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Impacts of Land Use on Water Quality in the Sebeya Catchment Area, Rwanda

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Abstract

The catchment area of the Sebeya River is largely exploited usually for multi-purpose use. The Sebeya catchment is part of the Congo-Kivu catchment positioned in the upper portion of the Congo basin; so this has serious implications for water safety. The impacts of land use on water quality in the Sebeya catchment area, Rwanda, has been examined in this study because of serious implications for water safety. Samples of surface water were collected across agriculture, mining, forest, grazing and settlements land use types in the Sebeya River catchment area with a view to understanding the contributions of those land uses to seasonal variation in the water quality parameters. Most of the measured water quality parameters were concentrated on samples that were retrieved around the settled area of the Sebeya catchment. We conducted a principal component analysis (PCA) to identify the water quality parameters mostly associated with various land use area surrounding the Sebeya water catchment area. Turbidity, Total Suspended Solids (TSS), and Chemical Oxygen Demand (COD) concentration levels remained very relevant to the component loading at both wet and dry seasons at some of the sample locations. Turbidity values ranged between 2330-3880 NTU, TSS values ranged between 2455-1555 mg/l and COD values ranged between 157-245 mg/l in the wet and dry season respectively.

It is recommended that an effective waste management, of both liquid and solid waste, be implemented in the urban areas of the Sebeya catchment area to prevent water pollution. Furthermore, the waste management program should incorporate a water quality monitoring program so the status of water quality can be assessed accordingly.

Keywords: Land use; Water quality parameters; Principal Component Analysis (PCA); Sebeya catchment area; Rwanda

Introduction

The land use within a catchment has great impacts on the water quality of rivers (Huang et al., 2013). The water quality of rivers may degrade due to the changes in the land cover patterns or land use practices within the catchment as human activities increase (Sliva et al., 2001; Ngoye and Machiwa, 2004; Huang et al., 2013).

Comparative studies have found that land use significantly impacts river water quality and that the mechanisms involved can be complex. Human activities such as deforestation, agricultural activities and urbanization generally modify landscape characteristics, alter runoff volume, change water temperature, generate pollution, increase algal production and decrease concentrations of dissolved oxygen in water bodies (Ding et al., 2015). In the course of industrialization, urbanization and agricultural expansion many countries strongly depend on natural resources and this result in land use and land cover change (Lamek et al., 2016).

In Rwanda, surface water is currently polluted by various land use practices such as the use of fertilizers and pesticides in agriculture to improve the yield productivity as the soil is becoming more and more degraded (Christian et al., 2012). These chemicals find their way into surface water through runoff. In the same vein, land use practices such as trampling of stocks, human disturbances, burning of veg-

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etation, increased housing developments associated with urbanization, dumping of untreated effluent in rivers and marshlands, roofing of housing complexes and paving of roads and other access routes, soil excavation processes have devastated vegetation cover to such an extent that the soil surface of areas has become susceptible to erosion (Christian et al., 2012). The impact of intense land use and land use practices in the Albertine Rift region was highlighted at the side of Democratic Republic of Congo (Kimbadi et al., 1999; Bagalwa, 2006). From our knowledge, similar assessment is missing for Sebeya River and its catchment. The Sebeya catchment is part of the Albertine Rift region on Rwanda side, where (rural) population density and land cover/use changes are much higher in various river catchments of Rwanda, pollution is an issue of concern. For instance, the Nyabugogo River carries high loads of nutrients in terms of total nitrogen and phosphorus (Nhapi et al., 2011). The authors concluded that the Nyabugogo River system is heavily polluted and urgent action to control both rural and urban pollution is required. However, a river that is strongly affected is Sebeya River with high loads of sediments and high bacteria counts (Minirena-RNRA, 2015).

Like many other river catchments in developing countries, Sebeya catchment also lacks data on its water quality monitoring. However, a concern has been raised recently about its water quality status in terms of elevated levels of *E. Coli*, coliform bacteria and other pathogens from untreated sewage, high organic loads, high biological oxygen demand (BOD^5) and chemical oxygen demand (COD), low dissolved oxygen (DO) concentrations, very high sediment loads and turbidity (W4GR, 2016). Therefore, it is of crucial importance to study and understand how current land use types and their practices have impacted the quality of water in the Sebeya catchment area. The findings could be used for proper informed planning and management decisions as well as promoting integrated water resource management in Rwanda. In order to understand the impacts of current land use on water quality of the Sebeya catchment area, we considered the seasonal variation of various water quality parameters across the different land use/land cover in the study area. Additionally, we examined the relationships between different land use/land cover based on the physiochemical and bacteriological composition of the water samples in the Sebeya catchment area across the wet and dry season, respectively.

Material and Methods

Study area

Sebeya catchment is a part of the Congo-Kivu catchment positioned in the upper portion of the Congo basin. The catchment has a main river, the Sebeya River which runs48 km, flowing in a north-westerly path from its origin in the highlands of the Congo-Nile divide, at an elevation of 2,660 meters above the sea level, into the catchment outflow at Lake Kivu at an elevation of 1,470 meter above the sea level, in Rubavu town (W4GR, 2018). The catchment has other rivers contributing to the main river. Figure 2.1 shows the Sebeya catchment drainage network, elevation and sub-catchments

Due to its position, the Sebeya catchment is classified by the World Wildlife Fund for Nature (WWF) as 'Albertine Rift Montane Forests Eco-region'; the eco-region is an area of unique faunal and moderate floral endemism; the region similarly supports the mountain gorilla (*Gorilla beringei beringei*), which is one of the most appealing gorilla species in Africa (W4GR, 2018).

Sebeya catchment is characterized by short dry season and long rainy season with high rainfall of 1200mm/year and above. The population in the catchment confirmed that within a period of 20 minutes to 3 hours after a heavy rain, floods occur; regions with an altitude higher than 2,000 meters above the sea level and an annual average temperature of around 17°C (W4GR, 2018). Flooding in the catchment naturally occurs in mid flat areas of the steep parts created by rift formation situated mostly in the flat area around Nyundo. Such resulting impact acts as a natural retention buffer for floods. Consequently, resulting in flash flood type which causes property and infrastructure damages. The Sebeya catchment is dominated by agriculture land use followed by forestry and grazing land uses.

Water quality data collection

Samples of water were collected using glass bottles of 0.75 land were stored at 40C before conducting laboratory analysis. Sampling frequency was set to be two times to cover both the rain (in April) and dry seasons (in July) in order to be able to assess all the changes that might occur due to seasonal variations. A total of 24 samples were collected consisting of 12 samples collected in the wet season and 12 samples in the dry season. The water quality parameters considered in the study were temperature, electrical conductivity, total suspended solids, turbidity, pH, total nitrogen, total phosphorus, dissolved oxygen, chemical oxygen demand, biological oxygen demand, and *Escherichia coli*. These parameters were chosen because they were anecdotally reported to be in high concentration in the Sebeya catchment and needed to be confirmed. IDEXX Quanti-Tray 2000 MPN (most probable number) table, incubation, spectrophotometry, and digestions methods were used to analyse E-coli, BOD^5, COD, and TN/TP respectively.

Table 1: Pertinent information on sampling locations

Site	Site name/location	Longitude	Latitude	Surrounding land use
SP1	Sebeya river headwater	440709	4795956	Grazing
SP2	Pfunda headwater	431563	4797689	Cropland, Grazing
SP3	Bihongora headwater	438893	4802970	Grazing
SP4	Sebeya river before mixing with Karambo	429140	4810941	Radical terraces, settlements, tea plantation
SP5	Bihongora river at EIP_Bihongora	434218	4808779	Grazing and terraces
SP6	Karambo river headwater	431596	4810745	Cropland and forestry
SP7	Bihongora river before mixing with Sebeya river	430200	4807990	Radical terraces
SP8	Sebeya river before mixing with Bihongora river	430275	4808071	Cropland, mining and forestry
SP9	Sebeya river after mixing with Karambo	424879	4811865	Settlements, tea plantation and forestry
SP10	Pfunda river before mixing with Sebeya river	423209	4810919	Mining, tea plantation Settlements
SP11	Karambo river before mixing with Sebeya river	428885	4810764	Settlements and cropland
SP12	Sebeya river exit into Lake Kivu	417923	4811515	Settlements and trees

Table 2.1 provides information on the sampling locations.

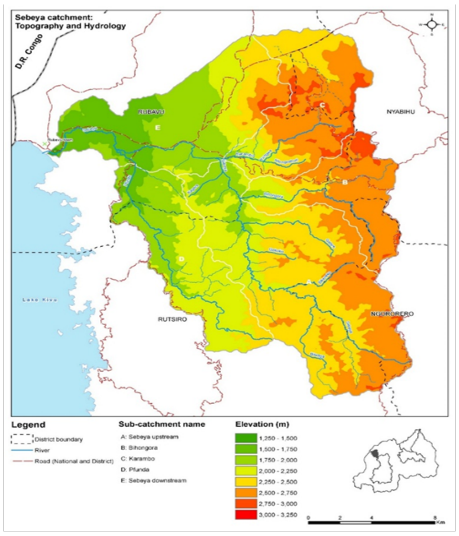

Figure 1: Sebeya catchment elevation, waterways, and sub-catchments. Source: W4GR, 2018

The map of Sebeya catchment area where sample points are collected is shown in Figure 1.

Method of Statistical analysis

The study used Principal Component Analysis (PCA), a statistical technique that uses an orthogonal transformation to convert observations of possibly correlated variables values of linearly uncorrelated variables called principal components. This helps streamline the number of contributing variables for the data analysis and interpretation. This transformation is defined in such a way that the first principal component has the largest possible variance (that is, it accounts for as much of the variability in the data as possible), and each succeeding component in turn has the highest variance possible under the constraint of orthogonality, that is, it is orthogonal to the preceding components. The

Table 2: Laboratory results of the analysed water quality parameters in the wet season

WQP	DO	TOC	Turb	pH	EC	TSS	TN	TP	BOD	COD	E-coli
Unit	mg/l	0C	NTU	NA	µS/cm	mg/l	mg/l	mg/l	mg/l	mg/l	MPN/100ml
SP1	4.32	14.8	0.52	6.5	37.9	2	18.9	1.06	18.8	32	22.2
SP2	7.31	14.8	1.79	4.5	53.5	127	15.7	1.33	17.4	48	3950
SP3	6.77	17	0.75	5.5	46.4	1	18	0.63	8.4	21	0
SP4	7.83	18.4	1300	7.198	61.1	1140	0	2.35	12.9	87	6630
SP5	6.74	16.1	69.1	7.516	57.1	59	2.1	1.55	13.5	33.8	359
SP6	6.32	17.45	756	7.935	158.6	558	13.2	1.93	26.7	85	20630
SP7	6.54	18.14	117	7.439	78.6	87	0.8	1.66	22.5	56.3	14430
SP8	7.5	18.36	1570	7.012	64.8	1360	27.6	2.65	16.8	78.5	8130
SP9	6.82	19.52	2125	7.319	92	2455	18	1.62	20.7	157	14450
SP10	6.94	19.78	492	7.824	66.3	333	0	1.59	15.3	38.3	7308
SP11	6.47	18.1	2330	7.744	145.6	1700	39.2	3.7	24	105	17850
SP12	6.18	19.83	2160	7.568	85.8	1945	51.4	3.38	18.1	79	12360
Standard	5	25	5	6.5-8.5	< 1000	<30	<3	<5	<30	<50	4

Note: S: Sample, WQP: Water Quality Parameter, DO: Dissolved Oxygen, TOC : Temperature, Turb: Turbidity, EC: Electrical Conductivity, TSS: Total Suspended Solids, TN: Total Nitrogen, TP: Total Phosphate, BOD: Biochemical Oxygen Demand, COD: Chemical Oxygen Demand, E-coli: Escherichia Coli, NA: Not Applicable. Standard: Rwanda Standard Board (RSB) 2008; WHO (2004) and Wyness et al. (2003)

resulting vectors are uncorrelated orthogonally.
PC's may be defined in terms of the population (using ∑) or in terms of a sample (using S). Let

$$y_1 = a_1^T x$$
$$y_2 = a_2^T x$$
$$y_p = a_p^T x$$

Where $y_j = a_{1j} x_1 + a_{2j} x_2 + \cdots + a_{pj} x_p$ are a sequence of "standardized" linear combinations (SLC's) of the x's such that $a_j^T a_j = 1 (\sum_{i=1}^{p} a_{ij}^2 = 1)$ and $a_j^T a_k = 0 (\sum_{i=1}^{p} a_{ij} a_{ik} = 0)$ for $j \neq k$: *i.e.* $a_1; a_2, \ldots, a_p$ form an orthonormal set of *p*-vectors. Equivalently, the (*p x p*) matrix A formed from the columns $\{a_j\}$ satisfies $A^T A = I_p (= AA^T)$; so by definition is an orthogonal matrix.
We choose a_1 to maximize,

$$Var(y_1) = a_1^T \sum a_1 \, , \qquad (1)$$

subject to $a_1^T a_1 = 1$. Then, we chose a_2 to maximize,

$$Var(y_2) = a_2^T \sum a_2 \, , \qquad (2)$$

subject to $a_2^T a_2 = 1$ and $a_2^T a_1 = 0$, which ensures that y_2 will be uncorrelated with y_1. Subsequent PC's are chosen as the SLC's that have maximum variance subject to being uncorrelated with previous PC's.
To find the first PC, we use the Lagrange multiplier technique for finding the maximum of a function f(*x*) subject to an equality constraint g (*x*) = 0. We define the Lagrangean function

$$L(a_1) = a_1^T \sum a_1 - \lambda(a_1^T a_1 - 1) \, , \qquad (4)$$

where λ is a Lagrange multiplier. We need a result on vector differentiation.

Result

Let x = ($x_1, x_2 \ldots x_n$) and $\frac{d}{dx_1} = (\frac{d}{dx_1}, \ldots, \frac{d}{dx_n})^T$. If b (n x 1) and A (n x n), symmetric, are given constant matrices, then,

$$\frac{d}{dx_1}(b^T x) = b,$$
$$\frac{d}{dx}(x^T Ax) = \frac{1}{2} Ax$$

1st PC
Differentiating (4) using the results, give

$$\frac{dL}{da_1} = 2\sum a_1 - 2\lambda a_1 = 0,$$
$$2\sum a_1 - 2\lambda a_1 = 0,$$
$$\sum a_1 = 2\lambda a_1 \qquad (5)$$

Showing that a_1 should be chosen to be an eigenvector of ∑; say a_1 = v with Eigen value λ. Suppose the Eigen values of ∑ are ranked in decreasing order $\lambda_1 \geq \lambda_2 \geq \lambda_3 \geq, \ldots, \geq \lambda_p > 0$.

$$Var(y_1) = a_1^T \sum a_1,$$
$$= \lambda a_1^T a_1,$$
$$= \lambda \qquad (6)$$

Therefore, in order to maximize Var (y_1), a_1 should be chosen as the eigenvector v1corresponding to the largest Eigen value λ_1 of ∑.

Table 3: Laboratory results of the analysed water quality parameters in the dry season

WQP	DO	TOC	Turb	pH	EC	TSS	TN	TP	BOD	COD	E-coli
Unit	mg/l	0C	NTU	NA	µS/cm	mg/l	mg/l	mg/l	mg/l	mg/l	MPN/100ml
SP1	4.12	15.01	0.58	4.02	40.8	2	1.418	0.47	17.5	82.5	0
SP2	6.75	16.3	6.61	6.5	52.3	4	1.416	0.48	18.9	126	1732.8
SP3	6.34	15.8	0.69	5.5	37.8	0	1.63	0.88	18.8	104	0
SP4	6.19	22.69	940	6.5	67.3	860	1.73	1.71	34.9	245	3448
SP5	6.3	15.31	39.5	7	46.8	27	1.5	0.29	36.1	6.5	3150
SP6	6.19	15.16	163	7.5	144.1	142	0.908	1.48	41.7	26	2818
SP7	6.4	14.92	45.2	7	78	33	1.261	2.04	11.6	21.5	1553
SP8	6.26	15.37	3880	6.2	57.9	1555	3.031	0.56	41.7	90.5	3000
SP9	6.27	18.21	1830	6.7	73.3	1281	1.947	2.01	120	402	2419.6
SP10	6.62	19.74	251	7	60.2	145	2.487	0.84	36.9	95	8664
SP11	6.68	20.39	208	7.5	173.4	197	1.856	0.9	35.4	172	9804
SP12	5.99	22.67	1750	6.7	90.9	1347	3.019	1.86	75.9	119	2519.6
Standard	5	25	5	6.5-8.5	< 1000	<30	<3	<5	<30	<50	4

Note: S: Sample, WQP: Water Quality Parameter, DO: Dissolved Oxygen, TOC : Temperature, Turb: Turbidity, EC: Electrical Conductivity, TSS: Total Suspended Solids, TN: Total Nitrogen, TP: Total Phosphate, BOD: Biochemical Oxygen Demand, COD: Chemical Oxygen Demand, *E-coli: Escherichia Coli*, NA: Not Applicable. Standard: Rwanda Standard Board (RSB) 2008; WHO (2004) and Wyness et al. (2003)

Results and Discussions

Results presentation of the measured water quality parameters

Table 2 and 3 show the laboratory analysis results of the water quality parameters from water samples collected at the 12 sample points in the wet season and in the dry season.

Descriptive Evaluation of the Variation water quality parameters at various sample points with the International Standard

In evaluating the level of DO variation in the Sebeya catchment across the different land use with respect to the standard values. The DO values across these catchment is expected to be greater than or equal to (the same as) the DO standard value. That is, the permissible limits for DO value of any water body. Our result shows that all the sampled points DO values were far greater or above the DO standard value with sample point 4, 8 & 2 respectively, having the most significant variation in Wet season among samples taken at Sebeya river headwater. As shown in Table 4 and Figure 2 below.

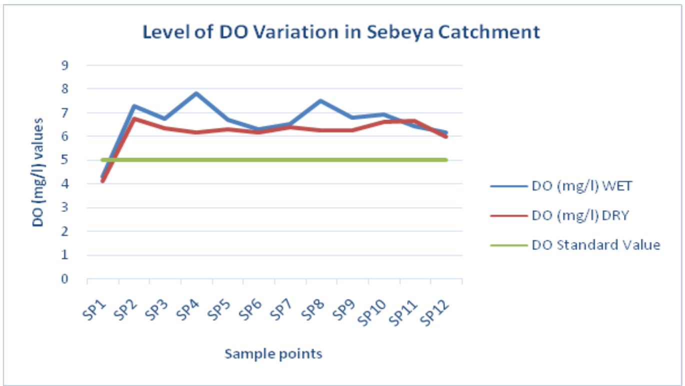

Figure 2: DO variation in the Sebeya Catchment with respect to Standard value

Table 4: DO (mg/l) variation from the Standard value

Sample points	VDW	VDD
SP1	-0.68	-0.88
SP2	2.31	1.75
SP3	1.77	1.34
SP4	2.83	1.19
SP5	1.74	1.3
SP6	1.32	1.19
SP7	1.54	1.4
SP8	2.5	1.26
SP9	1.82	1.27
SP10	1.94	1.62
SP11	1.47	1.68
SP12	1.18	0.99

Key: VDW: Variation of Dissolved Oxygen from the standard value in wet season; VDD: Variation of Dissolved Oxygen from the standard value in the dry season.

In similar sense, the temperature level variation in the Sebeya catchment across the different land use with respect to the standard values is examined. The temperature values across this catchment are expected to be very close to the standard temperature value. That is, the permissible limits for temperature value for any water body. Our result shows that at all the sampled points, the temperature values fall below the standard temperature value. As shown in Table 5 and Figure 3 below.

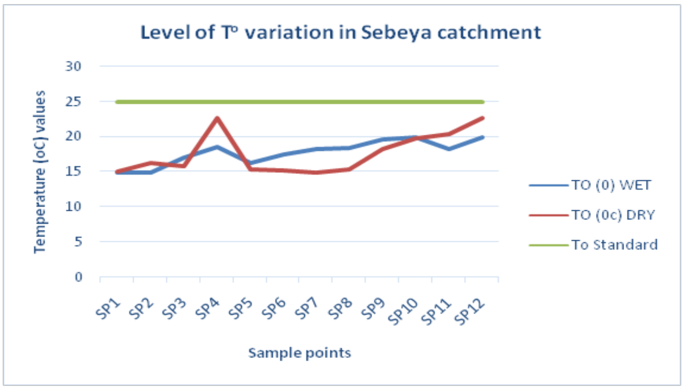

Figure 3: Variation of Temperature in the Sebeya Catchment with respect to Standard value.

Table 5: T°C variation from the Standard value.

Sample points	VTW	VTD
SP1	10.2	9.99
SP2	10.2	8.7
SP3	8	9.2
SP4	6.6	2.31
SP5	8.9	9.69
SP6	7.55	9.84
SP7	6.86	10.08
SP8	6.64	9.63
SP9	5.48	6.79
SP10	5.22	5.26
SP11	6.9	4.61
SP12	5.17	2.33

Key: VTW: Variation of Temperature from the standard value in wet season; VTD: Variation of Temperature from the standard value in the dry season.

The variation of turbidity in the Sebeya catchment during wet and dry seasons ranged between 0.52 NTU and 3880 NTU. At all the sampled points, turbidity values recorded were far beyond the highest turbidity permissible limits of 5 NTU except at SP1, SP2 and SP3 which were the reference points and located in the livestock grazing land use. Largely, wet season turbidity values were higher compared to dry seasons due to erosion, deforestation, poor road construction and landslides of fragile hills. However, SP8 recorded the highest turbidity value in the dry season than in the wet season. This can be attributed to upstream mining activities, reduced river dilution and low discharge during dry season. Extremely turbid water is unhealthy for household use, is visually unappealing, can choke fish gills, can clog drip irrigation and water treatment equipment and is the reason of nasty taste and odours of surface water (Pullanikkatil et al, 2015). As shown in Table 6 and Figure 4 below.

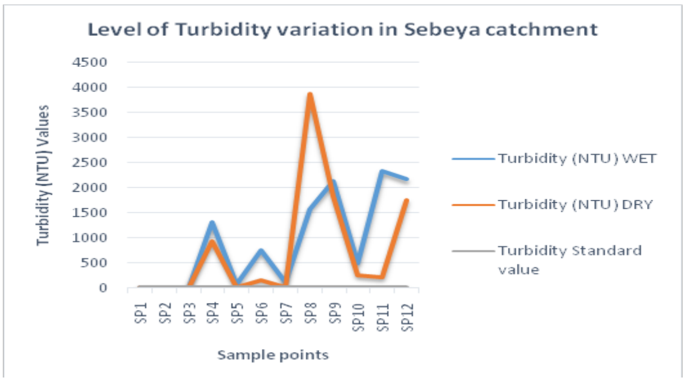

Figure 4: Variation of Turbidity in the Sebeya catchment with respect to the standard value

Table 6: Turbidity variation from the standard value

Sample points	VTW	VTD
SP1	4.48	4.42
SP2	3.21	-1.61
SP3	4.25	4.31
SP4	-1295	-935
SP5	-64.1	-34.5
SP6	-751	-158
SP7	-112	-40.2
SP8	-1565	-3875
SP9	-2120	-1825
SP10	-487	-246
SP11	-2325	-203
SP12	-2155	-1745

Key: VTW: Variation of Turbidity from the standard value in wet season; VTD: Variation of Turbidity from the standard value in the dry season.

The variation pH in the Sebeya catchment ranged between 4.02 and 7.82. Mostly pH was high in the wet season than in the dry season. Most of the sampled points had pH values ranging between 6.5 and 8.5 which is the standard range for pH except SP1, SP2, SP3 and SP8 which had pH values lower than 6.5. These sites were located in forested areas and it was found that streams flowing through forested areas are usually acidic due to decomposition of soil organic matter which releases acids thus lowering pH (Hunchak – Kariouk and Nicholson, 2001; Coulter and Kolka et al., 2004; Kambwiri et al., 2014). On the other hand, SP8 was downstream of tea plantation which is known to grow well in acidic soils thus tea plantation may cause acidification of river especially through tea drainage which is practised in the Sebeya catchment (Kambwiri et al., 2014). The pH is an important variable in water quality assessment as it influences many biological and chemical processes within a water body. Low pH in streams may release toxic heavy metals such as Cd, Co, Cu, Hg, Ni, Pb and Zn which in return eliminate many types of aquatic life through influencing adversely the structure of macro- invertebrate community and species diversity (Kimmel et al.,1985; Abel, 2002). As shown in Figure 5 below. Fig 5

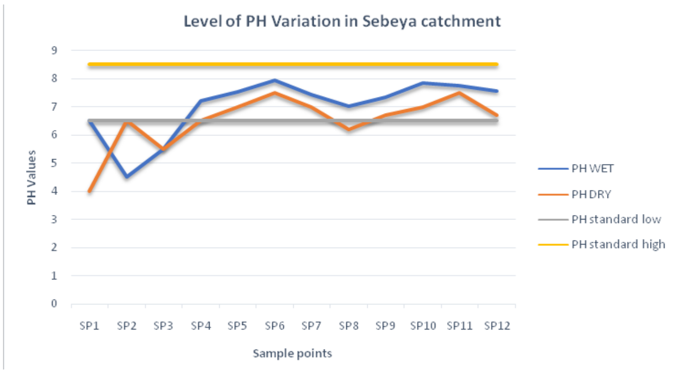

Figure 5: Variation of pH in the Sebeya catchment with respect to the standard value

EC varied between 37.9 µS/cm -158.6 µS/cm and 37.8 µS/cm -173.4 µS/cm in the wet and dry season respectively. In both seasons, EC values were almost the same with a slight increase at SP6 and SP11 during wet and dry season respectively. However, all the sampled points had an electrical conductivity which were in acceptable range with respect to the Standard value (EC < 1000µS/cm). As shown in Table 7 and Figure 6 below.

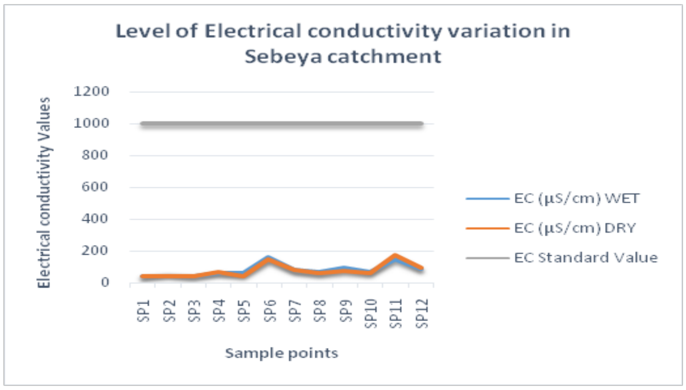

Figure 6: Variation of Electrical conductivity in the Sebeya catchment with respect to the standard value

Table 7: Electrical conductivity variation from the standard value

Sample points	VEW	VED
SP1	962.1	947.7
SP2	946.5	962.2
SP3	953.6	932.7
SP4	938.9	953.2
SP5	942.9	855.9
SP6	841.4	922
SP7	921.4	942.1
SP8	935.2	926.7
SP9	908	939.8
SP10	933.7	826.6
SP11	854.4	909.1
SP12	914.2	1000

Key: VEW: Variation of electrical conductivity from the standard value in wet season; VED: Variation of electrical conductivity from the standard value in the dry season.

TSS varied between 1 mg/l and 2455 mg/l during the wet and dry seasons in the Sebeya catchment. All the values recorded at sampled locations exceeded standard value of less than 30 mg/l except at SP1, SP2 and SP3 which were the headwaters with no to minimum anthropogenic activities. High TSS values were observed in the wet season than dry season. TSS in the rain season peaked at SP9; this sample was taken after a heavy rain which carried a lot of sediment from the highlands of Karambo sub-catchment. High sediment loads result in increased flood damage, reduced water body capacity via sedimentation, and a rise in water treatment costs (Skinner et al. 1997). As shown in Table 8 and Figure 7 below.

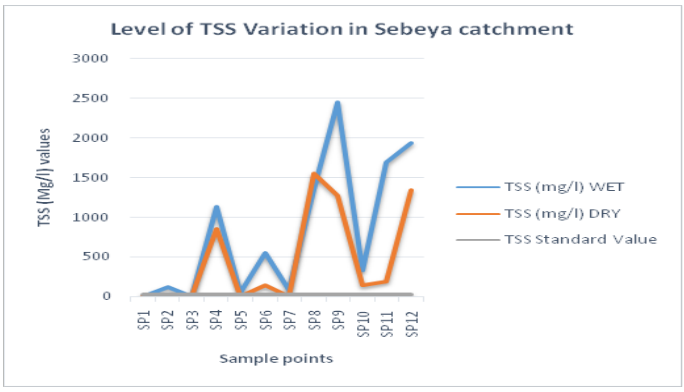

Figure 7: Variation of TSS in the Sebeya catchment with respect to the standard value.

Table 8: TSS variation from the standard value

Sample points	VTSSW	VTSSD
SP1	28	28
SP2	-97	26
SP3	29	30
SP4	-1110	-830
SP5	-29	3
SP6	-528	-112
SP7	-57	-3
SP8	-1330	-1525
SP9	-2425	-1251
SP10	-303	-115
SP11	-1670	-167
SP12	-1915	-1317

Key: VTSSW: Variation of TSS from the standard value in wet season; VTSSD: Variation of TSS from the standard value in the dry season

Seasonal variation of total nitrogen in Sebeya catchment was evidently significant. TN varied between 0 mg/l and 51.4 mg/l. All recorded values in wet season were above the standard value of 3 mg/l. On the other hand, dry season recorded values were in acceptable range since 3 mg/l is the highest permissible limits. On one hand SP1, SP2 and SP3 which are headwaters where there is almost no human activities recorded TN values higher than the standard and they are located in grassland/grazing land use. This may be attributed to some vegetation in the grassland may be leguminous in nature and aid in fixing atmospheric nitrogen into the soil which later gets denitrified to inorganic nitrates and with runoff action end up into the river (Kambwiri et al., 2014). On the other hand, the high variation of TN from the standard value at SP6, SP8, SP9 SP11 and SP12 in the wet season can be attributed to the decomposition of livestock wastes, human wastes, plant decomposition and runoff of fertilizers used in agricultural lands as well as the discharge of municipal waste into rivers through runoff. High nitrogen level can encourage rapid growth of algae and other aquatic plants which may lead to eutrophication of rivers. Besides, excessive growth of aquatic organisms, results in water intakes clogging, reduced dissolved oxygen, and poor light penetration to deeper waters (Chambers et al., 2001). As shown in Table 9 and Figure 8 below.

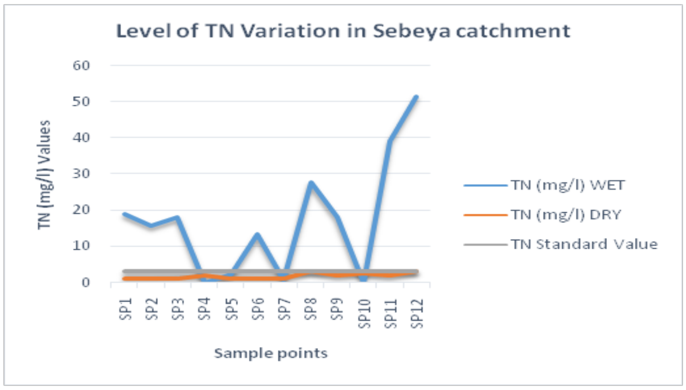

Figure 8: Variation of TN in the Sebeya catchment with respect to the standard value.

Table 9: TN variation from the standard value

Sample points	VTNW	VTND
SP1	-15.9	1.582
SP2	-12.7	1.584
SP3	-15	1.37
SP4	3	1.27
SP5	0.9	1.5
SP6	-10.2	2.092
SP7	2.2	1.739
SP8	-24.6	-0.031
SP9	-15	1.053
SP10	3	0.513
SP11	-36.2	1.144
SP12	-48.4	-0.019

Key: VTNW: Variation of TN from the standard value in wet season; VTND: Variation of TN from the standard value in the dry season

Total phosphorus varied between 0.29 mg/l and 3.7 mg/l. Although the high levels of total phosphorus were observed in the wet season than dry season; all the sampled locations were below the highest acceptance value (standard value) of 5 mg/l. As shown in Table 10 and Figure 9 below.

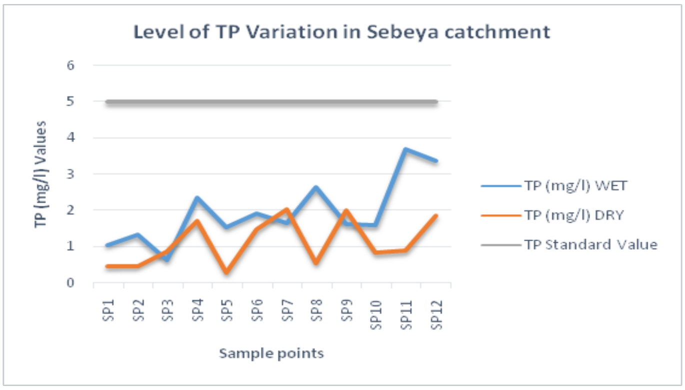

Figure 9: Variation of TP in the Sebeya catchment with respect to the standard value

Table 10: TP variation from the standard value

Sampled points	VTPW	VTPD
SP1	3.94	4.53
SP2	3.67	4.52
SP3	4.37	4.12
SP4	2.65	3.29
SP5	3.45	4.71
SP6	3.07	3.52
SP7	3.34	2.96
SP8	2.35	4.44
SP9	3.38	2.99
SP10	3.41	4.16
SP11	1.3	4.1
SP12	1.62	3.14

Key: VTPW: Variation of TP from the standard value in wet season; VTPD: Variation of TP from the standard value in the dry season.

BOD^5 varied between 8.4 mg/l and 119.7 mg/l. While the recorded values of BOD^5 in wet season were below the standard value; the BOD^5 recorded values in dry season were above the standard value. High BOD^5 at SP9 in the dry season may be caused by sewage discharge, animal waste and industrial effluents discharge into the river. Beside SP9 is located downstream of an urban area (Mahoko city) which is characterized by poor solid and liquid waste disposal leading to inadequate effluent/ sewage discharge and poor disposal of animal waste. High BOD^5 reduces the amount of dissolved oxygen. The decrease in dissolved oxygen in aquatic ecosystems may have adverse effects on many aquatic organisms such as Ephemeroptera (mayflies), Trichoptera (caddisflies), and Plecoptera (stoneflies) which respire with gills or by direct cuticular exchange drop and may be entirely eliminated with oxygen depletion (Abel, 2002). As shown in Table 11 and Figure 10 below.

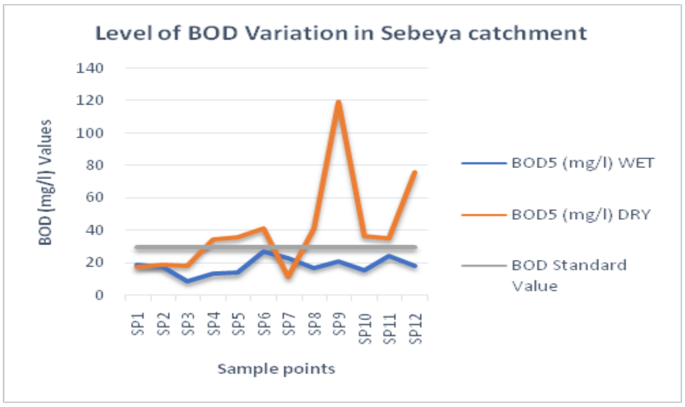

Figure 10: Variation of BOD in the Sebeya catchment with respect to the standard value

Table 11: BOD variation from the standard value

Sampled points	VBODW	VBODD
SP1	11.2	12.54
SP2	12.6	11.13
SP3	21.6	11.22
SP4	17.1	-4.86
SP5	16.5	-6.12
SP6	3.3	-11.7
SP7	7.5	18.45
SP8	13.2	-11.7
SP9	9.3	-89.7
SP10	14.7	-6.9
SP11	6	-5.4
SP12	11.9	-45.9

Key: VBODW: Variation of BOD from the standard value in wet season; VBODD: Variation of BOD from the standard value in the dry season.

COD varied between 6.5 mg/l and 402 mg/l during the wet and the dry seasons. COD recorded values were higher than the standard value of 50 mg/l in both seasons except at SP1, SP2, SP3, SP5 and SP10. High variation from the standard value were observed in the dry season peaking at 402 mg/l at SP9. The reason for this is that the same sample point was recorded to have a high BOD which implies organic matter pollution of the river. COD parameter is related to organic matter and it can be described as the oxygen amount that is required to oxidise all organic matter prone to oxidation by a strong chemical agent such as dichromate (Du Plessis 2014). Same as BOD^5, high COD leads to dissolved oxygen depletion and affect aquatic life and diversity. As shown in Table 12 and Figure 11 below.

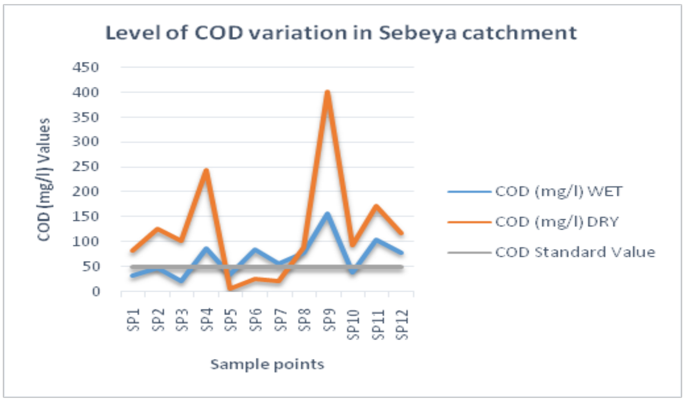

Figure 11: Variation of COD in the Sebeya catchment with respect to the standard value.c

Table 12: COD variation from the standard value

Sampled points	VCODW	VCODD
SP1	18	-32.5
SP2	2	-76
SP3	29	-53.5
SP4	-37	-195
SP5	16.25	43.5
SP6	-35	24
SP7	-6.25	28.5
SP8	-28.5	-40.5
SP9	-107	-352
SP10	11.75	-45
SP11	-55	-122
SP12	-29	-68.5

Key: VCODW: Variation of COD from the standard value in wet season; VCODD: Variation of COD from the standard value in the dry season.

E. Coli varied between 0 MPN/100ml and 20630 MPN/100ml. According to the RSB standard, surface water should not have *E.coli* more than 4 MPN/100ml. All sampled points had *E.coli* values far beyond the standard value in both rain and dry season. Dry season *E.coli* values increased remarkably at downstream sites (SP10, SP11 and SP12). This may be attributed to direct discharge of raw or partly untreated sewage from households or industries since they are close to the rivers. The rain season concentrations were very high and that can be related to recent increased run-off in the rain season from agricultural land with manure fertilizers; it can also be caused by leaking septic tank or inappropriate disposal of animal wastes in the urban areas. *E.coli* peaked at SP6 with 20630 MPN/100ml in the wet season. This site was located downstream of a livestock grazing land where livestock dung may be washed by rainfall; the site was also surrounded by scattered households without proper sewage disposal and human wastes were seen in most of the small routes heading to the sample points. This showed how open defecation around SP6 was prevalent. *E.coli* recorded values at SP9 and SP11 were also high during the wet season. These sites were located in the centre and downstream of Mahoko city respectively where the Sebeya River has been flooding washing all urban waste ranging from raw sewage to leaked waste from septic tanks. The increase in *E.coli* during the wet season showed diffuse pollution from runoff from the catchment and points to inadequacies in land management, poor sanitation and waste management in the catchment area. So intense rainfall, runoff and soil erosion carrying manure applied in agricultural lands led to the recorded elevated values of *E.coli*. It was found that untreated slurry and faeces of grazing animals can convey a variety of bacterial and protozoan pathogens (Hooda et al., 2000). Hooda et al. (2000) further discussed that faecal contamination has been reported in streams draining dairy farms, subsurface runoff from manure applied fields and surface runoff from grazed grasslands. The presence *E.coli* indicates fresh faecal contamination and may be indicators of disease causing organisms that cause diseases such as intestinal infections, dysentery, hepatitis, typhoid fever, cholera and other illnesses, thus making the water unfit for drinking (Pullanikkatil et al, 2015). As shown in Table 13 and Figure 12 below.

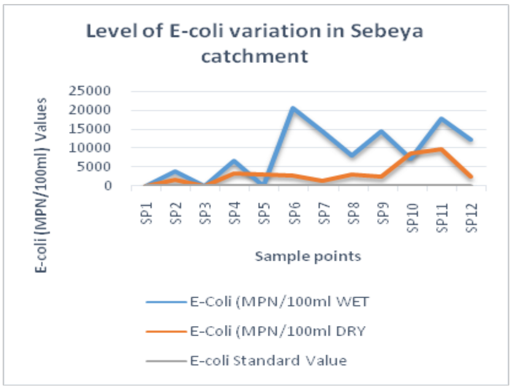

Figure 12: Variation of E-coli in the Sebeya catchment with respect to the standard value

Table 13: E-coli variation from the standard value

Sampled points	VELW	VELD
SP1	-18.2	-4
SP2	-3946	1728.8
SP3	4	-4
SP4	-6626	-3444
SP5	-355	-3146
SP6	-20626	-2814
SP7	-14426	-1549
SP8	-8126	-2996
SP9	-14446	2415.6
SP10	-7304	-8660
SP11	-17846	-9800
SP12	-12356	-2515.6

Key: VELW: Variation of *E-coli* from the standard value in wet season; VELD: Variation of *E-coli* from the standard value in the dry season.

Variation of the water quality parameters across season.

We conducted the principal component analysis (PCA) to identify the water quality parameters mostly associated with various land use area surrounding the Sebeya water catchment area. Each sample points have mixed land use characteristics as shown in

Table (1).

We consider the concentration of the water quality parameters across these sample points during the dry and wet season. This helps us understand the variability of these water quality parameters across the various sample points with respect to the two seasons (Dry & Wet). This was carried out to better assess the concentration of these water quality parameters across season with respect to sample points.

We also considered in the PCA seasonal variation of the parameters concentration across the sample points under consideration. The analysis was then classified into two major categories (Dry and Wet season).

Dry Season: During the dry season, the PCA successfully extracted three components which accounted for 75% total variation (Figure 13). Figure 13 shows the visual extraction of the components with their various Eigen values. Based on Eigen value of 1 and above, three components were extracted.

We subjected the components loading and parameters identification (in respect of most concentrated parameters at various land use) on land use on the first two (2) extracted components which accounted for 62% of the total variation. As shown in Figure 13 and Table 14.

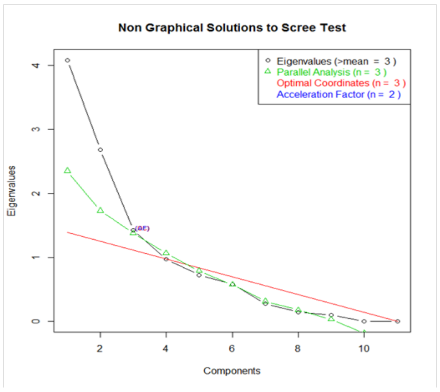

Figure 13: The visual component extraction

Basically, this led to the plot (Figure 13) which shows the visual concentration of the parameters across each sample points (land use area) around the Sebeya catchment. We however present the detailed loadings of each water quality parameters with respect to the first 6 components extracted. See Table 14 for the statistics.

Meanwhile, considering the visual plot (Figure 13), water quality parameters under concentration are found to be mostly concentrated at sample points 12,9, 4, 8, 10 and 11 (see Table (1) for land use characteristics) based on components 1 and 2 respectively.

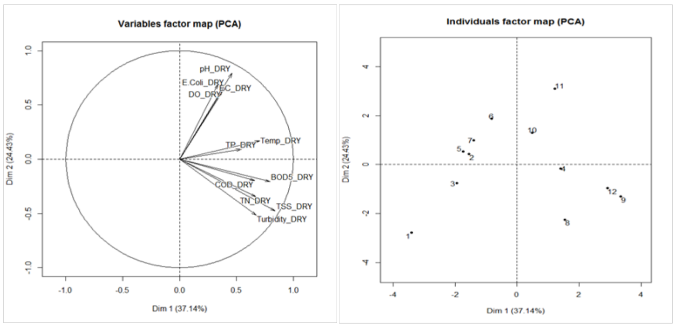

Figure 14: Concentration of water quality parameter based on the first two extracted components.

In order to measure the loading power (the percentage accounted for by each parameter to the components loading) of each water quality parameters, we consider Table 3.14. The most pronounced water quality parameters (using 30% and above) with respect to the first component are TSS, BOD, Temperature, Turbidity, TN, and COD respectively.

Table 15: Parameters loadings

Parameters	Comp 1	Comp 2	Comp 3
DO	0.1863	-0.3868	-0.1858
Temperature	0.3474	-0.1026	0.0276
Turbidity	0.3322	0.3155	-0.2846
pH	0.2275	-0.4831	-0.0351
EC	0.1671	-0.4218	0.1219
TSS	0.4144	0.2915	-0.0763
TN	0.3318	0.2114	-0.4895
TP	0.2682	-0.0555	0.5614
BOD^5	0.3931	0.1260	0.2562
COD	0.3265	0.1193	0.3582
E.coli	0.1993	-0.4077	-0.3363

Wet Season: During the wet season, the PCA successfully extracted three components which accounted for 83% total variation (Figure 14). Figure 14 shows the visual extraction of the components with their various Eigen values. Based on Eigen value of 1 and above, three components were extracted.

We subjected the components loading and parameters identification (in respect of most concentrated parameters at various land use) on land use on the first two (2) extracted components which accounted for 70% of the total variation. As shown in Figure 15 and Table 16.

Table 14: Important Components extracted

Loading	Comp 1	Comp 2	Comp 3	Comp 4	Comp 5	Comp 6
Eigenvalue	4.0859	2.6869	1.4250	0.9712	0.7251	0.5826
Standard deviation	2.0214	1.6392	1.1937	0.9855	0.8515	0.7633
Proportion of Variance	0.3714	0.2443	0.1295	0.0883	0.0659	0.0525
Cumulative Proportion	0.3714	0.6157	0.7452	0.8335	0.8995	0.9524

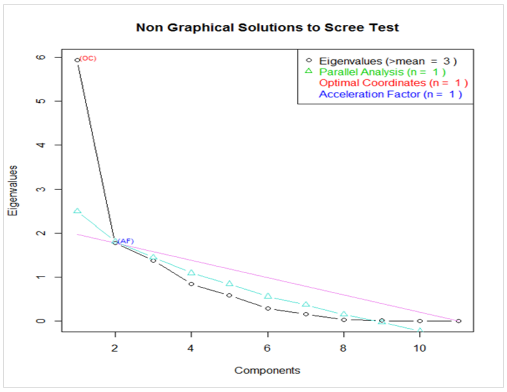

Figure 15: The visual component extraction

Basically, this led to the plot (Figure 14) which shows the visual concentration of the parameters across each sample points (land use area) around the Sebeya catchment. We however present the detailed loadings of each water quality parameters with respect to the first three (3) components extracted. See Table 3.16 for the statistics.

Meanwhile, considering the visual plot (Figure 15), water quality parameters under concentration are found to be mostly concentrated at sample points 11, 6, 12, 9, 8 and 4 (see Table (1) for land use characteristics) based on components 1 and 2 respectively.

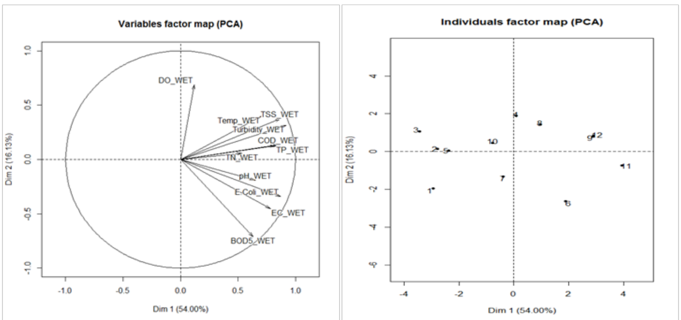

Figure 16: Concentration of water quality parameter based on the first two extracted components.

In order to measure the loading power (the percentage accounted for by each parameter to the components loading) of each water quality parameters, we consider Table 3.16 the most pronounced water quality parameters (using 30% and above) with respect to the first component are TSS, Turbidity, EC, TP, COD and E-coli respectively.

Table 17: Parameters loadings

Parameters	Comp 1	Comp 2	Comp 3
DO	0.0490	-0.5175	0.4194
Temperature	0.2874	-0.2991	0.2790
Turbidity	0.3759	0.2358	-0.1802
pH	0.2665	-0.1451	0.3449
EC	0.3199	-0.3408	0.1387
TSS	0.3549	0.2804	-0.1684
TN	0.2180	0.0434	-0.6839
TP	0.3366	-0.0960	-0.1812
BOD^5	0.2581	0.5342	0.0356
COD	0.3470	-0.1003	0.0517
E.coli	0.3557	0.2544	0.2066

As discussed, our result show that some of the water quality parameters occur in high concentration at the sample points 4, 6, 8, 9, 11 and 12 in both seasons. As shown, turbidity, temperature, TSS, TN, BOD^5 and COD are more pronounced at the identified sample points during the dry season. For example, high turbidity and TSS at S8 can be attributed to intense mining activities that occur upstream and use the Sebeya River for sieving minerals such as coltan. So low dilution of the Sebeya River in the dry season coupled with those unsustainable mining practices lead to high turbidity and sedimentation of the Sebeya River.

In Wet season, turbidity, EC, TSS, TP, COD and E-coli are more concentrated at the indicated sample points. This can be explained by increased soil erosion and agriculture runoff coupled with landslides which have been happening in the study area due to prolonged intense rainfall. Thus, turbidity, TSS, and COD concentration levels remain very significant at both seasons at the specified sample points.

Considering the characteristics or features of the land use area under which each of the identified sample points is taken, majority of the sample points constitute settlements, mining sites, forestry, croplands and tea plantation. See figure 17 below.

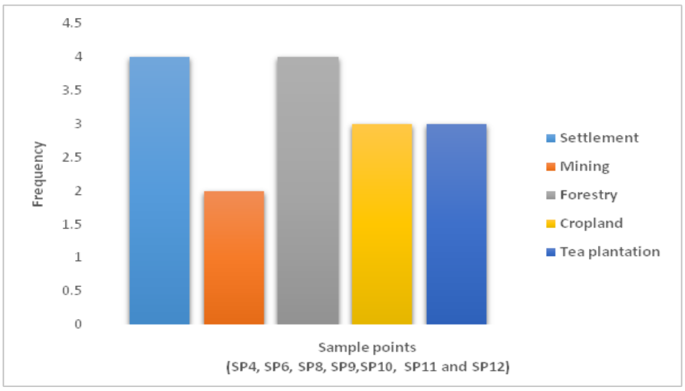

Figure 17: Visual Description of the relevant sample Locations across mixed land use types

Table 16: Important Components extracted

Loading	Comp 1	Comp 2	Comp 3	Comp 4	Comp 5	Comp 6
Eigenvalue	5.9402	1.7739	1.3739	0.8405	0.5809	0.2869
Standard deviation	2.4370	1.3319	1.1721	0.9168	0.7622	0.5356
Proportion of Variance	0.5400	0.1613	0.1249	0.0764	0.0528	0.0261
Cumulative Proportion	0.5400	0.7013	0.8262	0.9026	0.9554	0.9815

The result reveals that these water quality parameters (leading to higher water pollution) is majorly associated to land use area with human settlements and forestry. Our result corroborate literature reports which stated that, settlements land use area has poor waste management which result in direct discharge of sewage into the river; mining and deforestation activities being done in forestry area lead to high turbidity and sedimentation of the Sebeya river and its tributaries (W4GR, 2018). Our results also establish that, land use areas such as cropland and tea plantations also contribute significantly to high concentration of the identified water quality parameters (causing high water pollution).

Conclusion

This study examined the impacts of current land use on water quality of the Sebeya catchment area. This assessment was made possible through the collection and analysis of water quality samples from the Sebeya River and some of its tributaries during the wet and the dry seasons. Most of the water samples taken from the Sebeya River and its major tributaries had high concentrations of the measured parameters which exceeded standard values. Some parameters varied strongly from the standard value more in the wet season than in the dry season.

Most of the measured water quality parameters were concentrated on sample points that are in settled areas around the Sebeya catchment. Waste management, of both liquid and solid in the urban areas of the Sebeya catchment area and periodic water quality monitoring are recommended to assess the level of pollution. Furthermore, all users and relevant stakeholders should take an active role in the conservation of the Sebeya River and its major tributaries in order to reduce and avoid further degradation of the catchment through different land uses.

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