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Assessment of seasonal variation in Physico-chemical water quality of river Athi basin, Kenya

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Abstract

This study assessed seasonal variations in physicochemical water quality of the Athi river basin, Kenya. Water quality data was collected for eight months, covering dry and rainy seasons. The study used ten physicochemical parameters (pH, EC, TDS, NO_3, K, PO_4, BOD, COD, Cd and Cr) to determine the seasonal water quality for Athi River. Independent T test was used to compare the mean levels for physico-chemical parameters between dry and rainy seasons. In addition, multiple linear regression was employed to model the influence of physico-chemical parameters on BOD, COD, Cd, and Cr, while Pearson correlation was performed to establish the relationships amongst the parameters. Results revealed statistical significant variations between dry and rainy seasons. The scrutiny of the results indicated that the Athi river water quality is more polluted in the dry season as compared in the rainy season. This can be attributed to large accumulation of pollutants from industries, agriculture, water treatment plants, as well as reduced river flow, weathering processes, and sediment resuspension driven by sand harvesting. Multiple linear regression analysis indicated that the physico-chemical parameters predicted 62% and 70% of BOD and COD variation in the water (R^2= 0.62 and 0.7). Similarly 36% of both Cd and Cr variations in the water (R^2 = 0.36) was influenced by the physicochemical parameters. Pearson correlation analysis indicated strong correlations between EC and TDS, EC and BOD^5, TDS and BOD^5, Cd and K, Cr and K, Cd and Cr, pH, BOD^5 and COD, NO_3, and PO_4 and NO_3. These correlations indicated that these parameters have a common origin in the environment. The seasonal variations in Athi river water quality parameters highlighted persistent pollution challenges, induced by both natural and anthropogenic processes. Consequently, parameters such as EC, TDS, PO_4, K, BOD^5, COD, Cr, and Cd persistently exceeds WHO permissible drinking water limit, indicating adverse health effects of water and aquatic consumptions in the river basin. Therefore, the Kenya Government in collaboration with non-governmental organizations should establish buffer zones within the riverbanks to restrict industrial and agricultural operations near waterways. Enacting and strengthening regulations on agricultural practices, urban waste management, and industrial discharges will help reduce the pollutant loads entering the river.

Keywords: Seasonal Variation; Water Quality; Physicochemical parameters; Multiple linear regression; Pollution

1. Introduction

The increase in human population, coupled with rapid technological advancements and economic development, has propelled a pivotal phase in the degradation of natural water quality. These trends have intensified, subjecting humanity to current and impending global water quality crises, leading to greater risks of hunger, disease, and mortality. Agriculture, industry, and human settlement have emerged as major drivers of water pollution globally [10, 54]. Land use change, climate change, radioactive waste, plastic waste, oil and gas, urbanization, emerging contaminants, and chemical weathering has ascribed as sub-agents or attributes of socio-economic and natural processes that impair water quality globally [13, 7]. The mixture of industrial and agricultural effluents, including solid waste and wastewater,

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introduces substantial amounts of organic and inorganic toxins into water bodies. Globally, an estimated 80% of wastewater, including 40 million liters, and another 80% sourced from industrial and domestic activities, were discharged into water bodies untreated [41, 53, 4]. Approximately 65% of global reports on water quality pollution are attributed to regions primarily in developing countries, largely due to the substantial and uncontrolled release of crude byproducts from economic activities.

Water quality at regional scale varies due to broader environmental trends, which are influenced by land use, geographical, and climatic factors. To meet global demands, industrial and agricultural activities contribute to wastewater discharge and eutrophication. According to Pericherla et al. [45], large-scale agricultural and industrial operations heavily impact regional water bodies, introducing nutrients (nitrogen and phosphorus) and heavy metals that induced variations in water quality. GIWS [13] concluded that eutrophication affects approximately 54% of lakes and reservoirs in Asia, 53% in Europe, 48% in North America, 41% in South America, and 28% in Africa. In 2023, about 38% of European surface water was in good health, 60% of rivers, lakes, and coastal waters remain polluted, including 30% of groundwater [8]. In contrast, the sub-Saharan Africa lacks adequate efforts and mechanisms to control oil pollution, the fertilizer and pesticides applications, indiscriminate discharge of untreated wastewater, and the dumping of mixed solid wastes on land and water bodies.

Pollution of water quality has been driven by anthropogenic activities and natural processes over time. Climatic factors and the release of effluents into the environment contributed to seasonal variation and pollution of water quality. River waters are highly heterogeneous at temporal scales and this variation influences the distribution and concentration of pollutants. Water quality is not a uniform aspect, and it varies according to sources and the amounts of solutes and/or effluents released. The variation is due to changes between major land uses such as agriculture, industrial, urban, and per-urban, and between wet and dry seasons [32]. Studies of spatiotemporal and seasonal variations of physicochemical parameters have shown fluctuation of pollution concentrations on surface water [48, 46, 31]. Different authors have discussed the relationship between anthropogenic and natural processes during different seasons and how they affect water quality. Ojok et al. [40] revealed high concentrations of physicochemical pollutants in surface water during the dry season. Higher concentrations of DO, BOD, and COD in the dry and wet seasons was detected in Temple pond, Jharkhand, India [34]. Significant difference in concentrations of TSS, TP, TN, PO_4, P and coliform between the rainy and the dry seasons in the Hau River Segment, Vietnamese Mekong Delta Province has been discussed [6]. Study conducted on seasonal variation of surface water quality in the Nairobi River system showed pollutions in the dry and the rainy seasons [18]. Moreover, various studies has identified the concentrations of nutrients variability between seasons [26, 61, 29, 50].

In Kenya, agriculture is a major sector that pollutes surface water, because of its intensification, with increased agrochemical application and irrigation, contributing to the widespread deterioration of water bodies [60]. Another activities such as urban development, increase in population, deforestation, and sand harvesting contribute to water quality degradation in Kenya's Rivers to a great extent [47]. However, this study was conducted due to proximity of the river to settlements and networks, which support various economic activities and pollution transportation from the source to the mouth. Given the foregoing, the study analyzed temporal trends for a period of eight months, focusing on seasonal variations in the physicochemical water quality of the Athi River Basin.

2. Study area

The study area is located in Athi river basin covering Machakos, Makueni, and Kitui Counties. The upper mid reaches of the study stations are located at latitude 1 26' 38 29''S and longitude 36 58' 52.49''E, down to Kibwezi bridge sampling location at latitude 2 12' 09.45''S and longitude 38 03' 30.36''E (Figure 1). The basin has an area of 66, 559 km^2 covering 11 % land surface and borders Tanzania to the south, the Indian Ocean coastline to the east, the Tana basin to the north, and the Rift Valley basin to the west. The river flows through the plains and valleys of Kenya, forming Fourteen Falls, meanders through Nairobi, and passes through Tsavo National Park. It cut across informal settlements and industrial sections of cities and towns including Nairobi, Machakos, suburban, and rural communities where it collects all forms of effluents. The headwaters of the basin are in the high-rainfall of central Kenya highlands in the Kikuyu Escarpment of 1,800-2,250mm. The Southern Aberdare ranges from 1,800 to 3,000m, and Ngong Hills is 2,200 to 2,400m [14].

The altitude, Inter-Tropical Convergence Zone (ITCZ), and the Orographic effects of high mountains and hills control rainfall in the basin [24].

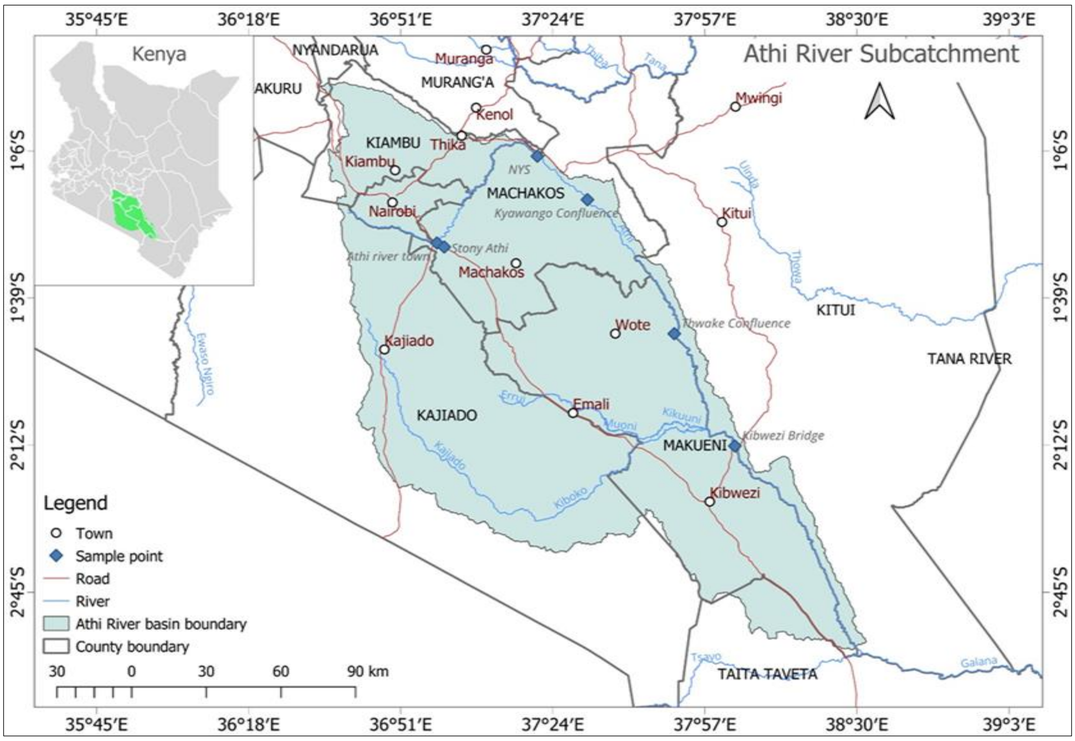

Figure1 The Location of the Study Area

The Athi River Basin experiences a close interplay between rainfall and temperature patterns, which strongly influence the hydrological dynamics of the region. Rainfall in the basin is seasonal and largely bimodal, with two main rainy periods such as the long rains occurring from March to May and the short rains from October to December (Figure 2). The total annual rainfall in the basin ranges from 481mm to 1764mm annually while Temperature ranges between 60 C and 280 C annually [58].

The sample points represent six sampling stations within the river basin. The study area covers Machakos and Makueni counties which share large part of the study, and some parts in Kitui County. A total population of the Athi River in Machakos is 322,499 with an intersex of 5% based on Sub-County results [22]. An un-estimated number of people residing within the river from Makueni to Kitui counties make use of the river water. This population accesses the river basin as their main source of water used for domestic, agriculture, and other purposes.

3. Material and methods

The study employed descriptive research design since there was no manipulation of variables. Six (6) sampling stations were purposefully chosen, namely Athi river town (S1), Stony Athi (S2), NYS (S3), Kyawango confluence (S4), Thwake confluence (S5), and Kibwezi (S6). These sampling sites are illustrated in Figure 1. Water samples were collected for eight months, covering dry and rainy seasons. The sampling took place between the years 2023 and 2024. A manual composite sampling technique was used to collect samples under stable flow conditions. The samples were collected in triplicates using 500ml plastic bottles for heavy metals and 1.5liter plastic bottles for the other physicochemical parameters. Each heavy metal sample was acidified with 1.5ml of nitric acid (analytical grade) immediately collected from the river to avoid adsorption of heavy metals to the container wall [1, 3]. After the sampling, the bottles were corked and inserted in an ice cooler, and were taken to the Water Resource Authority (WRA) laboratory for analysis in Nairobi. The physicochemical and heavy metals water quality parameters examined include pH, EC, TDS, NO_3, K, PO_4, BOD, COD, Cr, and Cd. The standard method for laboratory analysis was used in all the parameters including pH potentiometric scale, to test the intensity of the acidity and alkalinity condition of a solution [3]. Iron electrode meter was used to analyze EC and TDS parameters. Spectrophotometer UV/VS was used to analyze Nitrate solution. Flame photometric method was used for potassium analysis. Phosphate was analyzed using Ascorbic acid. COD used a titrimetric analytical method. BOD was conducted using a 5 Day analytical test [3]. Heavy metals used Atomic absorption spectrophotometer (APHA 3113-B) analytical method.

4. Result and discussion

Independent T test, multiple linear regression, and Pearson product-moment correlation coefficient (PPMCC) were used for the analysis.

Data presented in Figure 2 was used to discuss the seasonal and temporal trends of rainfall pattern in the Athi River Basin. It indicated a notable rainfall peak, with 393 mm falling in April and 425 mm falling in November. With bimodal rainfall patterns in the basin, these months experiences the most rainfall, signaling the start of both long and short rains. There is extremely little rainfall in June, July, August, and September, less than 30 mm, especially in September, when there is only about 9 mm (Figure 2).

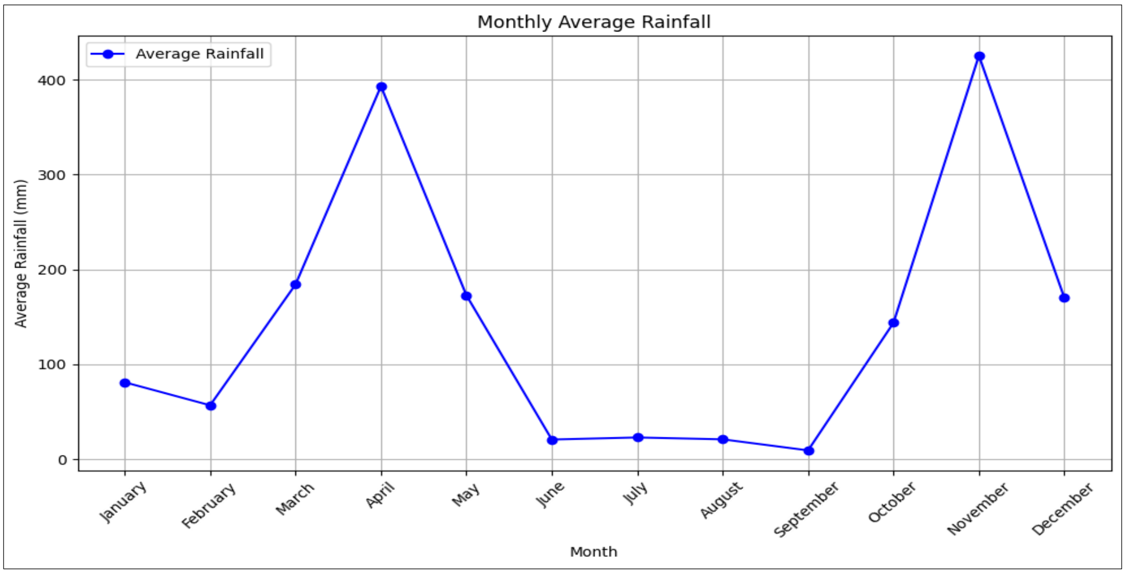

Figure 2 Bimodal Rainfall Trend of Athi River Basin

This study used independent T test analysis to compare the mean levels of physicochemical and heavy metals water quality parameters for dry and rainy seasons. Monthly average rainfall of the river basin was analyzed to explain the temporal trends and their impact on hydrological processes, water availability, and potential implications for water quality.

The pH differed significantly ($p < 0.00$) between dry and rainy seasons. The mean levels of EC, TDS, Nitrate, Potassium, Phosphate, BOD, COD, Cadmium, and Chromium were significantly different ($p < 0.00$) and varied between the dry and rainy seasons, which were above the WHO standard limit for drinking water (Table 1).

Table 1 Statistical Comparison of Temporal Mean of Water Quality Parameters.

Parameters	Dry Season Mean	Rainy Season Mean	P-value	WHO,2011/2022
pH	7.60(0.53)	7.03(0.59)	0.00	6.5-8.5
EC	1785.84(328.99)	1002.63(418.07)	0.00	400dS/m
TDS	1192.56(304.23)	622.01(251.55)	0.00	500mg/l
NO_3	26.82(14.29)	8.59(8.80)	0.00	50mg/l
K	15.38(13.28)	4.42(2.73)	0.00	0.3mg/l
PO_4	0.26(0.26)	0.03(0.04)	0.00	0.2mg/l
BOD	340.80(59.37)	118.99(90.07)	0.00	20mg/l
COD	473.47(89.42)	193.71(131.85)	0.00	10mg/l
Cd	0.10(0.15)	0.06(0.01)	0.00	0.003mg/l

Cr	0.41(0.61)	0.11(0.03)	0.00	0.05mg/l

The temporal trend indicated fluctuations and concentrations of all the parameters. The pH levels was relatively stable across the 8 months of study in the river basin.

The Figure 3 indicated that the water pH for River Athi remained constant in the months of August, September, November, December, January, and February. However, it decreased significantly in the months of April and May.

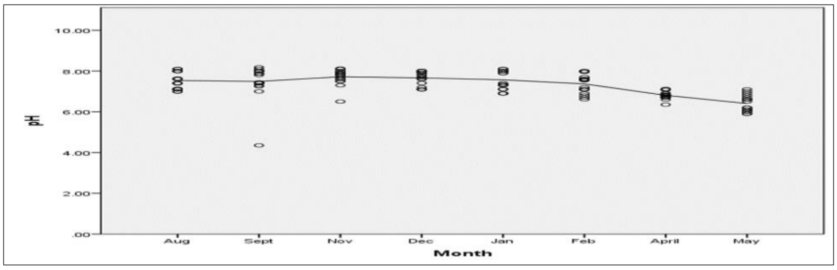

Figure 3 Temporal Trend of pH in Athi River for a Period of Eight Months

A close examination of Figure 4 showed that the EC of the river Athi fluctuated by increasing from August to September, decreased in the month of November, and increased moderately in December, January, and February. A significant drop was recorded in April and May.

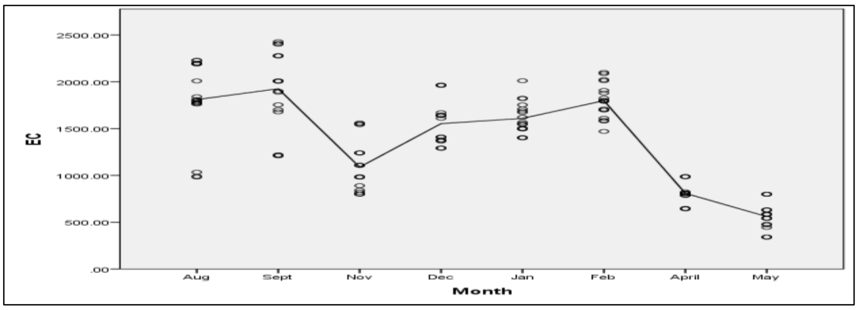

Figure 4 Temporal Trend of EC in Athi River for a period of Eight Months.

A close examination of Figure 5 indicated that the TDS of river Athi exhibited similar fluctuation to EC by increasing from August to September, with a significant decrease in the month of November and a moderate increase in December and January and peaking in February. It decreased in the months of April and May.

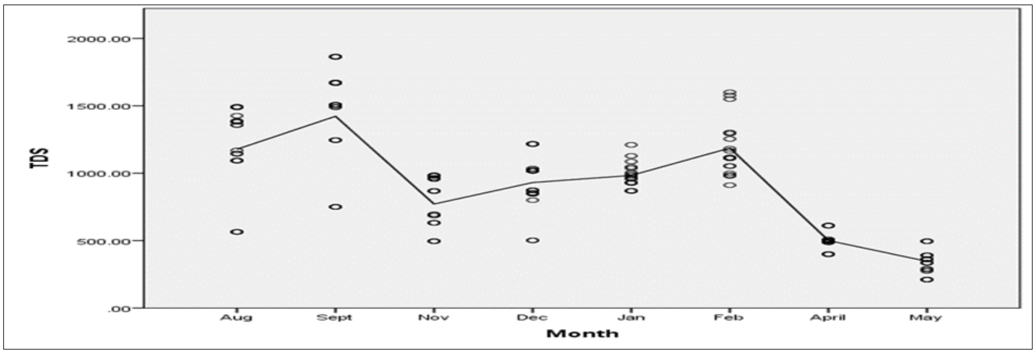

Figure 5 Temporal Trend of TDS in Athi River for a Period of Eight Months

Close examination of Figure 6 showed that Nitrate began a slight decrease from August, September to November, with a sharp increase in December, and January, and reached a peak in February. However, it decreased significantly in the months of April and May respectively.

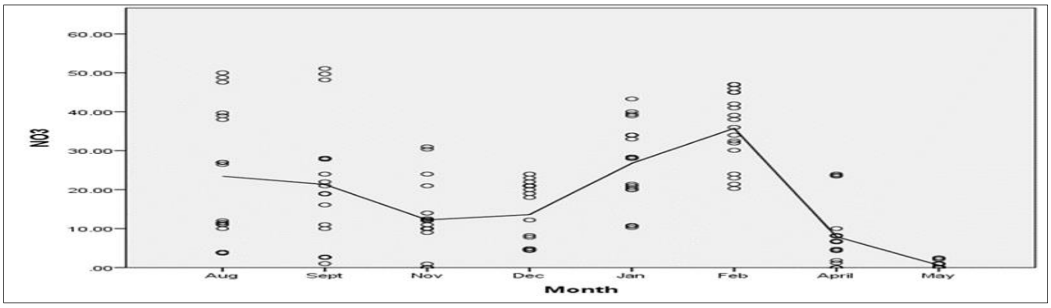

Figure 6 Temporal Trend of Nitrate (NO_3) in Athi River for a period of Eight Months.

The examination of Figure 7 indicated that Potassium stabilized in August and September decreased significantly in November and December, increased in January, and reached a peak in February. However, Potassium decreased in April and bottomed out in May.

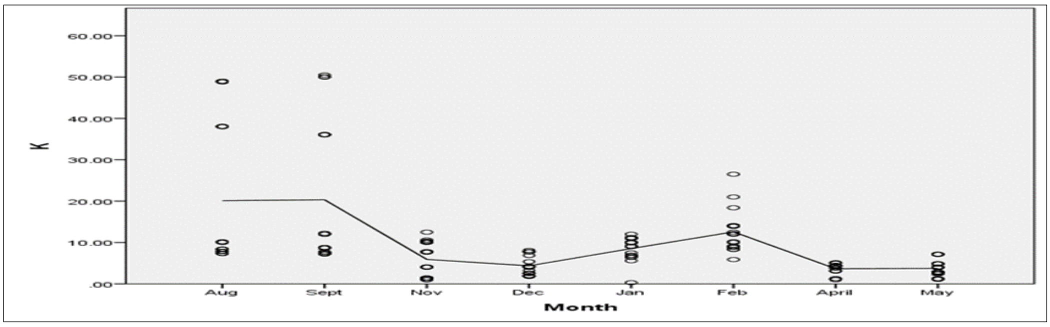

Figure 7 Temporal Trend of Potassium (K) in Athi River for a period of eight Months

A thorough examination of Figure 8 indicated that Phosphate was constant in August and September, with a decrease in November and increased from December, January, and February. However, it decreased in the month of April and bottomed out in May.

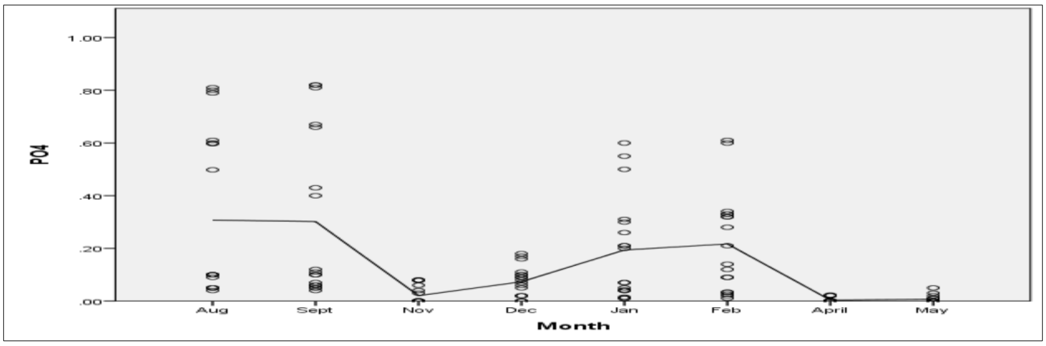

Figure 8 Temporal Trend of Phosphate in Athi River for a Period of Eight Months

A thorough observation of Figure 9 indicated that BOD fluctuated throughout the months. BOD decreased considerably from August to September with a significant decrease in November, and moderately increased in December, January and reached a peak in February. However, in the month of April, it had a sharp decrease and bottomed out in May.

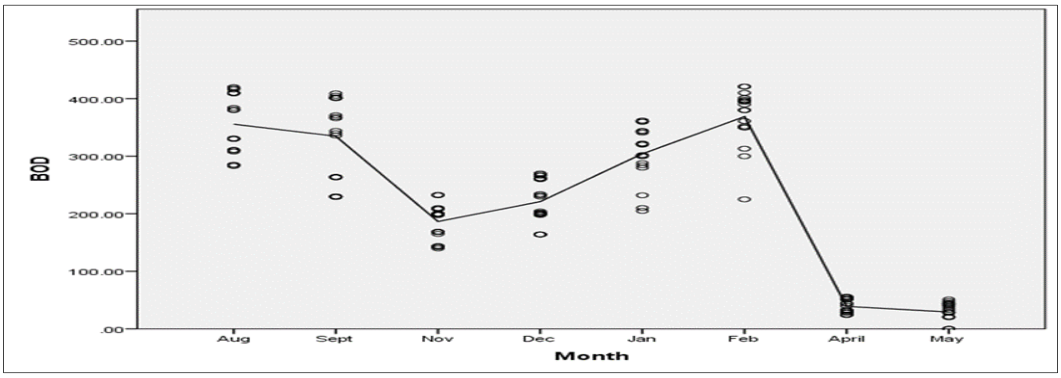

Figure 9 Temporal Trend of BOD in Athi River for a Period of Eight Months

A close scrutiny of Figure 10 presaged that COD fluctuated across the months having similar fluctuation pattern with BOD. It decreased considerably from August to September with a significant decrease in November, and moderately increased in December, and January and reached a peak in February. However, in the month of April, it had a significant decrease and bottomed out in May.

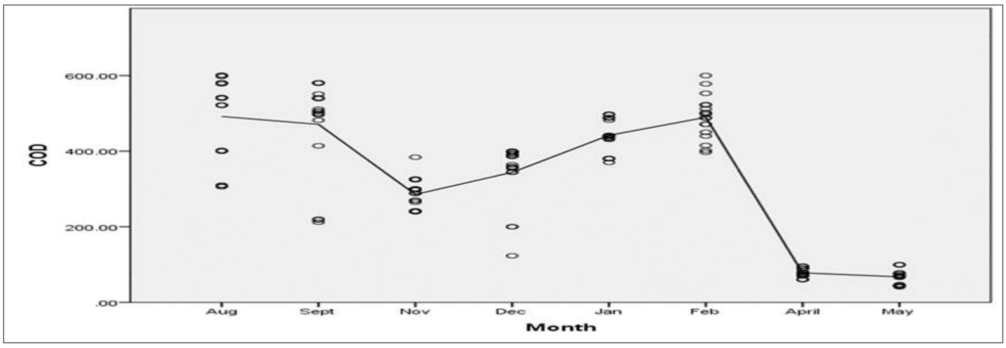

Figure 10 Temporal Trend of COD in Athi River for a Period of Eight months

A thorough examination of Figure 11 showed a sharp decrease from August, September to November. It increased considerably in December, stabilized in January and February. However, it decreased significantly in April and bottomed out in May.

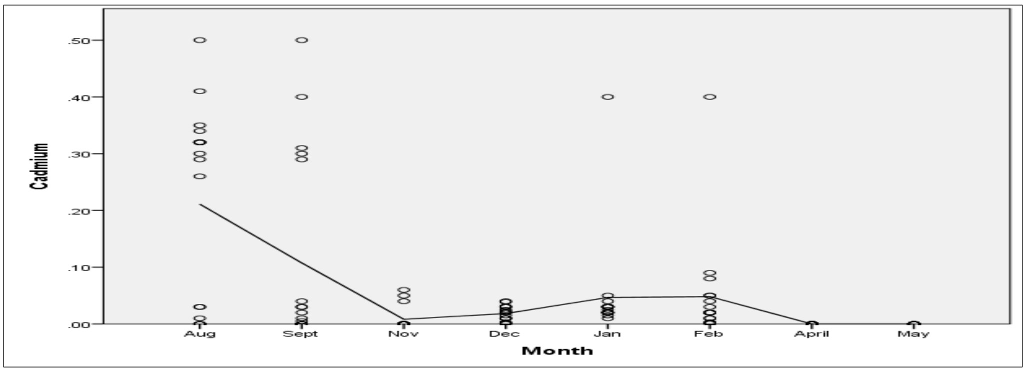

Figure 11 Temporal Trend of Cadmium (Cd) in Athi River for a Period of Eight Months

Close scrutiny of Figure 12 showed a sharp decrease from August, September, and November, it remained constant in December and January, then significantly decreased in February and April and bottom out in May respectively.

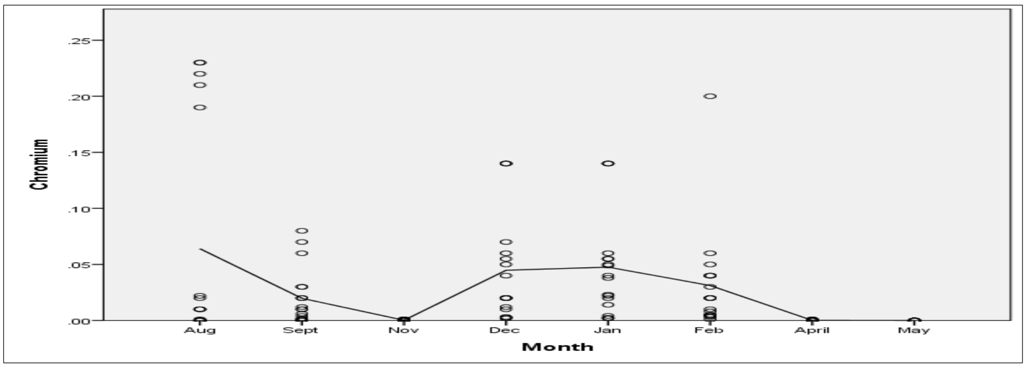

Figure 12 Temporal Trend of Chromium (Cr) in Athi River for a Period of Eight Months

Multiple linear regression analysis tested the influence of pH, EC, TDS, NO_3, K, and PO_4 on BOD and COD (oxidation parameters), and Cadmium and Chromium (heavy metals). The result indicated that six predictors pH, EC, TDS, NO_3, K, and PO_4 explained 62% ($R^2 = 0.62$) of the variation in BOD levels in the water [$F(6, 137) = 36.7$, p 0.00]. The 6 predictors pH, EC, TDS, NO_3, K, and PO_4 explained 70% (R^2 =0. 70) of the variation in COD levels in water [$F(6,137) = 53.68$, p = 0.00]. In heavy metals, 6 predictors namely pH, EC, TDS, NO_3, K, and PO_4 explained 36% ($R^2 = 0.36$) of the variation in Cadmium (Cd) level [$F(8, 135) = 9.64$, p = 0.00]. The 6 predictors pH, EC, TDS, NO_3, K, and PO_4 explained 36% ($R^2 = 0.36$) of the variation in Chromium (Cr) level in water [$F(8,135) = 9.49$, p = 0.00].

Pearson product-moment correlation coefficient (PPMC) analysis conducted, indicated relationships between water physicochemical parameters and heavy metals (Table 2). EC and TDS showed a significant positive correlation r - .93, p < .05. A strong positive correlation between EC and BOD (r = .78, p < .01). The results showed a significant correlation between TDS and BOD^5 (r = .73, p < .01), and a significance correlation between Cd and K (r =.52, p < .01), correlation between Chromium and potassium (K) (r = .54, p < .01). There was a significant correlation between Cadmium and Chromium (r = .35, p < .01), a moderate and strong positive correlation with EC (r = .67, p < .01), TDS (r = .61, p < .01), NO_3 (r = .61, p < .01), and PO_4 (r = .43, p < .01), also a strong positive correlation of pH with COD (r = .65, p < 0.01). High correlation between BOD and COD (r = .91, p < 0.01) was indicated. A high correlation with EC (r = .75, p < 0.01), TDS (r = .65, p < 0.01), and PO_4 (r = .71, p < 0.01), as well as moderate positive correlation with Chromium (r = .51, p < 0.01) were indicated. The results indicated a high correlation with K (r= .74, p < 0.01) and NO_3 (r = .71, p < 0.01) respectively.

Table 2 Pearson Correlation Matrix of Water Quality

	pH	**EC**	**TDS**	**NO_3**	**K**	**PO_4**	**BOD_5**	**COD**	**Cd**	**Cr**
pH	1									
EC	0.67**	1								
TDS	0.61**	0.93**	1							
NO3	0.61**	0.75**	0.65**	1						
K	0.38**	0.62**	0.55**	0.63**	1					
PO4	0.43**	0.67**	0.57**	0.71**	0.74**	1				
BOD5	0.55**	0.78**	0.73**	0.63**	0.48**	0.54**	1			
COD	0.65**	0.82**	0.73**	0.67**	0.51**	0.59**	0.91**	1		
Cd	0.10	0.26**	0.23**	0.24**	0.52**	0.35**	0.32**	0.36**	1	
Cr	0.29**	0.47**	0.35**	0.51**	0.54**	0.45**	0.28**	0.36**	0.35**	1

5. Discussion

The findings showed that both external and internal factors are playing significant role in pH stability and water pollution over time as shown in Figure 3. The constant pH level throughout the eight months periods is characterized by substantial bedrocks containing limestone, which dissolved in water, acting as a natural buffer that helps in stabilizing pH by releasing bicarbonate and carbonate ions. Seasonal changes have a significant contribution on pH stability, during the dry season, pH remains stable, but decreased during the rainy season (Table 1 & Figure 3). The rainfall significantly lowers pH levels in April and May, likely due to increased runoff leading to soil leaching, dilution effects, sedimentation, and transportation of acidic substances into the river [44, 18, 43]. The EC levels increased from August to September during the dry season, likely due to the concentration of dissolved salts and minerals as water levels decreased (Table 1 & Figure 4). During the dry season, the mixing of drains from upper river areas, consisting of urban and semi-urban areas, transports pollutants from adjoining industries and sewage downstream. In the rainy season, the rivers' base flow accounts for a high proportion of streamflow, where water-rock interaction influences the river's conductivity levels [37]. Pollutants levels reduces during the rainy season, influenced by ion exchange, sedimentation, water velocity, and biological uptake [39, 43, 60]. High TDS concentrations in August, September, January, and February reflect the concentration of dissolved substances as river flow decreases during the dry season. TDS levels peaked in February during the recession period due to reduced flow as shown in Figure 5. Lemessa et al. [26] and Dulo [5] concluded that large amounts of dissolved solids in the river system, induced by salt materials and weathering minerals, contribute to high TDS levels. The consistent levels over time may be attributed to soil leaching and bedrock weathering, which add minerals to the river and affect the overall water quality in the Athi River basin. The decrease in TDS levels in November, December, April, and May could be attributed to the dilution effect from increased water levels as shown in Table 1 & Figure 2.

Nitrate (NO_3) concentration levels slightly decreased from August to November, indicating low discharge of pollutants containing chemical fertilizer and the onset of the rainy season, particularly convectional rain that occurred from mid-September to November (Table 1 & Figure 2). The concentrations peaked from December to February during the dry season due to reduced runoff, agricultural practices, release from settlements, and atmospheric deposition from automobiles (Figure 6). This is similar to the findings of Varma & Jha [57], who discovered that during the dry season, low water flow allows for the accumulation of nitrates from agricultural runoff and wastewater discharge, increasing concentration levels. NO_3 levels decreased in April and May, likely due to increased water levels, higher flow velocity during peak rainfall, and the dilution effect influencing chemical and biological processes [24, 43].

High potassium (K) concentrations were observed in August, September, and February during the dry season, indicating high temperatures and effluents containing potassium (Figure 7). Elevated potassium levels could be due to urban runoff, discharge from industrial processing, fertilizers, sewage, and animal waste, all contributing to higher potassium concentrations [11, 45]. However, the river high flow or laminar flow, sedimentation, degradation, adsorption, and redox reactions influenced the reduction of potassium levels in the river basin (Table 1).

Phosphate maintained constant levels in the dry seasons of August, September, January, and February due to limited effluent release, minimal temperature fluctuations, and reduced dilution (Table 1 & Figure 8). Higher temperatures increased phosphate levels due to reduced flow, decreased dilution, and effluent loads [50]. Phosphate levels decreased in the rainy months of November, December, April, and May, driven by sedimentation and dilution from increased rainfall and runoff as shown in Figure 2. This result aligns with the conclusions made by Owen et al. [42] that increased runoff, high or laminar flow, sedimentation, degradation, adsorption, and redox reactions collectively lower.

Biological Oxygen Demand (BOD^5) levels decreased progressively between the dry months of August and September due to reduced organic waste input into the river and decreased flow (Table 1& Figure 2). This limits the amount of organic matter available for microbial activity in the water [34]. BOD concentrations peaked in February following the onset of the rainy season and significant pollutant discharges from industries, untreated sewage, and agriculture, combined with a reduced and stable flow (Figure 9). The neutral pH levels and high temperatures in the river generally support the optimal microbial activity, leading to efficient decomposition of organic matter, which subsequently increased BOD levels [31]. The BOD^5 levels decreased in the rainy months of November, December, April, and May rainy season as shown in Figure 1. The lower levels of BOD is driven by the oxidation processes, increased flow velocity, dilution effects, and increasing oxygen levels [53, 40]. Chemical Oxygen Demand (COD) levels fluctuated throughout the sampling periods, influenced by the consumption of oxygen, inorganic matter that is difficult to decompose, leading to undissolved material in the river (Figure 10). Higher COD levels during the dry season experienced a slight decrease from August to September, attributing to reduced runoff and decreased discharge of organic pollutants (Table 1). Conversely, high runoff and dilution effects during the rainy months of November, December, April, and May decreased COD concentrations as shown in Figure 1 & 9. Dilution effect, domestic washing, river runoff, and changes in pollution sources reduced the concentrations of pollutants in the river [9].

High dissolved phase of Cadmium (Cd) levels from August to February, could be due to the discharge of waste materials containing cadmium and high pollution loads (Table 1 & Figure 11). The increase in Cd levels may also result from point-source contamination, changes in discharge patterns, and weak rainfall at the time of sampling. Cd levels remained stable in January and February due to steady pollution sources, reduced river flow, low biological material availability, and limited dilution [17]. Stable sources of industrial discharges, agricultural runoff, and mineral weathering throughout the year tend to stabilize pollutant levels as long as these sources do not change significantly. However, increased runoff, sedimentation, and high dilution processes reduced Cd concentrations in November, December, April, and May as shown in Figure 1. The slight increase in December indicated point-source contamination or changes in discharge patterns. Low Cd levels could also be due to reduced organic load, increased water residence time, evaporation, low industrial discharge, and dilution effects [29, 63, 35].

High Chromium (Cr) concentrations in August, September, December, and February were attributed to pollutant accumulation during the dry season (Table 1 & Figure 12). Discharged effluents from industries, agriculture, and mineral weathering contributed to Cr concentrations in surface water, with additional solutes from groundwater increasing Cr levels [15, 28]. The increase in Cr during December's rainy season could be due to runoff from industries, source accumulation, and bedrock release of Cr solutes. Singh & Sharma [52] found that chromium levels in rivers often fluctuate with seasonal changes due to dilution and runoff effects. Low Cr levels observed in November, December, April, and May could be aggravated by increased runoff, sedimentation, and dilution during the rainy season (Figure 2). Similar results were observed by [9], who found that dilution, runoff, and washing effects, together with changes in pollution sources, reduced pollutant levels in the river. Seasonal variations propelled the pollution dynamics of the river basin, with higher pollutant concentrations during the dry season compared to the rainy season.

Multiple linear regression results showed that the six predictors had stronger relationship between water quality parameters and BOD and COD levels. The model highlight the importance of pH, EC, TDS, NO_3, K, and PO_4 in influencing organic matter degradation, as reflected in BOD and COD levels in the water. It showed a positive and statistically significant relationship between EC and both BOD and COD levels. As EC ions increased, so did BOD and COD levels, due to the presence of more dissolved organic and inorganic substances contributing to oxygen demand. Seasonal changes and increases in EC over time were associated with the rising levels of BOD and COD due to changes in land use, industrial activities, and pollution sources [18]. The results on the heavy metals showed consistent relationship between the water quality parameters and heavy metal concentrations. The six predictors indicated a moderate effect on Cd concentrations, with unexplained 64%, indicating the impacts of other variables on Cd. The coefficient of variations indicated that increased in potassium (K) and COD decreased Cd levels, with a statistically significant inverse relationship. Uddin et al. [54] found that seasonal variations in COD levels had a negligible impact on Cd levels, due to small magnitude changes in Cd. Nitrate (NO_3), potassium (K), and BOD shows positive and statistically significant relationships with Cr levels in the river. Higher NO_3 concentrations leads to increased Cr levels over time. This positive relationship indicated that higher nitrate levels were associated with higher Cr concentrations. However, seasonal fluctuations in nitrate affects Cr levels depending on nitrate's interaction with other variables [16]. Potassium also showed a statistically significant positive relationship with Cr, meaning that higher potassium levels were associated with increased Cr concentrations, especially during the dry season. The increased in BOD significantly influenced Cr levels, similar with Wang et al. [59] conclusion that higher BOD levels and more organic matter in the water, can influence Cr behavior, possibly through adsorption onto organic particles. The Pearson product-moment correlation analysis shown in Table 2 indicated strong relationships between EC and TDS, EC and BOD, TDS and BOD, Cd and K, Cr and K, and Cd and Cr, while moderate relationships were found between pH and TDS, EC, NO_3, and PO_4, and strong correlation with COD. However, further studies are recommended to explore on temporal sources of persistent pollution such as heavy metals and their toxicological impacts on the river ecosystem and human health. Secondly, seasonal studies on rock water interaction in the river basin should be conducted to explore specific rocks generating heavy metals and phosphate mineral pollutants in the river basin.

6. Conclusion

The higher levels of pollution concentrations and fluctuations over time and seasons, indicated the influence of anthropogenic input, mineral weathering and climatic factors, inducing temporal and seasonal water quality dynamics of the Athi River Basin. August, September, January, and February observed the highest pollution concentrations of water quality than November, December, April and May. February was identified as pollution hotspot The pH levels remain relatively constant from August to February and decreased slightly in April and May, indicating slight alkaline, driven by the river bedrock (Limestone or dolomite) and soil mineral, buffering capacity of carbonate and bicarbonate ions. Therefore, the Government, in collaboration with non-governmental organizations should increase year round monitoring of water quality in Athi River, especially targeting February and other dry season months. This will help to better understand and manage seasonal variations and their impacts on water quality. There is a need to implement and enforced stricter regulations on agricultural runoff, industrial discharges, and urban waste management to help reduce pollution loads and improve water quality in the river basin.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest in this study.

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