Median	Mean	S- K	Sen's slope	Decision
Midmar inflow	4.200	11.800	8.175	8.153	0.6	0.002	No
Midmar outflow	4.300	10.200	8.100	7.926	0.7734	0	No
Nagle outflow	6.100	11.100	8.550	8.608	0.0658	0.007	No
Inanda inflow	7.800	11.500	9.500	9.385		−0.063	
Inanda outflow	6.200	11.100	8.500	8.457	0.036	0.006	Increase

Table 6.
Descriptive statistics for dissolved oxygen.

the performance and survival of aerobic organisms while levels below 2 mg/L may be fatal to fish. Regarding treatment, the causal relationship between dissolved oxygen and chemicals used during treatment is not well understood. Some reports have, however, highlighted that oxygen tends to attach to the floc particles making them lighter and relatively impossible to settle for easy flocculation.

4.7 Nitrate

The time-series plot (**Figure 9**) shows that nitrate exhibited an irregular pattern at the six stations studied. This could be attributed to many factors key among them being the irregular discharge of poor-quality sewage effluent along the basin. High concentrations observed in winter tended to be a response of reduced flows, which affected the dilution capacity. Peaks observed during the wet season can be explained by the increased surface run-off, which would encourage movement of fertilisers, animal feedlots effluent and increased sewage effluent discharge. Even though the results indicated that nitrate levels (**Table 7**) were within the regulatory limit for potable use (<11 mg/L), it is important to note that the parameter is the cause of eutrophication especially if levels exceed the recommended limits for no risk, i.e., 0 to 0.5 mg/L as N [44].

Under eutrophic conditions, dissolved oxygen greatly increases during the day, but is greatly reduced after dark by the respiring algae and microorganisms that feed on the elevated mass of dead algae. Oxygen is required by all aerobically respiring plants and animals and it is replenished during daylight by photosynthesising plants and algae. When dissolved oxygen levels decline to hypoxic (inadequate) levels, fish and other aquatic organisms that require oxygen suffocate. These challenges could cause odour and taste problems as well as death of aquatic animals. Additionally, algal blooms limit sunlight penetration to bottom-dwelling organisms and cause wide swings in the amount of dissolved oxygen in the water.

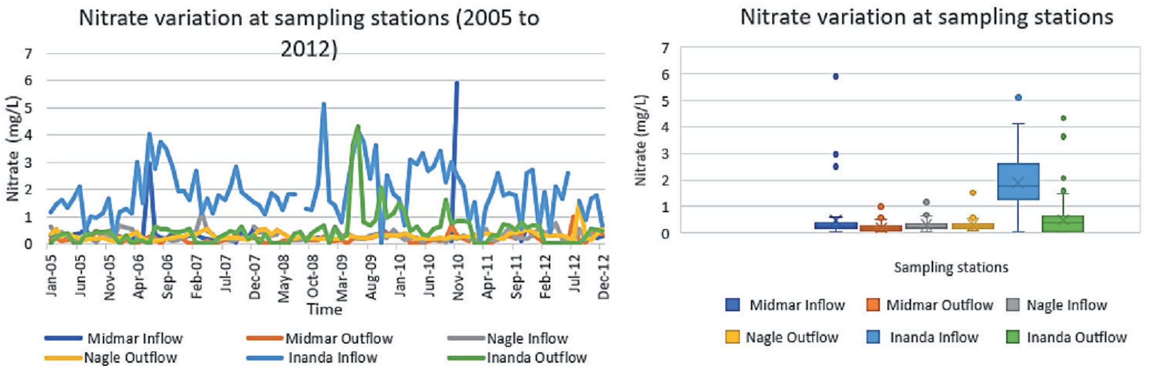

Figure 9.
Nitrate time series and the box-plot.

Sample	Minimum	Maximum	Median	Mean	Sen's slope	Decision
Midmar inflow	0.038	5.910	0.270	0.467	−0.001	No trend
Midmar outflow	0.038	1.000	0.165	0.197	2.45E-04	No trend
Nagle inflow	0.038	1.180	0.240	0.299	0	No trend
Nagle outflow	0.090	1.520	0.260	0.294	8.54E-04	Trend
Inanda inflow	0.038	5.120	1.780	1.910	0.003	No trend
Inanda outflow	0.038	4.330	0.385	0.492	0.002	Trend

Table 7.
Descriptive statistics for nitrate.

Nitrate (NO_3^-) as depicted in (**Figure 9**) could account for algae blooms in the wet season, which would ultimately cause increased chlorine and coagulant dosages during potable water treatment. However, the nitrogen levels along uMngeni Basin are not considered to pose a problem to communities when the receiving water bodies are used for domestic and recreational purposes. It is important to maintain the levels low as studies have reported that (NO_3^-) concentration above the permissible limits could be lethal to infants by causing the "blue baby" syndrome in bottle-fed babies [15, 61, 62].

4.8 Total phosphate

Just like nitrate, total phosphate showed irregular variation with peaks throughout the year (**Figure 10**). This suggests that the two variables could be emanating from the same sources. The most plausible sources could be fertilisers and sewage effluent pollutants from anthropogenic activities along the river. Furthermore, while considering that the soils of uMngeni Catchment are generally phosphorus deficient as highlighted by Furness and Richard [63], it is reasonable to suggest that human activities could be responsible for the peaks. The SK test reveals that there were no significant trends in total phosphate values at any of the stations during the study period (**Table 8**). Descriptive statistic results (**Table 8**) illustrate that Inanda Inflow station had comparably twice (130.078 μg/L) the total phosphate concentration as that of Nagle Inflow station (57.798 μg/L) which is upstream station. Darvill Wastewater Treatment Works (WTW) treats domestic and industrial effluent from Pietermaritzburg, contributing a significant nutrient load (total phosphorus is 15% and soluble phosphorus 50%) and high oxygen demand to Inanda Dam.

Regarding potable water treatment, the effect of total phosphate is indicative of the resultant algae bloom. Thus, in order to reduce the cost associated with the production of potable water along uMngeni River catchment, attention needs to be focused on the reduction of the nutrient load into the river system.

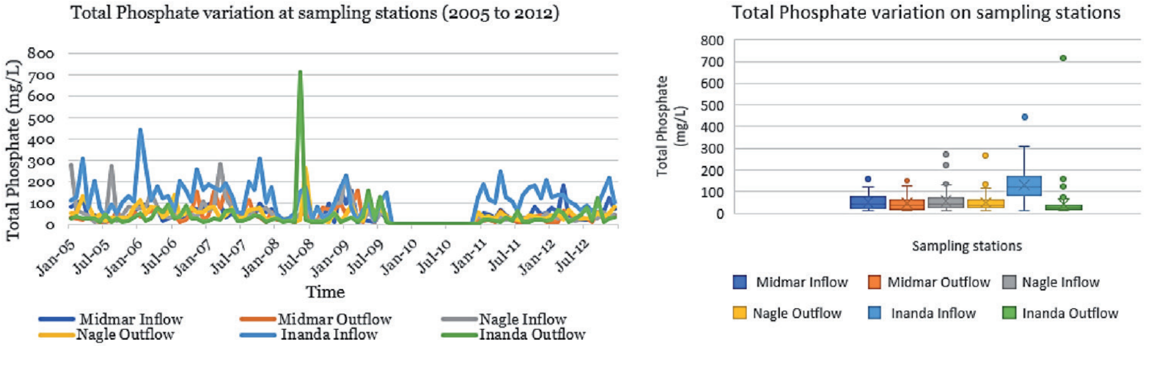

Figure 10.
Total Phosphate time series and the box–plot.

Sample	Minimum	Maximum	Median	Mean	S-K	Sen's slope	Decision
Midmar inflow	11.250	180.977	42.950	53.238	1	−0.065	No trend
Midmar outflow	11.250	161.000	35.200	46.245	0.913	−0.08	No trend
Nagle inflow	11.250	280.550	41.967	57.798	0.116	−0.389	No trend
Nagle outflow	11.250	265.400	39.700	49.922	0.074	−0.241	No trend
Inanda inflow	13.250	445.500	120.500	130.078	0.704	−0.234	No trend
Inanda outflow	11.250	714.300	26.100	42.012	0.347	−0.002	No trend

Table 8.
Descriptive statistics for total phosphate.

4.9 *E. coli*

The time-series plots in **Figure 11** depict seasonal fluctuation and peaks of *E. coli* levels. The peaks that are pronounced in the wet season could be as a result of increased surface runoff from burst sewer pipes and slurry from intensive livestock farming operations that flow into the river course [64, 65]. Storm wash-off containing accumulated human, animal and domestic waste material and overflowing pit-latrines also cause contamination during high flows [64, 65]. The mean range of 97 to 1319 CFU/100 mL (**Table 9**) shows that water quality along uMngeni Basin is not fit for direct drinking purposes without disinfecting. South Africa's guidelines stipulate that there should be zero *E. coli* in 100 mL of the test water [40]. The observed high range could be due to many factors chief among them being the discharge of poor-quality sewage effluent.

With regard to human health, the observed high *E. coli* levels recorded at Inanda Inflow are worrisome when considering that there are nearby rural communities of The Valley of a Thousand Hills, which might use the river water for domestic purposes. Serious faecal contamination problems have been reported, for example, in Pietermaritzburg and Durban, as well as in the settlements in The Valley of a Thousand Hills and Vulindlela (Henley), where Karar [66] reported that annual deaths were associated with water borne diseases. The major sources of pollution were noted to be leakage and blocked sewers in formally serviced residential areas (e.g. Pietermaritzburg and Durban) and illegal disposal of waste into stormwater drains as well as general drainage.

Regarding potable water treatment costing, the elevated levels of *E. coli* observed towards downstream at Inanda added pressure to the Wiggins Potable Water

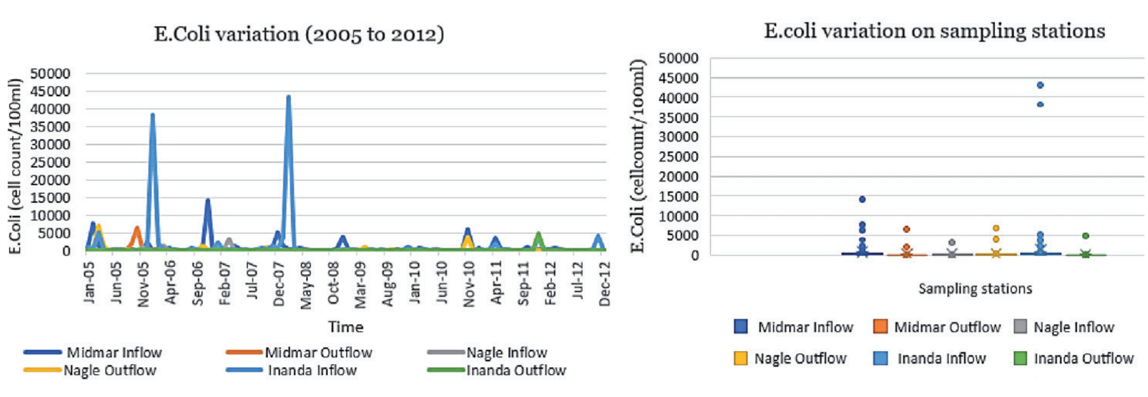

Figure 11.
E. coli time series and box-plot.

Sample	Minimum	Maximum	Median	Mean	S-K	Sen's slope	Decision
Midmar inflow	6.000	14200.000	272.500	745.319	0.572	−0.435	No trend
Midmar outflow	0.000	6490.000	23.000	126.729	0.235	−0.143	No trend
Nagle inflow	2.000	3100.000	38.000	126.246	0.132	0	No trend
Nagle outflow	7.750	6870.000	100.000	274.299	0.037	−0.47	Decrease
Inanda inflow	9.000	43100.000	213.000	1319.056	<0.0001	−3.038	Decrease
Inanda outflow	0.000	4838.000	26.000	97.917	0.449	0.05	No trend

Table 9.
Descriptive statistics for E. coli.

Treatment Plant. It is, therefore, reasonable to argue that more chlorine might be needed at Wiggins in order to thoroughly disinfect the water. Poor treatment of water with *E. coli* could cause the spread of waterborne diseases.

4.10 Ammonia

Ammonia concentration among the six stations studied showed irregular cyclic pattern with peaks (**Figure 12**). Of concern is the high monthly mean recorded at Midmar Dam outflow station of 3.640 mg/L (**Table 10**) that exceeded guidelines. Such an observation is worrisome when considering the toxicity of ammonia to aquatic animals, which is related to pH and temperature. Concentration 0.06 mg/L could damage fish gills while those above 0.3 mg/L be lethal to fish [67]. The presence of ammonia at higher than geogenic levels is an important indicator of faecal pollution [68].

Except for Nagle Dam station, the other dam inflow stations generally exhibited ammonia levels comparable to the corresponding outflow stations. Regarding treatment, ammonia is known to react with chlorine during treatment to form chloramine [21]. Chloramine is, however, a relatively weak oxidant [21] but with a long-lasting residual effect. Taste and odour problems as well as decreased disinfection efficiency are expected if drinking water containing more than 0.2 mg of ammonia per litre is chlorinated [68]. This is because up to 68% of the chlorine may react with the ammonia and become unavailable for disinfection [68]. Regarding the observed levels of ammonia in the data analysed, it can be argued that chlorine dosage at Wiggins Water Treatment Plant is more influenced by ammonia compared to Durban Heights Plant. The presence of elevated ammonia levels in raw water is also reported to interfere with the operation of manganese-removal filters as it may increase oxygen requirement due to nitrification and this may result in mouldy,

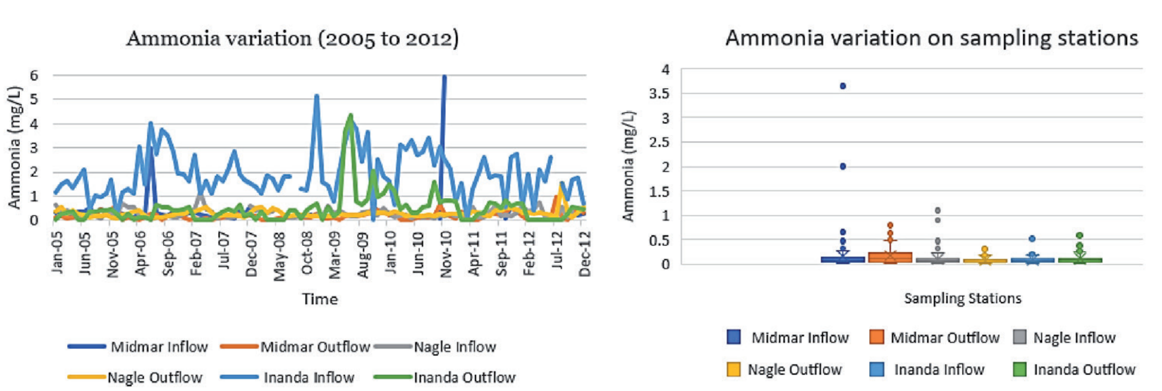

Figure 12.
Ammonia time series and box-plot.

Sample	Minimum	Maximum	Median	Mean	S-K	Sen's slope	Decision
Midmar inflow	0.020	3.640	0.070	0.162	1	−0.065	No trend
Midmar outflow	0.020	0.910	0.100	0.165	0.32	−0.08	No trend
Nagle inflow	0.010	1.100	0.060	0.100	0.004	−0.389	Decrease
Nagle outflow	0.020	0.400	0.050	0.075	0.074	−0.241	No trend
Inanda inflow	0.008	0.510	0.070	0.082	0.491	−0.234	No trend
Inanda outflow	0.008	0.600	0.080	0.105	0.347	−0.002	No trend

Table 10.
Descriptive statistics for Ammonia.

earthy-tasting water [68]. Furthermore, the presence of the ammonium cation in raw water may result in drinking-water containing nitrite as the result of catalytic action or the accidental colonisation of filters by ammonium-oxidising bacteria [69].

4.11 Electrical conductivity

Electrical Conductivity (EC) is the measure of dissolved ions or inorganic materials including calcium, bicarbonate, nitrogen, phosphorus, iron and sulphur. This parameter, which was used in Dzwairo, Otieno [5] as a surrogate for pollution, showed irregular variation with peaks and fluctuations (**Figure 13**). The distinct low level that was more pronounced in summer could be explained by an increased river flow and discharge, which tended to dilute the downstream watercourse pollution. However, all values observed (5.280 mS/m - 52.95 mS/m) were within the acceptable level for drinking water purposes, hence, are no cause for concern (**Table 11**).

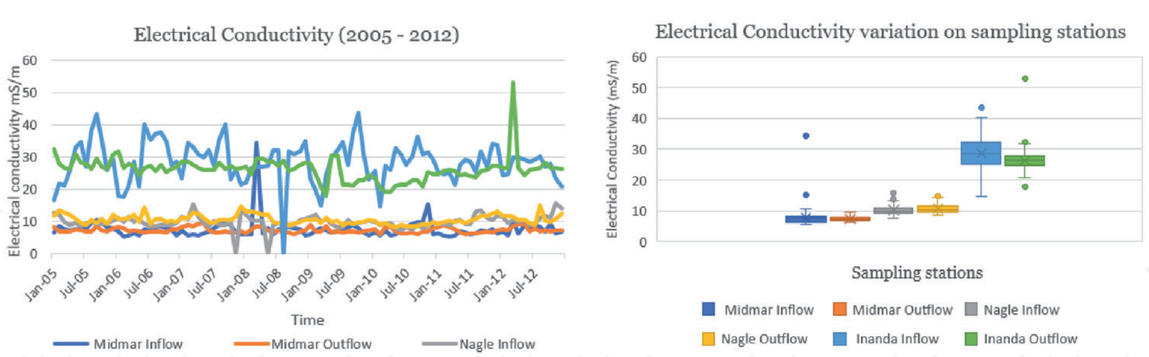

Figure 13.
Conductivity time series and the box-plot.

Sample	Minimum	Maximum	Median	Mean	S K	Sens slope	Decision
Midmar inflow	5.280	34.385	7.338	7.688	0.453	−0.003	No trend
Midmar outflow	5.990	9.400	7.080	7.339	0.248	−8.51E-04	No trend
Nagle inflow	7.360	15.680	9.765	10.100	0.179	0.004	No trend
Nagle outflow	8.430	14.915	10.330	10.622	0.045	−0.01	Decrease
Inanda inflow	14.740	43.600	28.600	28.644	0.278	−0.022	No trend
Inanda outflow	17.830	52.950	26.400	26.210	0.003	−0.028	Decrease

Table 11.
Descriptive statistics for Conductivity.

Previous studies have also reported uMngeni River as a low conductivity river. Graham [48], using data from 1990 to 1999, also noted that Nagle Dam had a daily average of 8.9 mS/m, which is slightly lower than the 10.361 mS/m observed in this study. This then implies that the concentration of dissolved ions at Nagle Dam has increased over time. As presumed, the box and whisker plot show that conductivity increased towards downstream of the uMngeni Basin. Regarding treatment, the relatively high conductivity observed at Inanda Outflow suggests that conductivity could be driving coagulant dosage more at Wiggins compared to Durban Heights. In an ecosystem, the combination of high EC coupled with high temperatures increases the toxicity of metals. At low temperatures EC tends to be low, which reduces the mobilisation of metals bound in sediments [70].

5. Conclusion

In a semi-arid country like South Africa, it is pertinent that the country's water resources be developed and managed for the benefit of the whole. Effective management of a basin such as uMngeni requires a sound understanding of the sources and status of water pollution as well as early detection of water quality changes. This will assist in strategising effective methods for combating pollution, making the water fit for various purposes including potable water production.

From the foregoing observations, it can be concluded that for the period under consideration, the quality of water along uMngeni River showed characteristics that favoured eutrophication with respect to turbidity, chloride, algae, conductivity and nitrate levels. This is more pronounced when comparing among the three inflow stations. Drinking water should be free from colour, turbidity, odour, and microbes in order to make it safe and aesthetically pleasant. Regarding the high *E. coli* levels that were observed at all stations, it could be concluded that the water was not fit for drinking purposes without at least disinfection. The high turbidity recorded at all stations suggests that the raw water was aesthetically unpleasant for drinking purposes.

The spatial analysis shows a downstream deterioration of river water quality for mineral salts namely chloride and conductivity. However, the quality of water was still acceptable for other uses such as irrigation, freshwater ecosystem habitat, and industrial use, which require less stringent guidelines than the standards for potable use. While, the quality of uMngeni River water was acceptable for agricultural purpose, it is important for the management and communities to implement effective measures for controlling agricultural practices that may significantly affect water quality such as stream bank cultivation and intensive fertiliser, which may be washed into the river. This is also the case with putting measures to control sewage bursts and open defecation, which have made the water unfit for human consumption. Future studies need to look at in-depth analysis of the ecological effectiveness of the temporal and spatial variation of the water quality in the basin.

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References

[1] Dzwairo B, Otieno FAO, Ochieng' GM. Making a case for systems thinking approach to integrated water resources management (IWRM). International Journal of Water Resources and Environmental Engineering. 2010;1(5): 107-13.

[2] Cullis JD, Rossouw N, Du Toit G, Petrie D, Wolfaardt G, De Clercq W, et al. Economic risks due to declining water quality in the Breede River catchment. Water SA. 2018;44(3): 464-73.

[3] Rangeti I, Dzwairo B, Barratt GJ, Otieno FAO. Ecosystem-specific water quality indices. African Journal of Aquatic Science. 2015;40(3):227-34.

[4] Dzwairo B, Otieno F, Ochieng G, Bezuidenhout J. Raw water quality weight factors: Vaal basin, South Africa. Water Science and Technology. 2012;66(5):1061-8.

[5] Dzwairo B, Otieno FAO, Ochieng' GM. Incorporating surface raw water quality into the cost chain for water services: Vaal catchment, South Africa. Research Journal of Chemistry and Environment. 2010;14(1):29-35.

[6] Kumar N, Singh SK, Singh VG, Dzwairo B. Investigation of impacts of land use/land cover change on water availability of Tons River Basin, Madhya Pradesh, India. Modeling Earth Systems and Environment. 2018;4(1):295-310.

[7] van Leeuwen FXR. Safe drinking water: the toxicologist's approach. Food and Chemical Toxicology. 2000;38: S51-S8.

[8] Dzwairo B, Ochieng GM, Letsoalo ME, Otieno FA. Data Reduction for Water Quality Modelling, Vaal Basin. In: Leite EP, editor. Scientific and Engineering Applications Using Matlab. Croatia: Intech; 2011. p. 71-86.

[9] Huang H, Wang Z, Xia F, Shang X, Liu Y, Zhang M, et al. Water quality trend and change-point analyses using integration of locally weighted polynomial regression and segmented regression. Environmental Science and Pollution Research. 2017;24(18):15827-37.

[10] Gonzales Inca C, Lepistö A, Huttula T. Trend detection in water-quality and load time-series from agricultural catchments of Yläneenjoki and Pyhäjoki, SW Finland. Boreal Environment Research. 2016;21:161-80.

[11] Reckhow K, Kepford K, Hicks WW. Methods for the analysis of lake water quality trends: EPA; 1993.

[12] Dallas HF, Pay JA, Reynolds EG. The effects of water quality variables on riverine biotas. Pretoria: Water Research Commission (WRC) 1994. Contract No.: Report 351.

[13] Dzwairo B, Otieno FA. Class frequency distribution for a surface raw water quality index in the Vaal Basin. Water SA. 2014;40(2):337-44.

[14] Palmer MA, Richardson DC. Provisioning services: A focus on fresh water. The Princeton Guide to Ecology Princeton University Press, Princeton, NJ. 2009:625-33.

[15] Dzwairo B, Hoko Z, Love D, Guzha E. Assessment of the impacts of pit latrines on groundwater quality in rural areas: A case study from Marondera district, Zimbabwe. Physics and Chemistry of the Earth, Parts A/B/C. 2006;31(15-16):779-88.

[16] Hoko Z, Dzwairo B, Sanyanga RA, Neseni N, Guzha E. A preliminary assessment of the gender sensitivity and health risk potential of ecological sanitation (ecosan) in Marondera Rural District, Zimbabwe. Journal of

Sustainable Development in Africa. 2010;12(1).

[17] Dzwairo B. Multi-date trends in groundwater pollution from pit latrines. Journal of Water Sanitation and Hygiene for Development. 2018:washdev2018177.

[18] Khan SS, Tareen H, Jabeen U, Mengal F, Masood Z, Ahmed S, et al., editors. Quality assessment of drinking water from the different colonies of Quetta city, Pakistan according to WHO Standards. Biological Forum; 2015: Research Trend.

[19] Pulles RW, Heat R, Howod M. A manual to assess manage the 06 gold mining operations on the surface water environmental. Pretoria: Water Research Commission (WRC); 1996. Contract No.: WRC Report No TT79/96.

[20] Otieno F, Ochieng G. Water management tools as a means of averting a possible water scarcity in South Africa by the year 2025. Water SA. 2007;30(5):120-4.

[21] Dzwairo B. Modelling raw water quality variability in order to predict cost of water treatment [DTech thesis]. Pretoria: Tshwane University of Technology; 2011.

[22] Gebremedhin SK. Analysis and Prediction of Chemical Treatment Cost of Potable Water in the Upper and Middle Vaal Water Management Areas [Master of Science in Agriculture]. Pietermaritzburg Campus: University of KwaZulu-Natal; 2009.

[23] Dennison DB, Lyne MC. Analysis and prediction of water treatment costs at the DV Harris Plant in Umgeni Catchment Area. Agrekon. 1997;36:40.

[24] Dzwairo B, Otieno FAO. Integrating quality and cost of surface raw water: Upper and Middle Vaal Water Management Areas South Africa. Water Science and Technology: Water Supply 2010;10(2):201-7.

[25] Voortman WJ, Reddy CD. Package Water Treatment Plant Selection,. South Africa: WRC; 1997. Contract No.: 450/1/97.

[26] Dearmont D, McCarl BA, Tolman DA. Costs of water treatment due to diminished water quality: a case study in Texas. Water Resources Research. 1998;34(4):849-54.

[27] uMgeni_Water_Amanzi. Corporate Profile 2020 [Available from: https://www.umgeni.co.za/about/].

[28] KZN_Treasury. Province of KwaZulu-Natal Provincial Budget–2019/20 2019 [Available from: http://www.treasury.gov.za/documents/provincial%20budget/2019/4.%20Guide%20to%20the%20Budget/KwaZulu-Natal%20-%202019%20Budget%20Summary.pdf].

[29] DWAF. uMngeni River and Neighbouring Rivers and Streams: State of the Rivers Report Pretoria2003 [Available from: http://www.dwaf.gov.za/iwqs/rhp/state_of_rivers/state_of_umngeni_02/umngeni.html].

[30] Roos J, Hassan F, Coleman T. Water Reconciliation Strategy Study of the Kwazulu Natal Coastal Metropplitan Areas. Water Quality Review Report. Department of Water Affairs and Forestry (DWAF); 2009. Contract No.: PWMA 11/000/00/2609.

[31] Deventer Rv. Impact of land use on water quality and aquatic ecosystem health of stream network in the upper uMngeni catchment feeding Midmar Dam, KwaZulu-Natal, South Africa [Masters]. Pietermaritzburg: University of KwaZulu-Natal; 2012.

[32] Olaniran A, Naidoo K, Pillay B. Assessment of physico-chemical qualities and heavy metal concentrations of Umgeni and Umdloti Rivers in Durban, South Africa. Environmental monitoring and assessment. 2013;186.

[33] Meals DW, Spooner J, Dressing SA, Harcum JB. Statistical Analysis for Monotonic Trends 2011 [Available from: https://www.epa.gov/polluted-runoff-nonpoint-source-pollution/nonpoint-source-monitoring-technical-notes].

[34] Morton R, Henderson BL. Estimation of nonlinear trends in water quality: an improved approach using generalized additive models. Water Resources Research. 2008;44(7).

[35] Helsel DR, Hirsch RM. Statistical Methods in Water Resources. Amsterdam, Netherlands: Elsevier Science Publisher B.V; 1992.

[36] Hirsch RM, Slack JR, Smith RA. Techniques of trend analysis for monthly water quality data. Water resources research. 1982;18(1):107-21.

[37] Antonopoulos VZ, Papamichail DM, Mitsiou KA. Statistical and trend analysis of water quality and quantity data for the Strymon River in Greece. Hydrology and Earth System Sciences. 2001;5(4):679-91.

[38] Hirsch RM, Slack JR, Smith RA. Techniques of trend analysis for monthly water quality analysis. Water Resource Research 1982;18 No 1:107-21.

[39] Darken PF. Testing for changes in trend in water quality data [Doctorate]. Blacksburg, Virginia: Virginia Polytechnic Institute and State University; 1999.

[40] DWAF. South African Water Quality Guidelines (second edition). Volume 1: Domestic Use. In: Forestry DoWAa, editor. Pretoria: Department of Water Affairs and Forestry; 1996. p. 214.

[41] Alkhatib E, Peters R. Wet weather impact on trihalomethane formation potential in tributaries to drinking water reservoirs. Environmental monitoring and assessment. 2008;139(1-3):173-81.

[42] WHO. Guidelines for Drinking Water quality. Geneva: World Health Organisation; 2004.

[43] Mann AG, Tam CC, Higgins CD, Rodrigues LC. The association between drinking water turbidity and gastro-intestinal illness: a systematic review. BMC public health. 2007;7(1):1-7.

[44] DWAF. South African Water Quality Guidelines: Volume 1: Domestic Water Use. Pretoria, South Africa: Department of Water Affiars and Forestry (DWAF); 1996.

[45] Kuutondokwa S. A dissertation submitted in partial fulfilment of the requirements for the degree of Masters in Intergrated Water Resources Management (IWRM). 2012.

[46] Pernitsky D, Edzwald J. Solubility of polyaluminium coagulants. Journal of Water Supply: Research and Technology - AQUA. 2003;52:395-406.

[47] Dzwairo B, Otieno F. Chemical pollution assessment and prioritisation model for the Upper and Middle Vaal water management areas of South Africa. IWA Journal of Water and Health. 2014; 12(4):14.

[48] Graham P. Modelling the water quality in dams within the Umgeni Water operational area with emphasis on algal relations [Philosophiae Doctor]: North West University; 2004.

[49] DWAF. South African Water Quality Guidelines, Vol 7: Aquatic Ecosystems. Pretoria: Department of Water Affairs and Forestry; 1996.

[50] Mesner N, Geiger J. Understanding Your Watershed: pH. Water Quality Extension, Utah State University. 2010.

[51] Dzwairo B. Assessment of the Impacts of Pit Latrines on Groundwater Quality in Rural Areas: a case study from Marondera District, Zimbabwe [MSc thesis]. Harare: University of Zimbabwe; 2005.

[52] Blignaut JN, Marais C, Turpie J. Determining a charge for the clearing

of invasive alien plant species (IAPs) to augment water supply in South Africa. Water Sa. 2007;33(1).

[53] Adriano DC. Trace Elements in Terrestrial Environments: Biogeochemistry, Bioavailability, and Risks of Metals: Springer New York; 2001.

[54] Dallas HF, Day JA. The effect of water quality variables on Aquatic Ecosystems: A Review. Pretoria, South Africa: Water Research Commission; 2004. Contract No.: TT224/04.

[55] Hanson A, Cleasby J. The effects of temperature flocculation: Fluid dynamics. . Journal of America Water Works Association. 1990;82(1):56-72.

[56] Veenstra JN, Schnoor JL. Seasonal-Variations in Trihalomethane Levels in an Iowa River Water-Supply. Journal American Water Works Association. 1980;72(10):583.

[57] Alkorta I, Epelde L, Garbisu C. Environmental parameters altered by climate change affect the activity of soil microorganisms involved in bioremediation. FEMS microbiology letters. 2017;364(19).

[58] Amiri M, Moghadasi J. The effect of temperature on calcium carbonate scale formation in Iranian oil reservoirs using OLI ScaleChem software. Petroleum science and technology. 2012;30(5):453-66.

[59] DWAF. South African Water Quality Guidelines. Volume 7: Aquatic Ecosystems. In: (DWAF) DoWAaF, editor. Pretoria, South Africa: Department of Water Affairs and Forestry (DWAF); 1996.

[60] Waston IM, Robinson JO, Burke V, Grace M. Invasive of Aeromonas spp. In relation to biotype virulence factors and clinical features. J Clin Microbiol. 1985;22(1):48-51.

[61] Manassaram DM, Backer LC, Moll DM. A review of nitrates in drinking water: maternal exposure and adverse reproductive and developmental outcomes. Environmental Health Perspectives. 2006;114(3):320-7.

[62] Schullehner J, Stayner L, Hansen B. Nitrate, nitrite, and ammonium variability in drinking water distribution systems. International Journal of Environmental Research and Public Health. 2017;14(3):276.

[63] Furness HD, Richard WN, editors. River Basin Management -Its role in protecting water quality South Africa: eWISA; 1987.

[64] Singh A, Lin J. Microbiological, coliphages and physico-chemical assessments of the Umgeni River, South Africa. International Journal of Environmental Health Research. 2015;25(1):33-51.

[65] Bartosova A, Strömqvist J, Arheimer B. Source to sea: Tracing causes of water quality problems and evaluating potential mitigation options. Case study of uMngeni River, south africa2017 07/10/2020 [cited 2020 07/10/2020]. Available from: https://www.smhi.se/polopoly_fs/1.117090!/SOURCE%20TO%20SEA%20-%20TRACING%20CAUSES%20OF%20WATER%20QUALITY%20PROBLEMS%20AND%20EVALUATING%20POTENTIAL%20MITIGATION%20OPTIONS.%20CASE%20STUDY%20OF%20UMNGENI%20RIVER,%20SOUTH%20AFRICA.pdf.

[66] Karar E. Promising water resources management approaches in the drinking water supply and sanitation sector: Evaluation document for the Mgeni Catchment Management Plan1997 07/10/2020 [cited 2020 07/10/2020]:[230 p.]. Available from: https://www.ircwash.org/sites/default/files/824-ZA-16276.pdf.

[67] Emerson K, Russo RC, Lund RE, Thurston RV. Aqueous ammonia equilibrium calculations: effect of pH and temperature. Journal of the Fisheries Board of Canada. 1975;32(12):2379-83.

[68] WHO. Ammonia in Drinking-water. Background document for development of WHO Guidelines for Drinking-water Quality. WHO/SDE/WSH/03.04/01. Originally published in Guidelines for drinking-water quality, 2nd ed. Vol. 2. Health criteria and other supporting information. World Health Organization, Geneva, 1996. Geneva: WHO Library Cataloguing-in-Publication Data; 2003. p. 9.

[69] WHO. Nitrate and nitrite in drinking-water. Background document for development of WHO Guidelines for Drinking-water Quality. WHO/SDE/WSH/07.01/16/Rev/1. Rev/1: Revisions indicated with a vertical line in the left margin. Geneva: WHO Library Cataloguing-in-Publication Data; 2011. p. 31.

[70] Li H, Shi A, Li M, Zhang X. Effect of pH, Temperature, Dissolved Oxygen, and Flow Rate of Overlying Water on Heavy Metals Release from Storm Sewer Sediments. Journal of Chemistry. 2013;2013:434012.