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Effects of Rainfall Variability on Water Quality of Yanze River in Kigali, Rwanda

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ABSTRACT

The effects of highly variable rainfall patterns on water quality of Yanze River in Kigali was investigated in this study. The study was divided into fieldwork and laboratory analysis where statistical analyses were used to establish the relationship between water quality and rainfall patterns. Anthropogenic activities along Yanze River were assessed by taking transect walks and conducting key informant interviews. Eight parameters were considered in this study and these include, turbidity, total suspended solids, conductivity, total dissolved solids, nitrate, phosphate, E-coli and total coliforms. This paper is focusing on the trend analysis of both rainfall and water quality of Yanze river for seven years (2012-2018). Trends of rainfall, water quantity and quality patterns of Yanze River were analysed using a non-parametric Mann–Kendall test and their relationship established using Pearson's Product Moment correlation coefficient. The Mann-Kendall statistical test showed that the characteristics of water quality, rainfall and water levels of Yanze River varied across the years from 2012 to 2018. In particular, the MK test indicated that all the weather stations in Yanze region had a negative trend ranging between -0.137 to -0.233 implying a decrease in rainfall over the period of study. The trend analysis of Yanze water level generally shows a positive trend of 0.187. The results show increased water levels ranging between 0.55m and 0.9m in all seasons. For the trend analysis of water quality of Yanze, all eight parameters that were considered in this study showed a positive and erratic trend except nitrate. The results by Mann Kendall test indicated that e-coli, total coliforms, turbidity and total suspended solids showed the highest positive trend of 0.520, 0.50, 0.47 and 0.40 respectively. The results also showed the pattern of erratic rainfall for the past 7 years, characterized by increase of rainfall in the years 2012 to 2013, 2015 to 2016 and 2017 to 2018 and a decrease of rainfall from the year 2014 to 2015 and 2017 and the observed changes were affecting the water quality of Yanze River in the corresponding years. Correlation analysis using Pearson Product Moment between water quality and rainfall ranged from -0.10 to 0.47 while their coefficient of determination r2 varied between 0.04 % and 22.39%. It was noted that precipitation had an influence on the increase in concentration of water quality parameters especially turbidity, total suspended solids, total dissolved solids and electric conductivity. The r2 values in this study were low, which indicated that there could be other factors that could be contributing to the degradation of Yanze water quality such as land use and land cover, topography of the area as well as high population density coupled with poor human settlement.

1. Introduction

Rwanda is a developing country in East Africa that is still convalescing from the 1994 genocide whereby about 800,000 people were killed. That tragic period affected almost all sectors in Rwanda and hindered the adaptive capacity of the society. Water sector in Rwanda was among the most affected sector as a number of water experts and professionals were killed or displaced, infrastructure was destroyed which compromised water sanitation hence affecting people's health in general (Vadi Moodley, 2010) .

Rwanda's total land area is 26.338 square kilometres with a population of 12,521,489 giving a population density of 507 per Km2 (NISR, 2007). The increase rate of the population is 2.40% which has been found to contribute to high internal migration from rural to urban areas at a rate of 4.2% resulting in high water demand.

Yanze River is one amongst the tributaries of Nyabugogo River, which provides important functions, the main one being the fact that it is the major intake for the supply of 80% of domestic water in Kigali City at the Kimisagara Water Treatment plant. Yanze River provides water for irrigation and domestic consumption and the activities around Yanze river include agriculture and forestry. Despite the rehabilitation activities and daily monitoring of Yanze River, the latter is still facing serious degradation both natural and human-induced.

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Yanze river like many other water bodies on this planet is facing universal changes in the quality of water and it is highly attributed to the lack of control measures for soil erosion on the hillsides, lack of buffer zones, poor human settlement, meticulous use of chemical fertilizers and pesticides, high population density that cause high dependency on agriculture and deforestation (MINIRENA/ RNRA, 2012).

The decline in water resources quality is caused by the aforementioned factors but also climate change is increasingly contributing and in Rwanda it is anticipated to augment temperature and precipitation fluctuations causing flooding in some areas and drought in others. Erratic climate events, mostly heavy rains, highly affect the quality of water bodies (lakes and rivers). Yanze River supplies water to a number of people living in Kigali, and those changes in climatic conditions and climate variability will affect the efficient treatment and also human health via indirect pathways, particularly via changes of parameters values that influence infectious disease transmission mainly water borne diseases (FONERWA, 2015).

Studies conducted in Nyabugogo Catchment by Uwonkunda in 2011 on the Assessment of Water Pollution Levels in the Nyabugogo Catchment, reported that the Yanze River has high levels of flooding, erosion, sedimentation and a high level of turbidity which reduces the biodiversity within the river and causes health problem to people consuming the water. This has been highlighted by the daily monitoring records by Rwanda Water Sanitation Corporation.

Intervention measures are being taken to enhance the monitoring of Yanze river's water and most of them are aiming to protect uphill of Yanze catchment by reducing the sediments in the river and enhance a better livelihood of communities in the watershed through participatory implementation approach of agroforestry technologies coupled with daily monitoring of water quality profile of the river for its sustainable use and management.

The aim of this study was to investigate the effects of erratic rainfall patterns on water quality of Yanze River, Rwanda by carrying out a broad statistical analysis for detecting the trends in water quality parameters (turbidity, total suspended solids, total dissolved solids, electric conductivity, e-coli, total coliforms, nitrate and phosphate), precipitation and water levels for a period of 7 years (2012-2018).

To test a range of hypotheses regarding the statistical properties of the time-series, Mann–Kendall test, a non-parametric statistical technique, was employed which is particularly useful for discovering the trends in time series data to determine statistically whether the values of a random variable are decreasing or increasing over some period of time.

Materials and methods

2.1 Study area

The Yanze sub-catchment is located primarily in Rulindo District, Northern Province, with a smaller part located in the Nyarugenge and Gasabo District of the City of Kigali. The Yanze watershed is composed of three main sub-watersheds namely Cyonyonyo and Mulindi in Northern part and Yanze downstream in the southern part. The Yanze River provides up to 30% of water requirements for Kigali through the Kimisagara Water Treatment Plant with a daily production of 29,000 cubic meters of water.

The Yanze watershed is highly prone to soil erosion. The potential sources of sediments in the Yanze River include erosion of poorly managed steep slope soil, poor vegetated and/or disturbed areas. These sediments increase the turbidity and reduce the quality of water reaching Kimisagara water treatment plant during the rainy season. Given the strategic importance of Yanze River for water supply to the City of Kigali, the Government of Rwanda and its partners have invested resources in landscape rehabilitation and protection of the Yanze River. Such interventions have helped to control soil erosion through the establishment of radical and progressive terraces, rehabilitation of river banks, and their watersheds (Fonerwa, 2015). Figure 1 shows the location of Yanze River catchment (Latitude: -1°53'48.48", Longitude: 30°0'45")

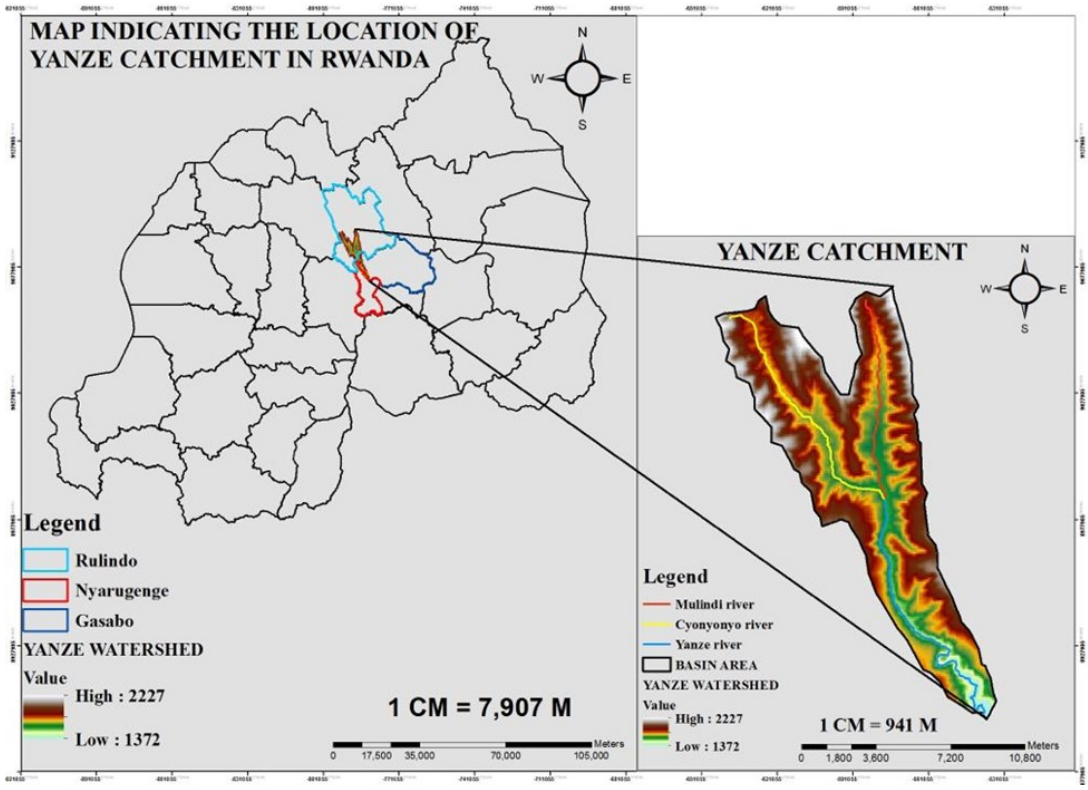

Figure 1: Yanze Catchment (Urinayo, 2019)

2.2. Data and Materials

Water quality, rainfall and water levels data of Yanze River for the period of 2012–2018 was acquired and analysed. Rainfall data for 7 years were obtained from the Rwanda Meteorological Department in Yanze Region which is made of 3 districts namely; Rulindo, Gasabo and Nyarugenge to represent the entire climatic zone of Yanze River which consists of 7 stations namely: Jali, Kanyinya, Kinzuzi, Mbogo, Ngoma, Rusiza and Shyorongi. The rainfall data were obtained using satellite estimates; TAMSAT (Tropical Application of Meteorology Using Satellite Data and Ground -Based Observations) merged with ground observed rainfall data for already existing stations in Yanze region.

The water quality data of Yanze River were collected from Water and Sanitation Corporation (WASAC) ltd from 2012 to 2018 excluding 2014. Due to lack of computerized data for the years before 2012 at the treatment plant, some data manually recorded on papers were lost. The parameters that were considered for time series analysis of water quality data of Yanze River were: turbidity, nitrate, and phosphate, total suspended solids, total dissolved solids, electric conductivity, electric conductivity, E-coli and total coli forms.

The water levels data of Yanze River for the years 2012, 2013 and 2016 were obtained from the former Ministry of natural resources which is now the department of water in the Ministry of Environment. The gaps found in the data were mostly attributed to lack of efficient system of paying and monitoring the field employees in charge of water levels recording in the country.

2.3. Methodology

Trends in time-series data of selected variables were evaluated using the Mann–Kendall test in order to test whether there has been improvement for the variables of concern within the last seven years in order to investigate whether the trend in water quality, water levels and rainfall data of Yanze River increases or decreases.

After the trend analysis of rainfall, water levels and water quality of Yanze River using Mann-Kendall test, and in order to investigate the associations between all the three parameters, Pearson's Product Moment correlation coefficient was used and the results showed that between the years 2012 to 2018 the water quality of Yanze River has undergone an enormous changes especially in rainy seasons.

To investigate the effect of erratic rainfall on water quality, quantitative models describing the dependence of water quality concentrations on precipitation were developed using regression analysis and the coefficient of determination (R2) was observed. The model was developed using historical data assuming the dependence of water quality on precipitation.

2.3.1 Mann-Kendall trend test

In order to detect the trends in turbidity, total suspended solids, conductivity, total dissolved solids, e-coli, total coliforms, nitrate and phosphate, precipitation and water levels; Mann–Kendall test was applied. The null hypothesis for the Mann–Kendall test is that there is no change in the probability distribution of a random variable with time. The test assumes that the random variables are independent and their values are from the same type of statistical distribution (normal, lognormal, etc.).

Mann-Kendall is a mathematical procedure for investigating whether the trend in data increases or decreases in a monotonic fashion. Mann- Kendall test was deployed to explore the general non repeated (trend) temporal pattern in the data. The technique involves computing a statistic that represents the slope (the Sen's Slope).

$$S = \sum_{k-1}^{n-1} \sum_{j-k+1}^{n} sgn(x_j - x_k) \quad (1)$$

Where the quantity given by is a mathematical function that operates on the series (x's) at time steps k, j and determines whether the value at time step ahead is higher than the preceding one, to output a unit (+1) , else if the difference is zero the output is zero, else if difference is negative, the output is negative one (-1). Recall that j and k are indices that represent different observation times with k being a step ahead; summation of the differences gives the S statistic whose significance can be checked in the S-table (Epa, 2009) whenever the data sample is less than 10. Whenever, the sample is greater than 10, the variance of the S is computed and a Z-statistic is hence computed whose significance is then checked for an increasing trend with time and vice versa. Significance was checked by testing the null hypothesis that there is no monotonic trend against the alternative hypothesis and that the upward/downward monotonic trend exists at type 1 error risk (alpha). The risk (alpha) was considered tolerable whenever it was less than the standard 0.5 significance level (risk of rejecting the null hypothesis falsely) (Higgins, 2005).

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} if S > 0 \quad (2)$$

$$0 if S = 0 \quad (3)$$

$$\frac{S+1}{\sqrt{VAR(S)}} if S < 0 \quad (4)$$

2.3.2 Correlation analysis

Analysis of the associations between water quality parameters, precipitation and water levels was done by correlation analysis where Pearson Product Moment correlation coefficient (Pohlert, 2016), (Higgins, 2005) was used. The coefficient ranges from -1 to 1 through 0 and it quantifies the strength and direction of linear relationships and it is given by

$$r = \frac{Cov(x,y)}{\sqrt{s_x^2 \times s_y^2}} \quad (5)$$

$$Cov(x,y) = \frac{\Sigma(X - \acute{X})(Y - \acute{Y})}{n-1} \quad (6)$$

$$s_x^2 = \frac{\Sigma(Xi - \acute{X})^2}{n-1}, s_y^2 = \frac{\Sigma(Yi - \acute{Y})^2}{n-1} \quad (7)$$

2.3.3 Regression analysis

The general linear regression equation is given as,

$$Y_i = \beta_0 + \beta_1 x_i + \varepsilon_i, i = 1, \ldots, n \quad (8)$$

In the above equation, β_o is the y-intercept, while coefficient β_1 represents slope of the line and indicates the error in the model. By definition, the error is given by the difference between the observation and estimated value by the model

$$\varepsilon_i = y_i - \hat{y}_i \quad (9)$$

In representing the goodness of fit for a regression equation, we used the R-square (R2). The technique also known as the coefficient of determination quantifies the variance explained; the proportion of the dependent variable that is explained by the independent series, and it is given by

$$r^2 = 1 - \frac{SS_{res}}{SS_{total}} \quad (10)$$

Where the quantity SS_{res}/SS_{total} represents the proportion unexplained (that is proportion of residues) and the terms sum of squares of residues SS_{res} and total sum of squares of the data SS_{total} are given by

$$SS_{total} = \sum_i (Y_i - \hat{y}_i) \ and \ SS_{res} = \sum_i \varepsilon_i^2 \quad (11)$$

3. Results and Discussions

3.1 Results from Trend analysis of rainfall of Yanze River region (2012-2018)

After the requisition of rainfall data, trend analysis was done using nonparametric Mann Kendall and the results are described in table 1 and figure 2. Seven years (2012-2018) of monthly rainfall data was analyzed using Mann-Kendall test and Sen's slope estimation methods. The analysis has been done by the use of XLSTAT 2017 software and the results are shown in the table 1 and figure 1.

Table1 shows the Sen's slope estimation factor and Kendall test statistics (Zc) (see equation 2) for the study period whereby all the months for the 7 years were constantly decreasing, generally showing a negative trend in all stations which are indicated by the negative sign.

Figure 2 shows the variation in Zc values for the seven stations namely: Jali, Kanyinya, Kinzuzi, Mbogo, Ngoma, Rusiza and Shyorongi found in Yanze region. All the stations show a negative trend in which the highest negative trend was observed in Rusiza region which is -0.233 and the lowest negative trend (-0.137) is shown in Ngoma station.

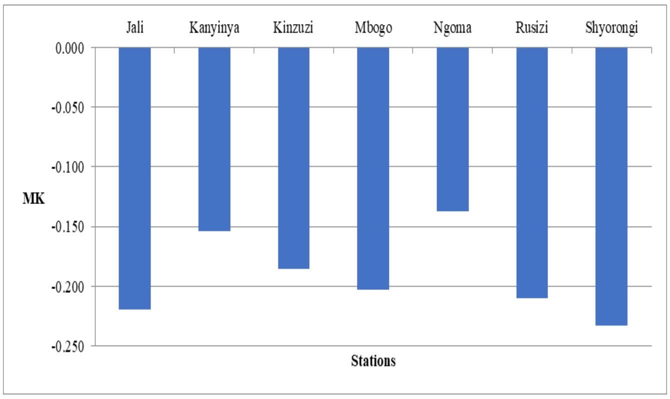

Figure 2: Mann Kendal trend results of rainfall from seven stations in Yanze region 2012-2018

Table 1: Mann Kendall test for trend analysis of rainfall in Yanze catchment (2012-2018)

Stations	Jali	Kanyinya	Kinzuzi	Mbogo	Ngoma	Rusizi	Shyorongi
MK	-0.220	-0.154	-0.185	-0.202	-0.137	-0.210	-0.233
p-value (Two tailed)	0.005	0.048	0.017	0.009	0.079	0.007	0.003

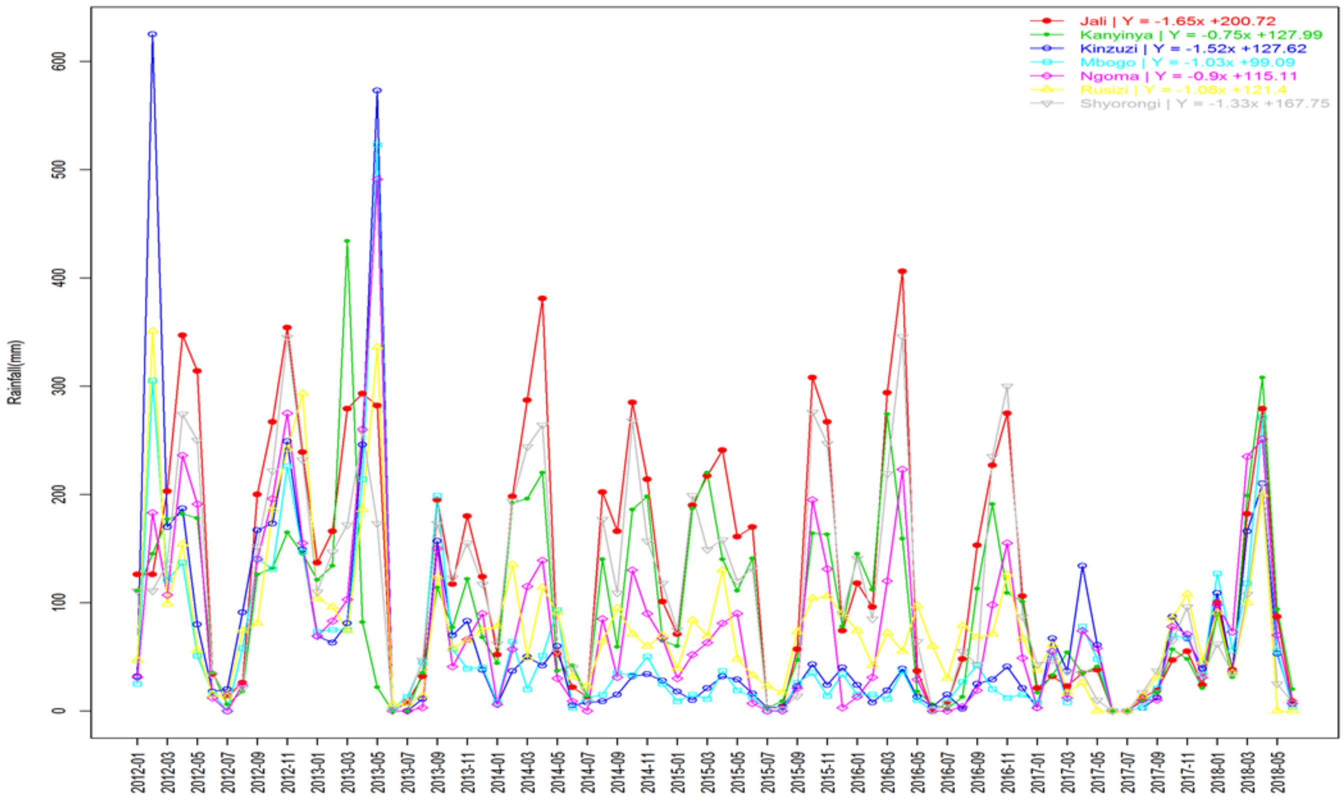

Figure 3: Average monthly rainfall from seven stations in Yanze region from 2012 to 2018

Figure 3 shows monthly total rainfall variation from 2012 to 2018. It is observed that the maximum rainfall in all stations in Yanze region occurred in 2012 and minimum rainfall occurred in 2015. The figure portrays a significant decrease in rainfall in Yanze region. Similar results were obtained by (Rwanyirizi, 2014) who reported that since 1992, the total annual rainfall has significantly changed and more unpredictable patterns of precipitation increased. The negative values of the slopes in all equations indicate negative trend. The amount of rainfall is generally decreasing and between 2012 and 2018 there was extremely high variability. The years 2011 to 2013, 2016 and 2018 show increasing trend while the years 2014 - 2015 and 2017 show decreasing trend. Yanze catchment has been prone to heavy floods and the former may be explained by increase in urbanization which results in increase of areas of impermeable soil (Munyaneza et al., 2015). With impermeable surfaces, there is a reduction in water infiltration thus causing high surface runoffs.

Figure 2 describes a decrease in the amount of rainfall in Yanze region from 2012-2018 while figure 3 details the state of rainfall variability during that period. This is characterized by rainfall increase in the years 2012 to 2013, 2015 to 2016 and 2017 to 2018 and a decrease in rainfall in the years 2014-2015 and 2017.

3.2 Results from Trend analysis of water level of Yanze

Monthly data for water levels of Yanze River between 2012 and 2016 were obtained from Ministry of environment, department of water. The trend analysis of water level was done using non- parametric Mann Kendall test and the results are described figure 4.

Water level of Yanze River from 2012 to 2018 was also analyzed using Mann-Kendall test and Sen's slope estimation methods. The analysis was done by the use of XLSTAT 2017 software. The Sen's slope estimation factor and Kendall test statistics (Zc) for the water levels historical data of Yanze River were done for the years 2012, 2013 and 2016 only due to missing data for the rest of the years. Monthly data of water levels of Yanze for the years 2012, 2013 and 2016 generally showed a positive trend which is 0.187 though not significant p = 0.112 (p>0.05). The Sen's slope estimation factor was found to be 118.00.

Analysis of the daily rainfall throughout the Yanze catchment as shown in figure 3 reveals strong daily variation for the 7 years of study from 2012 to 2018. Water levels in the Yanze River (figure 4) shows a peak in the late spring/early summer of both years that corresponds to the short and long rain seasons in the years 2012, 2013 and 2016 as well as a number of other peaks that typically follow precipitation events.

Figure 4 shows increased water levels ranging (0.55m - 0.75m) for the months of March, April and May and (0.62m - 0.9m) for the months September, October and November in the year 2012 which correspond to the expected precipitation for the long rainy season (MAM) and short rainy season (SON) respectively. For the year 2013, increased water levels were experienced in the month of January, February and March ranging (0.6m - 0.8m) attributed to long rainy season. Water levels in the short rainy season was reported to be in the range of 0.65m - 0.70m in the months of September, October, November and December (SOND). In the year 2016, there was increased water levels ranging (0.65m - 0.85m) for the months of February, March April and (0.57m-0.74m) for the months of September, October and November associated with the long and short rainy seasons, respectively.

The highest levels of water for Yanze River were reported in the month of November in 2012 and the month of April in 2016. This highly correlates with trends of rainfall in the years 2012 and 2016 which show an increased amount of precipitation in Yanze.

3.3 Results of Trend analysis of water quality data of Yanze River from 2012-2018

Water quality data of Yanze River for 7 years were obtained from WASAC (Rwanda water sanitation and corporation). Statistical analysis was performed considering eight (8) parameters namely: turbidity, total suspended solids, total dissolved solids, conductivity, nitrate, phosphate, e-coli and total coliforms. After the data pre-processing, Mann-Kendall trend test was used to detect the trends of water quality data of Yanze River and the results are shown in the table 2 and figure 5.

Trends for water quality data of Yanze River from 2012 to 2018 were analyzed using Mann-Kendall test and Sen's slope estimation methods. The analysis was done using XLSTAT 2017 software.

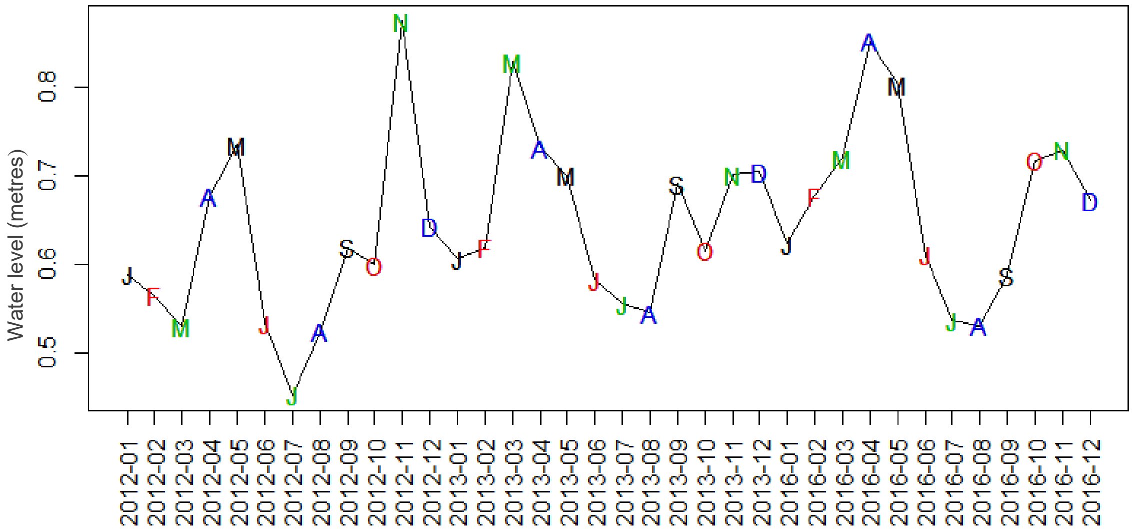

Figure 3: Monthly average water levels of Yanze River for the years 2012, 2013 and 2016

Table 2: Mann Kendall test for the trend analysis of Yanze water quality 2012-2018

	Turbidity	TSS	TDS	Conductivity	Nitrate	Phosphate	E-coli	Total coliforms
Kendall's tau	0.182	0.157	0.107	0.107	-0.278	0.246	0.491	0.386
p-value (2-tailed)	0.024	0.043	0.032	0.029	0.001	0.002	< 0.0001	< 0.0001

Table 2 shows the Sen's slope estimation factor and Kendall test statistics (Zc) for the study period whereby eight parameters considered for this study are turbidity, nitrate, phosphate, and temperature, total suspended solids, total dissolved solids, dissolved oxygen, electric conductivity, E-coli and total coli forms. Monthly data of water quality of Yanze for the 7 years generally shows a significant positive trend ($P<0.05$) for all parameters except nitrate which shows a negative trend.

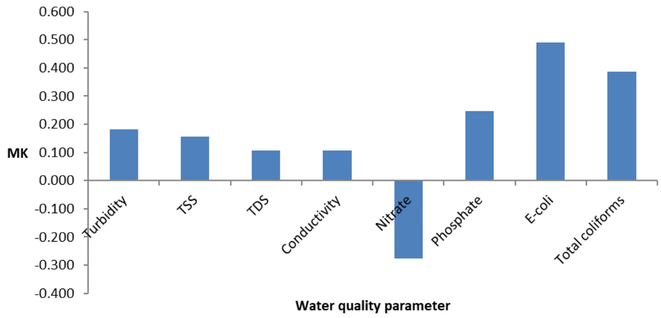

Figure 5: Mann Kendall trend results of water quality parameters from 2012 to 2018

Figure 5 shows the variation in Zc values for different parameters of water. All the eight parameters that were considered for this study, seven of them namely total suspended solids, total dissolved solids, total coliforms, turbidity, conductivity, nitrate, phosphate showed a positive trend except nitrate which shows a negative trend. In figure 5 above, e-coli shows the highest positive trend which is 0.520 and nitrate shows the highest and only negative trend of -0.300.

Figure 5 also shows that e-coli levels are higher compared to the rest of parameters followed by total coliforms levels and this may be attributed to open defecation and poor waste disposal system in the highly populated area of Yanze catchment known as Gatsata. Turbidity and total suspended solids patterns show a positive trend which may be associated with the fact that Yanze sub catchment consists of poor urban settlement coupled with its sloppy topography making it prone to erosion. TDS and conductivity patterns show a positive trend and it is safe to say that TDS is clearly linked to the electric conductivity of water, the higher the TDS the higher the conductivity which increases as water dissolved ionic species. Nitrate pattern is generally decreasing which is maybe attributed to a reduced use of chemicals fertilizers in the area. The patterns for all parameters are shown in figure 6.

Eight parameters were considered to describe the patterns in the trend of water quality. Those parameters were: turbidity, total suspended solids, total dissolved solids, electric conductivity, nitrate, phosphate, e-coli and total coliforms. The figure 5 shows a positive trend in all water quality parameters considered in this study except nitrate from 2012 to 2018 in general. This trend was characterised by erratic patterns more specifically in the end of the years 2013, 2015 and the beginning of the year 2018; see figure 6 and this highly correlates with the increase in rainfall in Yanze catchment in the years 2013, 2015 and 2018 which indicates that the increase of runoffs in the catchment washed all the surface material to the river.

3.4 Time series of water quality, rainfall and water levels of Yanze River

In a hydrological cycle, when the precipitation increases, it results in accumulation of rainfall in rivers and increases of precipitation increases surface runoffs which wash all the surface materials and deposit them in the river resulting to the degradation of water quality of the river. Yanze River supplies water to the largest part of Kigali through Kimisagara water treatment plant and during the rains seasons sometimes the plant is shut down due to high level of turbidity associated with increased concentrations of sediments and suspended solids washed in the river.

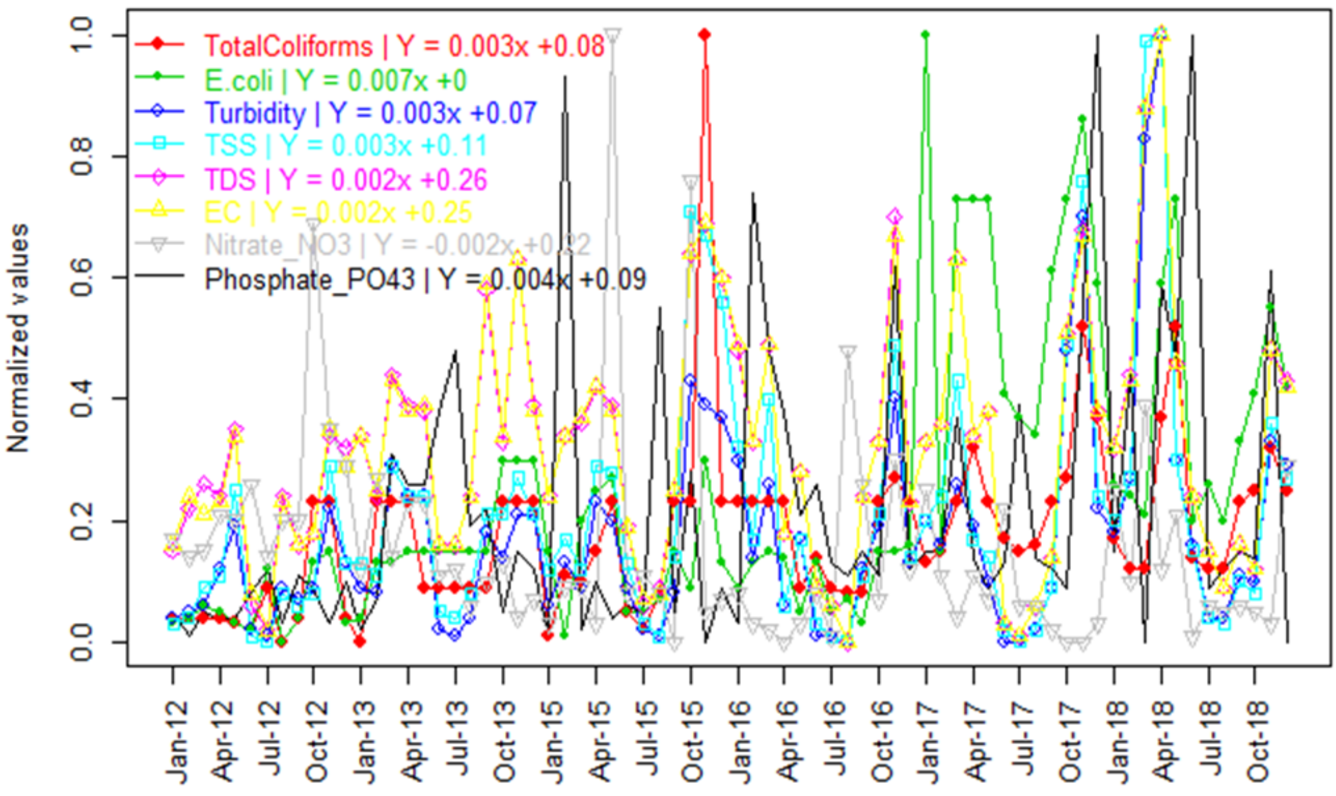

Figure 6: Monthly average of water quality parameters of Yanze river from 2012 to 2018

Figures 7 and figure 8 show the uniformity of rainfall, water levels and water quality patterns of Yanze River for the years 2012, 2013 and 2016 which means the increase of precipitation were also attributing to high levels of water and this also affect the water quality of Yanze and vice versa.

The figures 7 and 8 show a statistical three-year trend analysis that describe the variability of rainfall, water quality and water levels of Yanze River. The water quality parameters which were considered in this study are turbidity, total suspended solids, total dissolved solids, electric conductivity, nitrate, phosphate, e-coli and total coliforms and the figures 7 and 8 above provides a visualization of the patterns of the aforementioned factors for the years 2012, 2013 and 2016. In addition, as shown in the table 3, a positive correlation (correlation coefficient ranging between 0.02 and 0.47) for all parameters except nitrate which showed a negative correlation of -0.10 was observed between the daily precipitation and water quality of Yanze River.

Briefly, the figures 7 and 8 illustrate that the patterns for water quality parameters change with the change in precipitation and water levels where by the increased levels in concentration of turbidity, total suspended solids, total dissolved solids, electric conductivity, nitrate, phosphate, e-coli and total coliforms increases with the increase of precipitation amount mostly in both short and long rainy seasons for the years 2012, 2013 and 2016.

3.5 Results from Correlation analysis between Rainfall, water level and water quality of Yanze River (2012-2018)

Assessment of associations between different variables was achieved by correlation analysis where Pearson Product Moment correlation coefficient (Pohlert, 2016), (Higgins, 2005) was used. The coefficient ranges from -1 to 1 through 0 and it quantifies the strength and direction of linear relationships. The sign of the correlation coefficient indicates the direction of the association. The magnitude of the correlation coefficient indicates the strength of the association.

The correlation analysis in this study considered only three variables namely precipitation, water level and water quality parameters (turbidity, TSS, TDS, ED, nitrate, phosphate, e-coli and total coliforms). The matrix below shows the value of the correlation plus the significance level as asterisk. Each significance level is associated with a symbol: p values (0, 0.001, 0.01, 0.05, 0.1, 1) which correspond to ("***", "**", "*", ".", "") respectively.

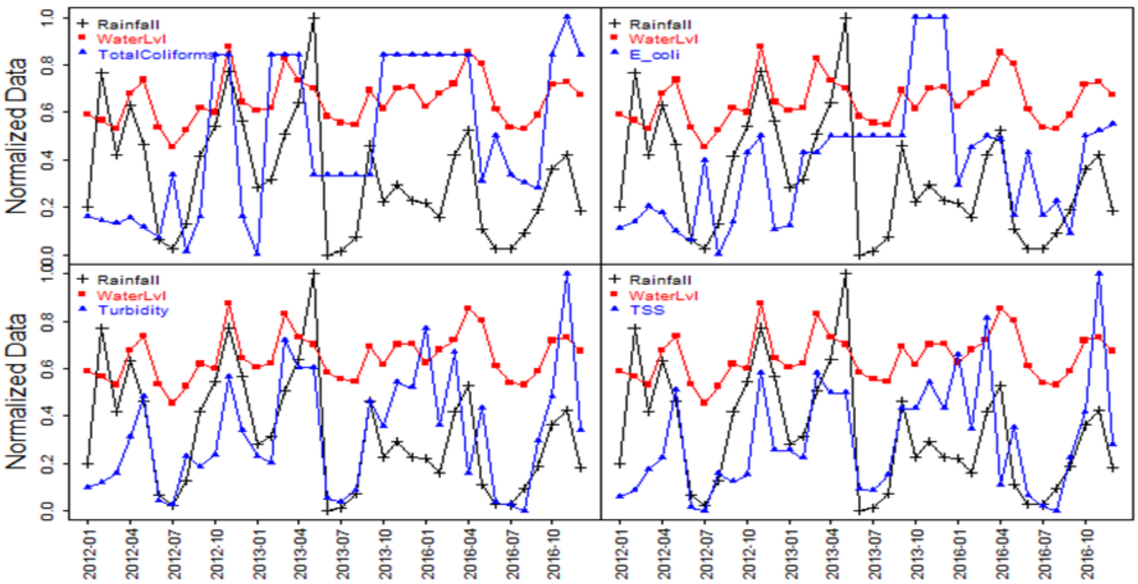

Figure 7: Trends of water quality parameters (Turbidity, TSS, e-coli and total coliforms) with rainfall and water levels 2012-2018

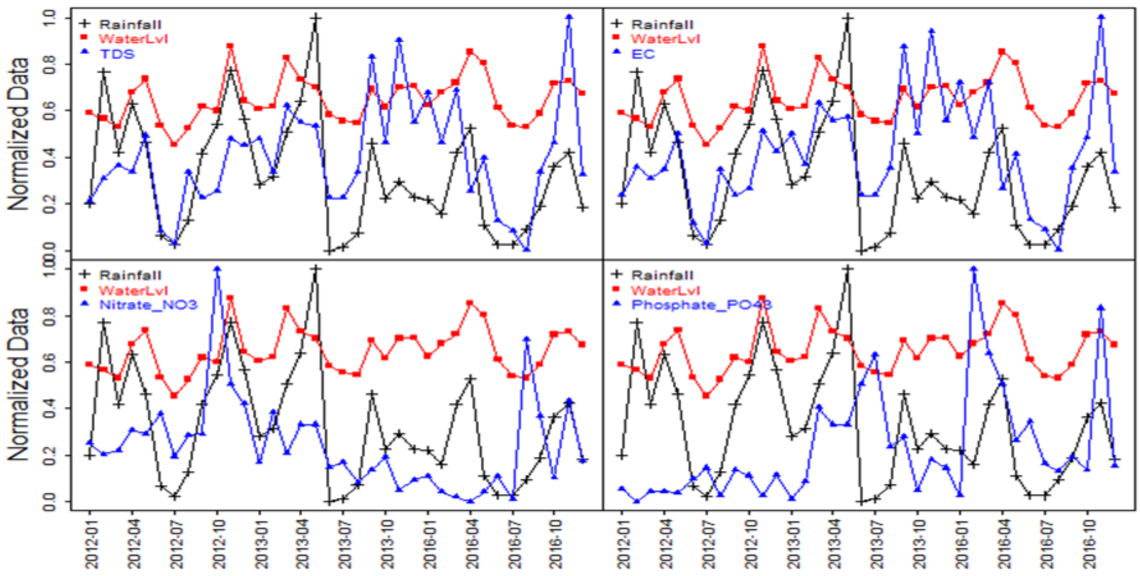

Figure 8: Patterns of water quality parameters (TDS, conductivity, nitrate and phosphate) with rainfall and water levels for the years 2012, 2013 and 2016.

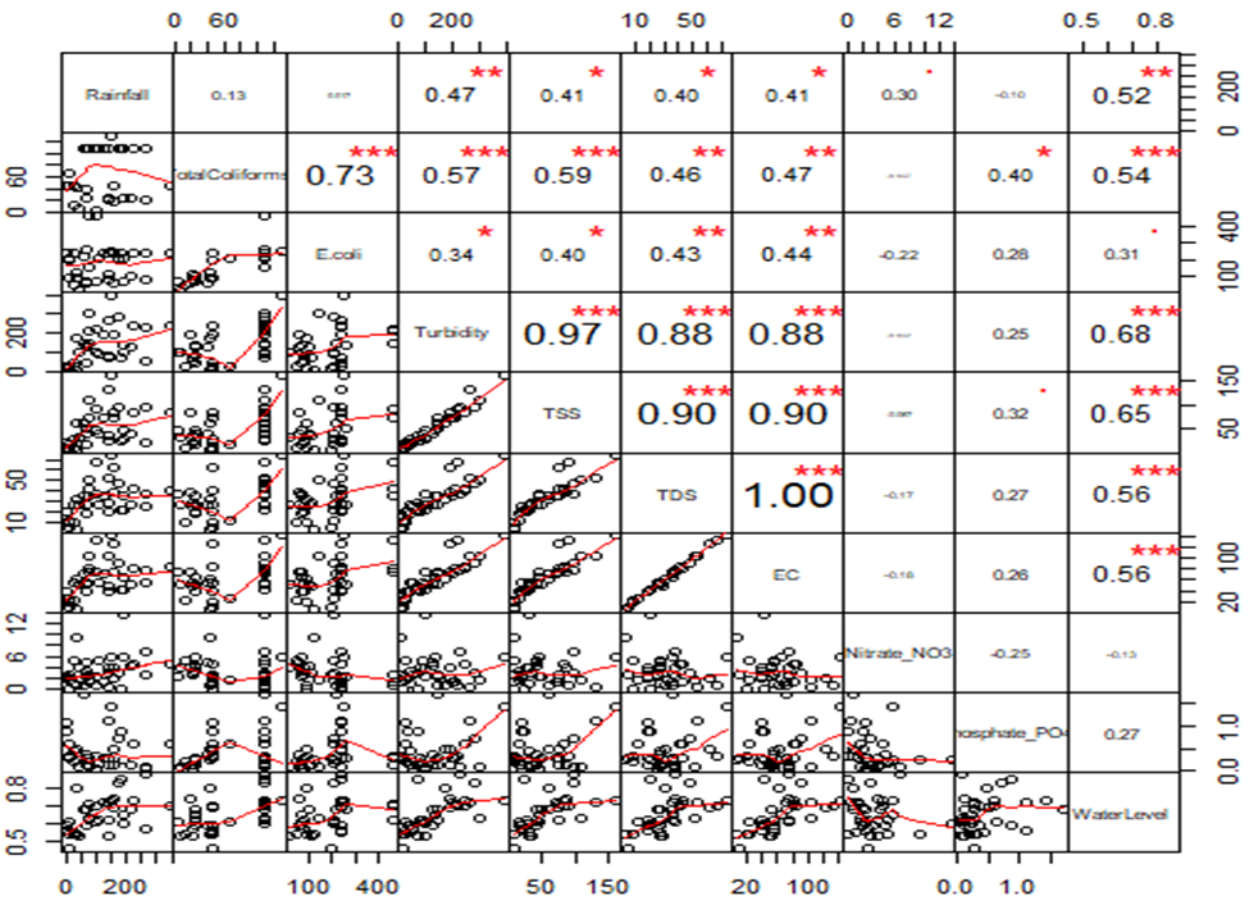

Figure 9: Correlation in trends of rainfall, water quality and water levels of Yanze River (2012-2018)

Figure 9 shows positive correlation of 0.52 between rainfall and water levels of Yanze River. Figure 9 also shows the correlation of the water levels and water quality parameters which ranged between -0.3 to 0.68. Turbidity showed the highest correlation with water level of 0.68 and nitrate showed the lowest correlation of -0.13. Also, figure 9 demonstrates the correlation between water quality parameters and rainfall which was found to be ranging between -0.10 and 0.47. Turbidity shows the highest correlation with rainfall of 0.47 and phosphate shows the lowest correlation with rainfall of -0.10. Turbidity, total suspended solids, total dissolved solids and conductivity are shown to be highly correlated with rainfall which is highly associated with the deposition of solids materials and water waste to the river by surface runoffs when it rains, and in figures 7 and 8, the levels of concentration of those water physical properties were found to increase with the increase of the amount of rainfall.

In the case of nutrient parameters NO3- showed weak positive correlations of 0.30 and PO43−showed a negative correlation of -0.10 with precipitation. Alexander et al. (1996) suggested that nutrient loadings in water bodies especially rivers would vary primarily with stream flow volume. These weak positive and negative correlations of nitrate and phosphate respectively with rainfall may be highly attributed to a reduced use of chemical fertilizers for agricultural activities in Yanze catchment.

And last but not least are biological parameters, as detailed in table 3, e-coli and total coliforms correlations with precipitation is found to be 0.02 and 0.13 respectively which indicate that the change in precipitation does not have too much influence on the presence or absence of both biological parameters. The presence on the aforementioned parameters in the river Yanze is highly attributed to open defecation which is prevalent in that area and also poor waste disposal system in Gatsata the most populated area in Yanze catchment.

3.6 Quantification of association between rainfall, water quality and water levels of Yanze River (2012 - 2018)

The conventional correlation analysis was adopted to investigate the associations between water levels and precipitation and between water quality and precipitation of Yanze River. The exploration of their associations in historical observations would help in identifying whether precipitation is an appropriate explanatory variable to predict Yanze water quality and subsequently to project it under a changing climate. Table 3 shows the Correlation coefficients (r) and the coefficient of determination (R2) of water quality concentrations and water levels of Yanze River for a study period of 7 years (2012-2018).

Table 3: Correlation of Rainfall with water quality and water level of Yanze River

	TC	E-coli	Turbidity	TSS	TDS	EC	Nitrate	Phosphate	Water Level
R	0.13	0.02	0.47	0.41	0.40	0.41	0.30	-0.10	0.52
R-square	0.02	0.0004	0.2239	0.1652	0.1624	0.1643	0.0897	0.0105	0.2749
% R-square	2	0.04	22.39	16.52	16.24	16.43	8.97	1.05	27.49

To investigate the erratic rainfall impact on water quality, quantitative models describing the dependence of water quality concentrations on precipitation were developed using regression analysis to produce coefficient of determination (R2). Results in table 3 reveal the correlations of rainfall, water levels and water quality parameters of the River Yanze: turbidity, total suspended solids, total dissolved solids, electric conductivity, nitrate, phosphate, e-coli and total coliforms. Precipitation had a fair positive correlation with mean water level 0.52 (see table 3). Changes in precipitation have very important influence accounting for 27.49% of variations in water levels of Yanze River.

Table 3 is also showing the correlation of rainfall with water quality parameters. Eight parameters considered for this study namely total coliforms, e-coli, turbidity, total suspended solids, total dissolved solids, electric conductivity, phosphate and nitrate show a fair correlation ranging between -0.10 and 0.47 and their coefficient of determination (R2) vary between 0.04 % to 2.30% which indicate that the precipitation has an influence on increase in concentration of water quality parameters especially turbidity, total suspended solids, total dissolved solids and electric conductivity. The R squared values in this study are low which indicate there is the attribution of other factors which contribute to the degradation of Yanze water quality such as land use and land cover, topography of the area as well as high population density coupled with poor human settlement.

Conclusion

The prevalent anthropogenic activity at Yanze River catchment is agriculture which occupies 65 % of its riparian. The impact of this activity on the catchment was found to contribute about 70% of degradation of the water quality. Mann-Kendall statistical test for 2012 to 2018 showed that all the rainfall stations in Yanze catchment had a negative trend ranging between -0.137 and -0.233. The rainfall trends were characterized by an erratic pattern over the years with a 39% decrease in the amount of rainfall. The analysis of water quality parameters showed a positive trend ranging between -0.25 to 0.52. The water quality trends in Yanze were also characterized by an erratic pattern over the years with a 32.5% increase in concentration of water quality parameters which get worse when the amount of rainfall is increased and vice versa. A positive correlation ranging from -0.10 to 0.47 was obtained and the coefficient of determination r2 varied between 0.04 % to 22.39% which indicate that the precipitation influences increase in concentration and value of water quality parameters especially, total suspended solids, total dissolved solids turbidity and electric conductivity.

The study showed that there is a relationship between the water quality degradation of Yanze River and rainfall pattern. However, the rainfall pattern over 2012-2018 was found to be erratic; hence the water quality over the same period was therefore erratic. Therefore, there is a need of efficient measures to deal with the impact of erratic rainfall related challenges in Yanze catchment. The solutions suggested by key informants include the enhancement of climate change and variability awareness, trainings on waste management as well as land conservation as pointed out by 40% environmental officers. Forty five percent of environmental officers interviewed suggested inclusion of hill side rehabilitation, buffer zone protection, terracing and construction of sewer lines with other waste disposal system. Local leaders proposed the training of environmental experts to monitor rehabilitation projects that are currently being implemented for the purpose of evaluating their effectiveness and impacts.

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