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Impact on Water Quality of Nandoni Water Reservoir Downstream of Municipal Sewage Plants in Vhembe District, South Africa

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Abstract: The deterioration of water quality in our freshwater sources is on the increase worldwide and, in South Africa, mostly due to the discharge of municipal sewage effluent. Here we report on the use of principal component analysis, coupled with factor and cluster analysis, to study the similarities and differences between upstream and downstream sampling sites that are downstream of municipal sewage plants. The contribution of climatic variables, air temperature, humidity, and rainfall were also evaluated with respect to variations in water quality at the sampling sites. The physicochemical and microbial values were higher than the Department of Water Affairs and Forestry (DWAF) and World Health Organization (WHO) guidelines. The cluster analysis showed the presence of two clusters for each of the Mvudi, Dzindi, and Luvuvhu Rivers and Nandoni reservoir sampling sites. The principal component analysis (PCA) accounted for 40% of the water quality variation and was associated strongly with pH, electrical conductivity, calcium, magnesium, chloride, bromide, nitrate, and total coliform, and negatively with rainfall, which represented Mvudi downstream and was attributed to the Thohoyandou sewage plant. The PCA accounted for 54% of the variation and was associated strongly with electrical conductivity, sulfate; total dissolved solids, fluoride, turbidity, nitrate, manganese, alkalinity, magnesium, and total coliform represented Dzindi downstream, with inflows from the Vuwani sewage plant and agriculture. The PCA accounted for 30% of the variation and was associated strongly with total dissolved solids, electrical conductivity, magnesium, fluoride, nitrate, sulfate, total coliform average air temperature, and total rainfall, and negatively associated with manganese and bromide represented Luvuvhu upstream and was associated with commercial agriculture. The PCA accounted for 21% of the variation and was associated strongly with turbidity, alkalinity, magnesium, chloride, fluoride, nitrate, and strongly negatively associated with rainfall, which represented Luvuvhu downstream, associated with inflows from Vuwani oxidation ponds, Elim and Waterval sewage plants, and agriculture. The PCA accounted for 14% of the variation and was moderately associated with rainfall and weakly associated with chloride and bromide and negatively associated with nitrate, which represented the natural Nandoni reservoir system. The continued discharge of effluent may render the raw water supply unsuitable for human consumption and lead to eutrophication due to nitrate enrichment and proliferation of harmful algal blooms and schistomiasis infections in the long term.

Keywords: pollution; water quality; municipal sewage plants; principal component analysis

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1. Introduction

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs [1]. One of the most severe environmental problems is the discharge of partially-treated sewage to freshwater bodies, thus reducing the quality of drinking water [2]. The effluents are rich in nutrients (nitrates, phosphates, ammonia, and nitrites), heavy metals and pathogens (bacteria, viruses, and protozoa) which are hazardous to the environment and may affect human health [3–5]. Hirji et al. [5] indicated that existing sewage plants were overloaded as a result of ever-increasing volumes of wastewater generated by the increasing urban population.

Though there is legislation in place to manage water pollution, there are challenges in the enforcement and implementation of that legislation [5]. The results of a study conducted along Fez and Sebou rivers in the region of Fez in Morocco indicate that severe pollution occurred in most urbanized and industrial areas [6]. Water is the most important resource for both economic and social development for modern societies. In South Africa, water quality management is essential since it is predicted that, by the year 2025, the demand for water will outstrip its supply [7]. The deterioration of water quality, coupled with semi-arid conditions, may jeopardize the economic growth and development of South Africa.

A study conducted by Bapela [8] indicates that poor agricultural practices, urban runoff, urbanization, and improper land use threaten the suitability of the water quality for domestic use in the Luvuvhu River basin. Bapela [8] asserted that regardless of contaminants from both point and non-point sources of pollution, in parts of the basin (which have changed the water quality to be unfit for different uses), Luvuvhu River is one of the main sources of water for drinking, agriculture, and other domestic uses in Thohoyandou, Makhado, and other areas in the Luvuvhu catchment. With a rising population, urban growth and the associated socio-economic developments, the deteriorating water quality is becoming a serious environmental challenge in the catchment area of Nandoni dam.

Principal component analysis (PCA), with cluster analysis (CA) and factor analysis (FA), is a multivariate statistical method for the interrogation of large, complex data now widely used in better understanding of water quality data coupled to climatic variables. A number of studies have used PCA and CA to categorize sampling sites and help identify underlying contamination by Zhou et al. [9] and Boyacioglu and Boyacioglu [10] in marine water sources in Southern Hong Kong and Tahtali river catchment in Turkey, respectively. The study of Mendiguchia et al. [11] showed how PCA and CA were used to identify four zones in a catchment and the main contaminates in the Guadalquivir river catchment in Spain. Zhang et al. [12] also used PCA and CA to characterize surface water quality in the Xiang river catchment, China, into clusters in order to design an optimum sampling strategy that reduces sampling sites and, thus, reducing operational costs. Kebede and Kebede [13] used principal component analysis in monitoring physicochemical monitoring in the Urgessa river catchment, Ethiopia, for organic pollution originating from coffee processing and its impact on macroinvertebrate communities.

The aim of the present study was to assess the ecological impact of effluent discharged downstream of the municipal plants on water quality of Luvuvhu river catchment, South Africa. The principal component analysis with factor and cluster analysis was used to study the similarities and differences between upstream and downstream sampling sites linked to municipal sewage plants. The contribution of climatic variables, air temperature, humidity, and rainfall were also evaluated with respect to the variation in water quality at the sampling sites. Thus, the coupling of principal component analysis (PCA) with cluster analysis (CA) and factor analysis (FA) to water quality data and climatic variables is a novel approach.

2. Materials and Methods

2.1. The Study Area

Nandoni dam was constructed by the Department of Water Affairs and Forestry (DWAF) in the Luvuvhu River to provide raw water supplies for 1.3 million people in the Vhembe and parts of Mopani districts, Limpopo province, and controlled releases downstream to provide water supply for wildlife in Kruger National park [14]. The climatic condition in the catchment area of the dam is characterized by hot, humid summers and cool, dry winters. According to DWAF [14], the average summer and winter temperatures are 23 °C and 17 °C, respectively. The mean annual precipitation ranges from 2000 mm in the mountainous areas of the northwest, to 440 mm at Limpopo River confluence, with a catchment average of 800 mm per annum [14]. There are several waterfront villages around the Nandoni dam are typical examples of developing rural communities in which there is poor service delivery, a high rate of unemployment, and poverty. The Nandoni dam provides an opportunity for these communities to obtain water for domestic purposes such as bathing, washing, drinking, and cooking. It has also become a source of income to many unemployed men in the area where they catch fish and sell them to local communities. There are a number of tributaries of the Luvuvhu River, namely Dzindi, Mudzwiri, Madikatla, and Mvudi, that contribute to inflows to the Luvuvhu River. However some of the base flows originated from municipal sewage plants that contribute to the Luvuvhu River. These activities are linked to the deterioration of the quality of the dam water. An excerpt from the environmental impact assessment report [14] indicated the potential risk of eutrophication and pollution by trace metals and biological pollutants arising from upstream municipal sewage discharges. Such pollutants cause the deterioration of water quality by reducing the water suitability for domestic use. Consequently, recreational use, treatment, and conveyance of water are also hampered.

There are five sewage plants located upstream of the Nandoni dam; namely, Elim sewage plant, Waterval sewage plant, Vuwani oxidation ponds, and Vuwani and Thohoyandou sewage plants (Figure 1). The only exception here is the Elim sewage plant because it discharges the effluent into the Muhohodi River (Doringspruit) that flows into the Albasini dam situated upstream of the Nandoni dam.

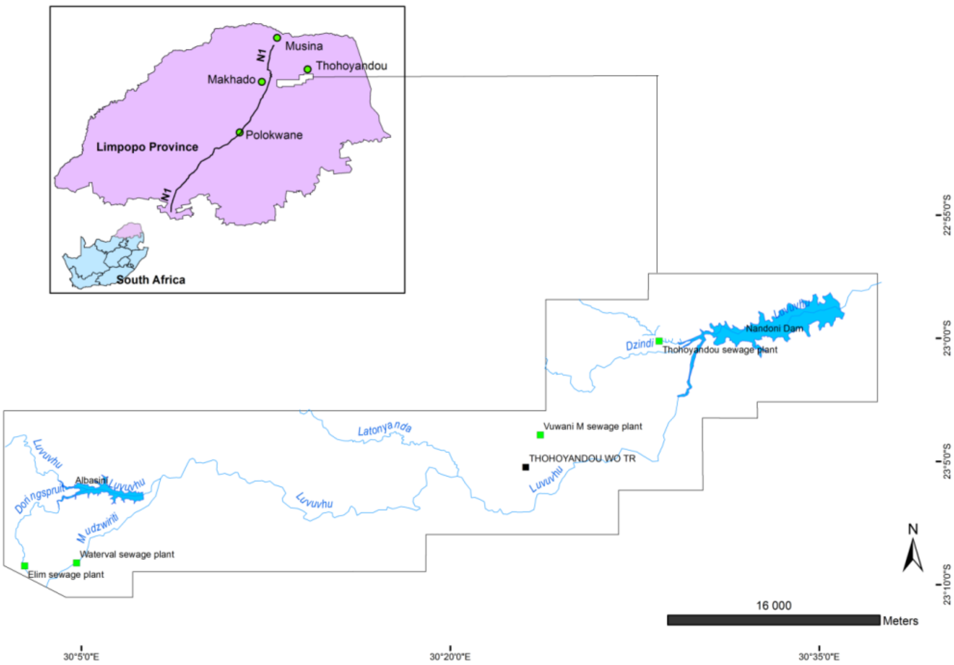

Figure 1. The location of the municipal sewage plants and the water sampling stations.

The effluent from the Waterval sewage plant and Vuwani oxidation ponds are directly discharged into the Luvuvhu River through the Mudzwiri and Madikatla rivers, respectively, which enter the Luvuvhu River from the south side.

Vuwani sewage plant effluents are discharged into the Dzindi River through the Dzondo rivulet that joins the river from the south. Thohoyandou sewage plant effluents are directly discharged into the Mvudi River that joins the Dzindi River just above the confluence point of the Luvuvhu and Dzindi rivers. Pollutants are finally discharged into the Nandoni dam through the Luvuvhu River, which enters the dam from the west side.

2.2. Water Sampling

The water samples were collected from the Luvuvhu River and the following tributaries of Dzindi and Mvudi rivers, as well as from the Nandoni Dam (Table 1). The water samples were collected on a monthly basis from July to December 2010. For chemical water samples, two-liter plastic sampling containers were rinsed with distilled water prior to sampling. Samples were also taken with the sampling container facing the stream current of flow. For microbiological water samples, 500 mL sterile sampling glass bottles were used. Samples were taken with the sampling bottle mouth facing the current flow of the stream. The sampling bottle was completely submerged into the water in order to avoid unwanted floating particles in the water. Samples were put inside a cooler box filled with ice and delivered to the laboratory within six hours from sampling time.

Table 1. Description of the sampling points at the Luvuvhu River basin and Nandoni Dam.

Sample #	Sample Name	Description
S1	Mvudi downstream	To assess the nature and amount of pollutants before and after the Mvudi River passes through the Thohoyandou sewage plant discharge point
S2	Mvudi upstream	
S3	Dzindi downstream	To evaluate the extent of the impact of the Vuwani sewage plant on the water quality of the Dzindi River. Dzindi upstream is before the discharge from municipal sewage plant and mainly subsistence farming, Dzindi irrigation scheme and washing of motor cars and brick making.
S4	Dzindi upstream	
S5	Luvuvhu downstream	Assessment of the impact of the Elim and Waterfall sewage plants and the Vuwani oxidation ponds, as well as the Levubu commercial and Lotanyanda subsistence farming areas
S6	Luvuvhu upstream	
S7	Nandoni reservoir	To verify the possible contribution to deterioration of water quality as a result of the upstream municipal sewage discharge activities

2.3. Physicochemical Water Quality Analysis

For the physical-chemical analyses, the water quality tests were conducted within 24 h at the Chemistry Department, University of Venda, and the Department of Water Affairs and Forestry (DWAF) laboratories. At the sample point, onsite measurements, in triplicate, were pH and temperature (a pH meter (Multi 340/Set Instruments), supplied by Wissenschaftlich-Technische werkstätten GMBH: Weilheim, Germany) and turbidity (portable 2100P turbidity meter, supplied by LABTEC: Midrand, South Africa). The pH meter was calibrated according to the manufacturer's guidelines using pH buffers of four and seven. In the laboratory, the ion chromatograph (Dionex Ion chromatograph, Supplier Thermo ARLabs, Gauteng, Switzerland) was used to determine the anions, chloride, bromide, fluoride, nitrate, phosphate, and sulfate. The metals, manganese, iron, potassium, calcium, and magnesium were determined by absorption spectrophotometer (Varian Spectra AA 110 Flame Atomic Absorption Spectrometer (220/880 series), Supplier SMM Instruments: Johannesburg, South Africa).

2.4. Microbiological Water Quality Analysis

For the microbiological analyses, the water quality tests were conducted within 6 h from the sampling time of the first sample at the DWAF laboratory in Thohoyandou. One packet of colilert-18 powder was added to a 100 mL water sample and was thoroughly mixed. The solution was then transferred into a quanti-tray. The quanti-tray was taken into a quanti-tray sealer and then transferred into an incubator at 35 °C for 18 h. After incubation, the quanti-tray was taken out of the incubator for total coliform and *Escherichia coli* observation. The yellow color indicated the presence of total coliform bacteria. Then, the quanti-tray was put under a ultra-violet (UV) light for *E. coli* observation. The numbers of *E. coli* and total coliform counts/100 mL were enumerated using the most probable (MPN) table. The interpolation method was used to count the amounts of total coliform and *E. coli* bacteria contamination.

2.5. Climate Data

The climate data was obtained from the South African Weather Station (Thohoyandou observation station) which was specially requested from the Department of Environmental Affairs and Tourism. The Thohoyandou observation station is situated 15 km southwest of Nandoni dam.

2.6. Data Analysis

A hierarchical method, average linkage cluster analysis, was applied to the mean values of the physical and chemical variables for each site using the IBM SPSS version 22 (IBM: Armonk, NY, USA) statistical package. Principal component analysis (PCA) was used to determine the water quality parameters that contribute to the water quality variation between the upstream and downstream sampling points. The data was subjected to factor analysis to determine suitability of PCA. The correction matrix showed that the loadings were above 0.3. Liu et al. [15] categorized that factor loading of strong, moderate, and weak were based on values of >0.75, 0.75–0.50, and 0.50–0.30, respectively. The Kaiser-Meyer-Olkin (KMO) was in the range of 0.4 to 0.5 which was slightly lower than the recommended value of 0.6 [16], and Bartlett's Test of Sphericity was in the range of 0.000 to 0.001 [17], indicating the suitability of PCA.

3. Results and Discussion

3.1. Sample Sites Analysis and Characteristics

The dendrogram using average linkage (between groups) revealed two clusters. Cluster 1 was composed of Mvudi upstream activities, which involved subsistence and vegetable cultivation and the washing of motor cars using the waters of the Mvudi River. Cluster 2 was the Mvudi downstream section which received municipal effluent discharges from Thohoyandou sewage plant and the human activities associated here were subsistence farming, brick-making using clay materials close to the Mvudi River at this point and also received inflows from Mvudi upstream.

The dendrogram using average linkage (between groups) revealed two clusters. Cluster 1 was the Dzindi downstream section which received municipal effluent discharges from Vuwani sewage plant and the human activities associated here were subsistence farming, brick-making using clay materials close the Mvudi River at this point, and also received inflows from Mvudi upstream, and this was more pronounced during dry months of July to September. Cluster 2 was composed of Dzindi upstream activities which involved subsistence and vegetable cultivation at the Dzindi irrigation scheme and the washing of motor cars using the waters of the Dzindi River, and this was more pronounced during the dry and wet periods of October to December.

The dendrogram using average linkage (between groups) revealed two clusters. Cluster 1 was the Luvuvhu downstream and the Nandoni reservoir, which were more pronounced during the months of October to December, a dry and wet period. The Luvuvhu downstream activities included subsistence farming, brick-making using clay materials close the Mvudi River at this point, and also received inflows from Mvudi upstream. The Luvuvhu downstream activities involved receipt of municipal effluent discharges from Elim, Waterval sewage plants and Vuwani oxidation ponds, and the human activities associated here were commercial farming in Levubu, and subsistence and vegetable cultivation along the Luvuvhu River. Cluster 2 was composed human activities of Luvuvhu upstream and the Nandoni reservoir, which were more pronounced during the months of July to September, a dry period. The Luvuvhu upstream is mainly affected by commercial agriculture and the natural riverine ecosystem. The Nandoni reservoir involved receipt of municipal inflows from Luvuvhu upstream and pollutants from Mvudi and Dzindi Rivers, fishing with nets in the Nandoni dam, and brick-making along the river banks and Nandoni reservoir (Figure 2).

(**a**) (**b**)

Figure 2. The making of farm bricks using clay materials located at the Nandoni reservoir: (**a**) raw clay material and (**b**) dry bricks waiting to be fired.

The water quality data, mean value, standard deviation, and range for the Luvuvhu river catchment are shown in Table 2. The physicochemical and microbial values are in excess of the DWAF guideline values [18–20] for surface water sources. The discharge of excess nitrates, for example, is likely to lead to eutrophication and growth of harmful algal blooms [21]. A previous study by Makhera et al. [22] in the Luvuvhu River showed the presence of microcystin-LR at 2 ppb which was higher than the 1 ppb safe limit suggested by the Word Health Organization for drinking and recreational water [23]. The ecological impacts of municipal sewage discharges contributes to issues of harmful algal blooms and their cyanotoxins, as represented by microcystin, is real in the Luvuvhu River catchment for three reasons. There is the Nandoni water treatment plant, which draws its raw water supply from the Nandoni reservoir. During spring and summer the operators at the Nandoni water treatment plant resort to the use of activated carbon in order to manage taste and odor problems in the drinking water, probably due to the presence of cyanobacteria and actinomycete organisms [24,25]. Secondly, the presence of nitrates and essential metals—such as magnesium, a central component of chlorophyll—encourages the growth of aquatic weeds that promote the proliferation of schistosomiasis vector snails in the shoreline of the Nandoni reservoir and along the Luvuvhu River downstream of the Nandoni reservoir [26–28]. The study of Dzaga [29] has shown a spike in the number of schistosomiasis infections among waterfront villagers living along the shoreline of Nandoni reservoir. Thirdly, the Luvuvhu River flows into Kruger National Park, thus bringing harmful algal blooms and their cyanotoxins to wildlife. The infrequent outbreaks of microcystin poisoning of wildlife has been recorded recently with wildlife fatalities in Kruger National Park [30]. Lastly, the high levels of *E. coli* in the surface waters is worrisome since the rural communities may resort to the use of these sources, the Nandoni reservoir, and river water, for human consumption because of erratic supply of municipal drinking water [31,32]. These high total coliform counts may be associated with waterborne diseases which may be caused by pathogenic organisms, such as *Vibrio cholerae* spp. and pathogenic *E. coli* [33].

Table 2. Water quality variables of the Luvuvhu river catchment from July to December 2010.

Sampling Stations	Luvuvhu River System			Dzindi River System			Mvudi River System		
Variables	**Mean**	**Std**	**Range**	**Mean**	**Std**	**Range**	**Mean**	**Std**	**Range**
pH	7.4	0.8	8.6–6.4	7.6	0.6	8.5–6.6	7.3	0.8	9–6.3
Turbidity (NTU)	8.3	4.5	14.3–2.4	11.7	4.1	15.5–5.4	23.2	18.4	67.9–8.1
Total Dissolved Solids (mg/L)	33.3	1.7	35.5–29.5	26.2	4.9	33.3–19.8	37.4	13.1	49.8–4.8
Electrical Conductivity (µS/cm)	4.9	0.6	5.6–4	4.2	1	6.2–3.2	4.5	1.3	7.5–3.3
Alkalinity (mg/L)	82.4	14.1	101–65	75	16.4	98–47	101.8	14	134–78
Manganese (mg/L)	0.2	0	0.3-0.2	0.2	0.1	0.4–0.1	1.2	0.7	1.9–0.4
Iron (mg/L)	0.1	0	0.2–0.1	0.1	0	0.2–0.1	0.2	0.1	0.3–0.1
Potassium (mg/L)	1	0.5	1.8–0.5	1.2	0.3	2–0.6	3.9	3	13–1.8
Calcium (mg/L)	14.4	4.1	22.0–8.2	23.3	13.1	38.0–1.0	36.3	15.6	58.0–12.0
Magnesium (mg/L)	135.3	5.3	143.1–129.3	92.7	29.5	138–56	114.7	47.3	198–68
Chloride (mg/L)	49.3	10.4	62–36	50.5	17.8	78–30	122.9	88.2	271–45
Bromide (mg/L)	0.9	0.7	2.6–0.3	0.9	0.6	2.2–0.3	0.4	0.1	0.8–0.3
Fluoride (mg/L)	36.8	2.2	39.1–32.5	19.4	19.9	39.3–0.3	18.8	19.4	39.2–0.2
Nitrate (mg/L)	56.1	36.7	96.6–17.7	30.1	8.2	48.6–23.6	52.3	33.2	92–14.6
Sulphate (mg/L)	3.8	1.8	6.3–1.0	2.4	1.3	4.2–1.1	3.7	2.1	7.4–1.4
Total coliform (colony forming units/100 mL)	780	420	1011–35	660	438	1011–21	773	430	1011–24
E. coli (colony forming units/100 mL)	323	373	1011–36	390	274	914–37	572	427	1011–44

3.2. Assessing the Impact of Thohoyandou Sewage Discharge on the Mvudi Downstream Sampling Site

Ten items of the Mvudi sampling sites, upstream and downstream, were analyzed with principal component analysis (Table 3). The principal component analysis showed the first three components accounted for 83% of the total variation in water quality and the scree plot of eigenvalues of the components is shown in Figure 3. The principal component 1 (PC1) accounted for 40% of the variation (Table 4) and was associated strongly with pH, electrical conductivity, calcium, magnesium, chloride, bromide, nitrate, and total coliform, and negatively with rainfall, which represented Mvudi downstream. There are several mechanisms that may account for the interaction of pH, electrical conductivity, calcium, magnesium, chloride, bromide, nitrate, and total coliform. First, the nitrate and total coliform in the Mvudi River downstream of the Thohoyandou sewage plant may be attributed to sewage discharge and or subsistence farming.

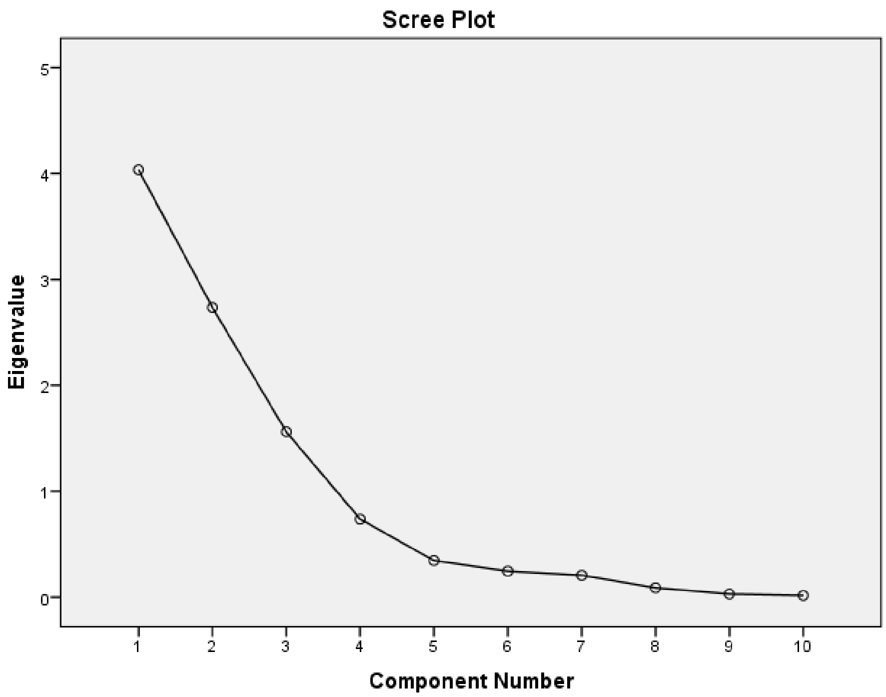

Figure 3. The scree plot of eigenvalues for the Mvudi river system.

Table 3. Water quality eigenvectors of the correlation matrix.

Parameter	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
pH		0.039	0.401	0.004	0.178	0.014	0.304	0.223	0.395	0.156
Total dissolved solids	0.039		0.042	0.179	0.079	0.345	0.348	0.124	0.226	0.464
Electrical conductivity	0.401	0.042		0.263	0.002	0.096	0.014	0.017	0.225	0.201
Calcium	0.004	0.179	0.263		0.085	0.001	0.203	0.310	0.195	0.007
Magnesium	0.178	0.079	0.002	0.085		0.008	0.112	0.000	0.047	0.278
Chloride	0.014	0.345	0.096	0.001	0.008		0.082	0.061	0.321	0.040
Bromide	0.304	0.348	0.014	0.203	0.112	0.082		0.326	0.470	0.160
Nitrate	0.223	0.124	0.017	0.310	0.000	0.061	0.326		0.011	0.348
Total coliform	0.395	0.226	0.225	0.195	0.047	0.321	0.470	0.011		0.100
Total rainfall	0.156	0.464	0.201	0.007	0.278	0.040	0.160	0.348	0.100	

Table 4. The Eigenvalues of the component matrix of water quality variables of Mvudi upstream and downstream.

Parameter	PC1	PC2	PC3
Eigenvalue	4.035	2.735	1.561
% variance explained	40.350	27.346	15.612
%Cumulative variance	40.350	67.696	83.308
pH	0.521	−0.590	0.512
Total dissolved solids	0.194	0.730	−0.455
Electrical conductivity	0.737	0.412	−0.421
Calcium	0.673	−0.673	0.009
Magnesium	0.910	0.346	0.080
Chloride	0.866	−0.334	0.126
Bromide	0.565	−0.031	−0.472
Nitrate	0.723	0.516	0.349
Total coliform	0.313	0.634	0.568
Total rainfall	−0.462	0.574	0.475

Note: three components extracted.

These research findings suggest the downstream sample point may be associated mostly with discharge from the Thohoyandou sewage plant. The sewage plant receives mostly sewage influent mainly associated with domestic with minimal industry in the Thohoyandou urban and Shayandima industrial areas. The presence of chloride in the sewage effluent indicates the origin is from sodium chloride, which is mostly associated with human consumption of table salt [34]. The research findings are in agreement with the study of Sudevi and Lokesh [35], who found that the sewage plant discharge affected the water quality of the downstream sample point. The association with rainfall was strongly negative and this may imply that rainfall did not contribute to washing of animal waste and/or nitrates from subsistence farming and soil erosion into the Mvudi River at the downstream section. Thus, the discharge of nitrates and total coliform to the Mvudi River originated from the Thohoyandou sewage plant and not from subsistence farming. The presence of bromide in Mvudi River downstream may be attributed to the Thohoyandou sewage plant. Here, the bromide probably enters from the stormwater drains that are connected to the sewage plant. The stormwater drains are located in the Thohoyandou commercial business district, which is close to Mvudi River upstream. The bromide originated from urban runoff when ethylene dibromide was added to petrol [36]. The average pH of the Mvudi River downstream was 7.3 and almost neutral. Thus, most of the anions and cations were in solution, thus contributing to electrical conductivity.

PC2 accounted for 27% of the variation (Table 4) and was associated strongly with total dissolved solids, electrical conductivity, magnesium, nitrate, total coliform, and rainfall, which represented Mvudi upstream. The association with rainfall was strongly positive and this may imply that rainfall did contribute to the washing of fertilizers, animal waste, and soil erosion into the Mvudi River at the upstream section. The Mvudi upstream is associated with subsistence farming (Figure 4) and transects a major tarred road (R524). The research findings are corroborated by the study of De Wit et al. [37] who found that rainfall had a positive effect of washing of road surfaces and discharging the stormwater wastes into rivers. At this particular sample point, there is a major tarred road (R524) and the stormwater waste may account for contaminates at the Mvudi upstream sample point. The presence of nitrates may be due from diffuse pollution from farming activities, which is supported by the study of Muriithi and Yu [38]. The stormwater may also account for high total dissolved solids and, correspondingly, with high electrical conductivity, that were observed at the Mvudi upstream point. This is supported by the study of Singh et al. [34] who found high levels of total dissolved solids and electrical conductivity were directly linked to stormwater intrusion.

Figure 4. Subsistence agricultural activities practiced at Mvudi upstream.

PC3 accounted for 15.6% of the variation (Table 4) and was associated strongly with pH, nitrate, total coliform, and rainfall, and weak association with chloride, which represented the natural Mvudi river system and the subsistence farming that is practiced in this section of the river (Figure 4). The presence of nitrates may be due from diffuse pollution from farming activities [38].

3.3. Assessing the Impact of Vuwani Sewage Discharge on Dzindi Sampling Sites

Eleven items from Dzindi sampling sites, upstream and downstream, were analyzed with principal component analysis (Table 5). The principal component analysis showed the first three components accounted for 86% of the total variation in water quality and the scree plot of eigenvalues of the components is shown in Figure 5. PC1 accounted for 54% of the variation (Table 6) and was associated strongly with electrical conductivity, sulfate, total dissolved solids, fluoride, turbidity, nitrate, manganese, alkalinity, magnesium, and total coliform, representing Dzindi downstream. The presence of ions (cations and anions) may account for the electrical conductivity and total dissolved solids. These research findings suggest origins downstream may be associated mostly with the Vuwani sewage plant and agriculture [37–39]. The sewage plant receives mostly sewage influent mainly associated with domestic use from Dzwerani, Mathule, and Khumbe villages, Khumbe poultry farm, and the Vuwani military base. There was no association with rainfall at the Dzindi River at the downstream section. PC2 accounted for 20% of the variation (Table 6) and was associated strongly with turbidity, manganese, total coliform, and weakly associated with chloride, which represented Dzindi upstream.

Table 5. Water quality eigenvectors of the correlation matrix.

Parameter	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11
Turbidity		0.004	0.028	0.165	0.000	0.466	0.209	0.063	0.065	0.055	0.000
Total dissolved solids	0.004		0.000	0.147	0.020	0.138	0.414	0.002	0.003	0.001	0.012
Electrical conductivity	0.028	0.000		0.021	0.035	0.043	0.442	0.000	0.002	0.000	0.114
Alkalinity	0.165	0.147	0.021		0.179	0.030	0.435	0.001	0.356	0.008	0.441
Manganese	0.000	0.020	0.035	0.179		0.481	0.263	0.070	0.035	0.040	0.007
Magnesium	0.466	0.138	0.043	0.030	0.481		0.339	0.008	0.212	0.021	0.397
Chloride	0.209	0.414	0.442	0.435	0.263	0.339		0.436	0.165	0.472	0.455
Fluoride	0.063	0.002	0.000	0.001	0.070	0.008	0.436		0.040	0.000	0.264
Nitrate	0.065	0.003	0.002	0.356	0.035	0.212	0.165	0.040		0.007	0.071
Sulfate	0.055	0.001	0.000	0.008	0.040	0.021	0.472	0.000	0.007		0.210
Total coliform	0.000	0.012	0.114	0.441	0.007	0.397	0.455	0.264	0.071	0.210	

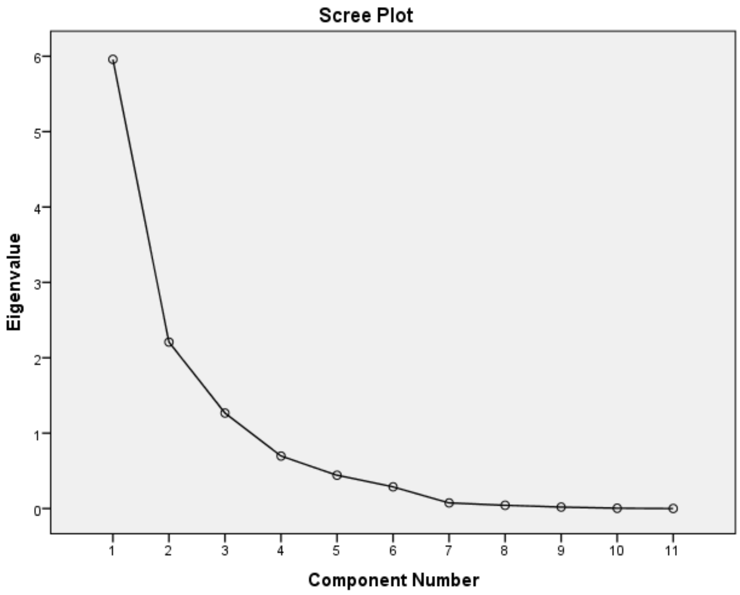

Figure 5. The scree plot of eigenvalues for Dzindi river system.

This is mainly due to subsistence agriculture that is practiced at Dzindi upstream, and the Dzindi irrigation scheme and the washing of motor cars at the Dzindi irrigation canal. PC3 accounted for 12% of the variation (Table 6) and was associated strongly with chloride, and negatively associated with nitrate, which represented the natural Dzindi river system.

Table 6. The eigenvalues of the component matrix of water quality variables of Dzindi upstream and downstream.

Parameter	PC1	PC2	PC3
Eigenvalue	5.959	2.208	1.266
% variance explained	54.170	20.073	11.513
%Cumulative variance	54.17	20.07	85.756
Electrical conductivity	0.944	−0.176	
Sulfate	0.926	−0.299	
Total dissolved solids	0.915	0.146	
Fluoride	0.894	−0.389	0.181
Turbidity	0.750	0.599	0.182
Nitrate	0.745		−0.534
Manganese	0.725	0.532	0.135
Alkalinity	0.610	−0.487	0.322
Magnesium	0.484	−0.701	
Total coliform	0.570	0.677	−0.173
Chloride		0.277	0.866

Note: three components were extracted.

3.4. Assessing the Impact of Upstream Municipal Sewage Discharge on Luvuvhu Sampling Sites

Fifteen items from Luvuvhu sampling sites, upstream and downstream, and the Nandoni reservoir were analyzed with principal component analysis (Table 7).

Table 7. Water quality eigenvectors of the correlation matrix.

Parameter	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13	PC14	PC15
Turbidity		0.086	0.105	0.025	0.276	0.090	0.000	0.215	0.105	0.327	0.441	0.387	0.016	0.493	0.023
Total dissolved solids	0.086		0.027	0.000	0.125	0.163	0.393	0.164	0.231	0.334	0.169	0.032	0.002	0.143	0.017
Electrical conductivity	0.105	0.027		0.156	0.103	0.349	0.127	0.059	0.457	0.041	0.235	0.107	0.002	0.218	0.419
Alkalinity	0.025	0.000	0.156		0.218	0.154	0.362	0.321	0.150	0.329	0.208	0.074	0.034	0.019	0.000
Manganese	0.276	0.125	0.103	0.218		0.230	0.184	0.273	0.189	0.133	0.088	0.018	0.163	0.073	0.070
Magnesium	0.090	0.163	0.349	0.154	0.230		0.004	0.026	0.000	0.101	0.466	0.094	0.437	0.425	0.429
Chloride	0.000	0.393	0.127	0.362	0.184	0.004		0.197	0.006	0.369	0.499	0.067	0.293	0.366	0.466
Bromide	0.215	0.164	0.059	0.321	0.273	0.026	0.197		0.033	0.000	0.013	0.006	0.326	0.437	0.423
Fluoride	0.105	0.231	0.457	0.150	0.189	0.000	0.006	0.033		0.139	0.354	0.109	0.425	0.455	0.491
Nitrate	0.327	0.334	0.041	0.329	0.133	0.101	0.369	0.000	0.139		0.001	0.006	0.356	0.472	0.423
Sulfate	0.441	0.169	0.235	0.208	0.088	0.466	0.499	0.013	0.354	0.001		0.067	0.260	0.321	0.169
Total coliform	0.387	0.032	0.107	0.074	0.018	0.094	0.067	0.006	0.109	0.006	0.067		0.013	0.394	0.010
Average air temperature	0.016	0.002	0.002	0.034	0.163	0.437	0.293	0.326	0.425	0.356	0.260	0.013		0.070	0.113
Average humidity	0.493	0.143	0.218	0.019	0.073	0.425	0.366	0.437	0.455	0.472	0.321	0.394	0.070		0.005
Total rainfall	0.023	0.017	0.419	0.000	0.070	0.429	0.466	0.423	0.491	0.423	0.169	0.010	0.113	0.005	

The principal component analysis showed the first five components accounted for 87% of the total variation in water quality and the scree plot of eigenvalues of the components is shown in Figure 6. PC1 accounted for 30% of the variation (Table 8) and was associated strongly with total dissolved solids, electrical conductivity, magnesium, fluoride, nitrate, sulfate, total coliform average air temperature, and total rainfall, and negatively associated with manganese and bromide, which represented Luvuvhu upstream (S6). There was strong association with rainfall at the Luvuvhu River at the upstream section, indicating the washing of animal wastes and leaching of fertilizers from commercial agriculture in the Levubu tropical area [40]. The Luvuvhu upstream section is located close to the source of the Luvuvhu River and is a high rainfall area in the Soutpansberg Mountains [40].

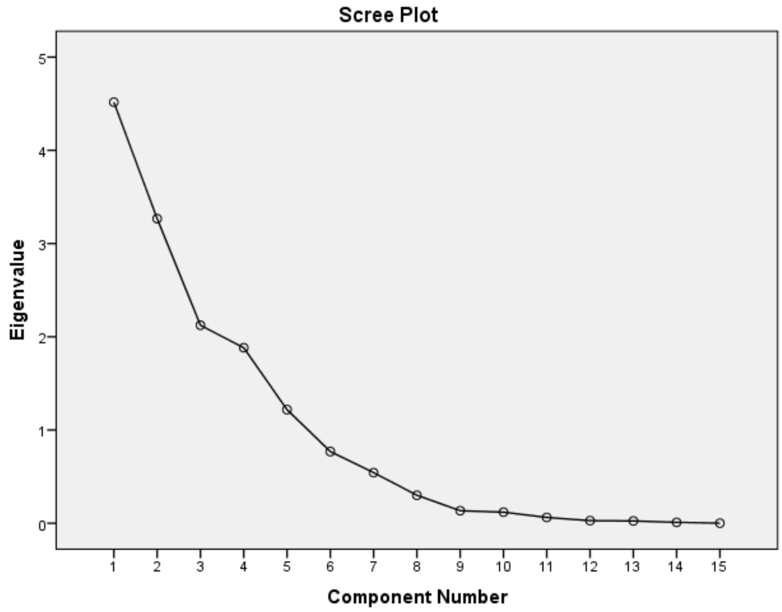

Figure 6. The scree plot of eigenvalues for Luvuvhu river system and the Nandoni reservoir.

Table 8. The Eigenvalues of the component matrix of water quality variables of Luvuvhu upstream and downstream and the Nandoni reservoir.

Parameter	PC1	PC2	PC3	PC4	PC5
Eigenvalue	4.516	3.267	2.124	1.882	1.218
% variance explained	30.108	21.283	14.160	12.547	8.123
%Cumulative variance	30.108	51.891	66.051	78.598	86.721
Turbidity	−0.212	0.817	0.070	−0.309	0.290
Total dissolved solids	0.754	−0.276	0.177	0.281	0.139
Electrical conductivity	0.536	−0.221	−0.583	0.198	0.189
Alkalinity	−0.704	0.349	−0.447	−0.243	0.189
Manganese	−0.479	0.126	−0.053	0.584	−0.545
Magnesium	0.421	0.729	0.133	0.486	−0.106
Chloride	0.195	0.760	0.335	−0.046	0.451
Bromide	−0.641	−0.457	0.336	0.167	0.289
Fluoride	0.377	0.722	0.221	0.478	−0.165
Nitrate	0.620	0.334	−0.444	−0.356	−0.323
Sulfate	0.534	0.000	−0.279	−0.535	−0.281
Total coliform	0.824	0.132	−0.052	−0.107	0.242
Average air temperature	0.589	0.132	−0.052	−0.107	0.242
Average humidity	0.261	−0.112	0.738	−0.419	−0.231
Total rainfall	0.599	−0.421	0.565	−0.124	−0.062

Note: five components were extracted.

PC2 accounted for 21% of the variation (Table 8) and was associated strongly with turbidity, alkalinity, magnesium, chloride, fluoride, nitrate, and strong negative association with rainfall, which represented Luvuvhu downstream (S5). The negative association with rainfall at the Luvuvhu downstream point implies that the rainfall was not involved and that the pollutants probably originated from the municipal sewage plants and agriculture return flows [36–39]. These research findings suggest origins downstream may be associated mostly with municipal sewage plants, such as Vuwani oxidation ponds, Elim and Waterval sewage plants, and agriculture. The sewage plant receives mostly sewage influent mainly associated with domestic use from Ha-Manavhela, Mambedi, Valdezia, Mabodo, and Mpheni villages, and small towns of Vuwani, Mambedi lodge, Waterval, and Elim and the Elim hospital, and no industry, as shown by the negative association with manganese. The presence of chloride in the sewage effluent indicates the origin is from sodium chloride, which is mostly associated with table salt and human diets [38,39]. The agriculture return flows are due to intensive irrigation that is practiced at the Levubu tropical area (Figure 7) with irrigation coming from the Luvuvhu River, Albasini dam, and groundwater sources [37,38]. Even the subsistence farming operations in rural areas, such Valdezia and Mambedi, also pump water from the Luvuvhu River. The study of Zhang et al. [12] in China also showed that the presence of nitrates in freshwater bodies are attributed to sewage plants, point sources of pollution and agriculture, as nonpoint sources of pollution which are difficulty to control.

(**a**) (**b**)

Figure 7. The practice of commercial agriculture: (**a**) maize growing and (**b**) banana plantations in the Levubu tropical area.

PC3 accounted for 14% of the variation (Table 8) and was moderately associated with rainfall and weakly associated with chloride and bromide, and negatively associated with nitrate, which represented the natural Nandoni reservoir system. The villages that are close to the Nandoni reservoir are Dididi, Makovha, and Mulenzhe, and the communities obtain some of their water for human and livestock watering here [22]. PC4 accounted for 13% of the variation (Table 8) and was moderately associated with manganese, magnesium, and fluoride, and negatively associated with turbidity and nitrate, which represented the Luvuvhu River downstream. PC5 accounted for 8% of the variation (Table 8) and was weakly associated with chloride, and negatively associated with manganese, which represented the natural Luvuvhu River downstream.

4. Conclusions

The use of principal component analysis, coupled with factor and cluster analysis, was used to study the similarities and differences between upstream and downstream sampling sites that are downstream of municipal sewage plants. Cluster analysis showed the presence of two clusters in each of the sampling sites. The principal component analysis identified nitrate and total coliforms as major pollutants in the downstream sections of the sampling sites and attributed this to effluent discharge from municipal sewage plants. Thus, the ecological impact of municipal sewage discharge contributes to proliferation of cyanobacteria due to available nitrates and aquatic weeds to provide a habitat for schistomiasis vector snails. This may render the raw water supply unsuitable for human consumption without conventional water treatment processes and an added cost on the use of activated carbon to reduce cyanotoxins in the final treated water supply. The other ecological impact is the increase in schistomiasis infections among the waterfront villagers along the Nandoni water reservoir and Luvuvhu River downstream of Nandoni dam.

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Abbreviations

The following abbreviations are used in this manuscript:

DWAF	Department of Water Affairs and Forestry
PCA	Principal component analysis
CA	cluster analysis
FA	factor analysis
MPN	most probable number
LD	linear dichroism

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