Spatial and Seasonal Concentration of Glyphosate, Nitrate, and Phosphate in Kuti Stream, Yaba, Abaji Area Council, FCT Abuja, Nigeria

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Abstract

This study determines the concentration of glyphosate ($C_3H_8NO_5P$), nitrate (NO_3^-), and phosphate (PO_4^{3-}) in Kuti stream, Abaji area council, Federal Capital Territory Abuja, Nigeria, for twelve months (January-December, 2019) at four sampling stations that were 500 m apart. Samples were collected monthly during the morning hours (06.00-10.00 h) from a depth of 5–10 cm below the water surface using high-density polyethylene bottles and analyzed by adopting standard protocols. Samples analyzed for $C_3H_8NO_5P$ concentration were pooled quarterly with the highest (0.27±0.01 mg/l) concentration observed in July-September at station 2, lowest (0.02±0.01mg/l) in January-March at station 4. Seasonal concentration differed significantly ($P \leq 0.05$), rainy season had 0.12mg/l, dry season had 0.06 mg/l. NO_3^- and PO_4^{3-} had their highest concentration (1.82±0.01mg/l; 0.87±0.01mg/l) in June at station 2 and 1, lowest (0.23±0.06mg/l; 0.21±0.05mg/l) in January and December at station 4 and 3. Rainy season had high concentration (1.82±0.01mg/l; 0.87±0.01 mg/l) of NO_3^- and PO_4^{3-} compared to dry season (0.23±0.01 mg/l; 0.21±0.01mg/l). Pairwise correlation coefficients show a strong positive relationship (r=0.53/1.00) between PO_4^{3-} and $C_3H_8NO_5P$. The mean concentration of $C_3H_8NO_5P$, NO_3^- and PO_4^{3-} (0.09±0.01 mg/l; 0.59±0.04 mg/l; 0.37±0.02 mg/l) were below the maximum contamination limit (MCL) of 0.7 mg/l, 50 mg/l and 5.0 mg/l by USEPA, WHO and NERN. The high concentrations observed in the rainy season and station 2 were linked to runoff and riparian agriculture, though their mean concentrations were low if not monitored, will increase and become harmful to aquatic and human lives, therefore, conservation farming was suggested.

Keywords: Agrochemicals, eco-friendly, eutrophication, permissible, United States Environmental Protection Agency (USEPA)

Introduction

Streams are sources of water, a vital resource that sustains the growth, survival, and continuity of organisms in the ecosystem (Adeola et al. 2015; Fella and Mohammed 2019; Surya et al. 2020; Xia et al. 2020). It serves as habitat and breeding site for insects, fishes, amphibians, and mammals and helps to maintain ecological balance in both terrestrial and aquatic habitats (Echude et al. 2020). Approximately 70% of the Earth's surface is covered by water but only 3% of it including groundwater, lakes, rivers, polar ice, and glacier are freshwater (Surya et al. 2020). Freshwater is a limited resource needed for sustainable economic growth and development through its usage in agriculture, industries, and domestic purposes (Nidhi et al. 2017; Georgieva et al. 2018; Berhanu et al. 2020; Surya, 2020), but its abundance and

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availability in agricultural communities are been threatened by agricultural intensification (Nidhi et al. 2017; Berhanu et al. 2018; Surya et al. 2021).

Agricultural intensification is an array of components, which includes; deforestation, removal of hedgerows, intense application of agrochemicals, deep tillage of soil, and the practice of monocropping (Jatinder et al. 2017; Holden et al. 2019). But the application of agrochemicals especially glyphosate-based herbicides (GBH) is one of the most common agricultural intensification component practiced in Kuti, Abaji area council, FCT Abuja, Nigeria, due to its non-selective nature to all kinds of plants and affordability compared to other herbicides which reduces the cost of farmers' production and maximizes their profits.

Glyphosate-based herbicides (GBH) are systemic, non-selective, broad-spectrum, and post-emergent herbicides (Carol et al. 2017; Jatinder et al. 2017; Ramdas et al. 2019; Eduardo et al. 2020). They are the most saleable and widely sprayed pesticides in human history (Robert et al., 2014; Carol et al. 2017; Vincenzo et al. 2018; Ramdas et al. 2019; Eduardo et al. 2020). It was reported that over 800 million kilograms are sold annually with a value of over 6.5 billion dollars and it is usually applied on average 2-4kg/ha (Eduardo et al. 2020). They are usually applied by spraying and control more than 150 weed species in aquatic and terrestrial habitats (Vincenzo et al. 2018; Ramdas et al. 2019; Eduardo et al. 2020).

Glyphosate-based herbicides (GBH) kill weeds by inhibiting the activity of 5-enolpyruvylshikimic acid-3-phosphate (EPSP) synthase, an enzyme necessary for the formation of aromatic amino acids; tyrosine, tryptophan, and phenylalanine that are localized in the chloroplast (Jatinder et al. 2017; Ramadas et al. 2019). The inhibition of the aromatic amino acids in plants by glyphosate affects protein synthesis and secondary products such as growth promoters, inhibitor precursors, flavonoids, tannins, and other phenolic compounds (Jatinder et al. 2017).

Glyphosate is mostly degraded by microbial metabolism into its main metabolite, aminomethylphosphonic acid (AMPA) which followed two paths; the first is the breakdown of the carbon-nitrogen bond which leads to the formation of AMPA, while the second is the splitting of the carbon-phosphorus bond, resulting in the formation of sarcosine and glycine (Ramdas et al. 2019). It contaminates surface water through runoff and spray drift. It is soluble in water and slowly dissipates from water into sediments or suspended particles (IARC, 2015). The presence of glyphosate in freshwater increases phosphate content which supports the growth of algae and leads to eutrophication when combine with nitrate, which leads to anoxia and hypoxia in aquatic organisms and decreases the quality of water (IARC, 2015). Glyphosate is currently listed by the world health organization (WHO) in group 2A as a possible human carcinogen (Eduardo et al. 2020). The increase in the use of agrochemicals correlates positively with the increase in the demand for food by the increasing human population (Friends of the earth, 2013). It has marginally increased crop yield but left adverse effects that outweigh its benefits in the ecosystem (Bijay and Eric, 2021). Nitrogen, phosphorous, and potassium (NPK) fertilizers and GBH are the most common agrochemicals that contribute to the concentration of (NO_3^-) and phosphate (PO_4^{3-}) in surface water (Friends of the earth, 2013; Vincenzo et al. 2018). Kuti stream is surrounded by agricultural farmlands which makes it a receiver of agrochemicals applied on the farmlands through runoff. This study determined the spatial and seasonal variation of glyphosate, nitrate and phosphate concentrations in Kuti stream, Abaji area council, FCT, Abuja, Nigeria.

Materials and Methods

Study Area and description of sampling stations

Kuti stream lies between 08° 38 ' 51.0 " to 08° 38'51.2"N and 006° 46'30.2"to 006° 46'30.4”

E and elevation of 90 m (Figure 1). It is 500 m down the slope from Leventis agricultural training farmland, Yaba, Abaji area council, FCT Abuja Nigeria. It is a non-seasonal, meandering stream that fluctuates in volume and has an average depth of 0.5 m. It is used by about 6,000 inhabitants of Kuti village, a border agricultural settlement between Federal Capital Territory (FCT) Abuja and Niger State Nigeria (NPC, 2006). It served as their major source of drinking water, domestic and irrigation for fadama farming. Vegetables such as Okro (*Abelmoschus esculentus* L.) and Spinach (*Spinacia oleracea* L.), and crops such as melon (*Cucumis melo* L.), rice (*Oryza sativa* L.), cassava (*Manihot esculatum* L.), maize (*Zea may* L.), benniseed (*Sesamum indicum* L.) and Soya bean (*Glycine max* L.) are cultivated which are partly consumed by the inhabitants and majorly supplied to major cities. The climate is warm-humid, with an average annual temperature of 24^0C and rainfall between 1000-1200mm per year which allows for a mono-modal rain-fed cropping season from May to October. The vegetation cover is made up of a mixture of shrubs and scattered trees.

Water was collected from four sampling stations that were 500 m apart along the stream (Adakole et al. 2003). Station 1 is the entrance to Kuti village, a bridge cut across the stream at this station, and it has high human activities. Station 2 is characterized by farming activities at the bank. Station 3 served as a drinking point for cattle and a rice farm located by the bank. Station 4 has a riparian cover at the bank and less human interference (Fig.1).

Water sampling and laboratory analysis

A composite sampling technique was used to collect samples monthly during the morning hours (06.00-10.00 h) from a depth of 5–10 cm below the water surface into two litres of white sterile high-density polyethylene bottles, fixed immediately, labeled, preserved in an icebox at 4^0C and transported to Mycotoxin and Pesticide laboratory, Department of crop protection, Ahmadu Bello University, Zaria for 12 months (January - December 2019) (Adegbe, 2014; Berhanu et al. 2020; Eduardo et al. 2020; Surya et al. 2020). Glyphosate concentration was determined using ELISA kit (PN 500086) following procedures established by the manufacturer (Abraxis, Warminster, PA USA) while NO_3^- and PO_4^{3-} were determined by APHA (1995). Samples for glyphosate were pooled together quarterly (January-March; April-June; July-September; and October-December) while that of NO_3^- and PO_4^{3-} were done monthly.

Statistical Analysis

Data collected were entered into Microsoft Excel (version, 2016). Descriptive statistics were used to analyze the mean concentration of glyphosate, nitrate, and phosphate across

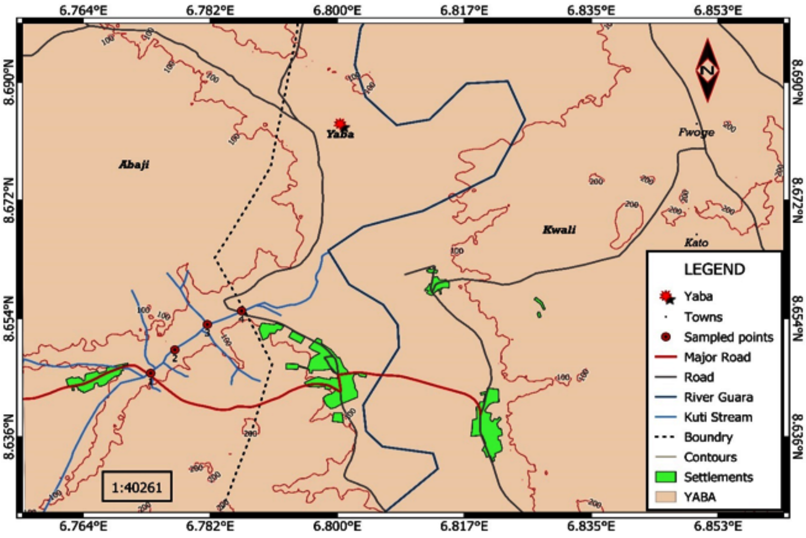

Figure 1 Water sampling stations
Source: Google earth (2021)

stations, months, and seasons. ANOVA was used to compare the concentrations, sources of variation, and statistical significance, Student's t-test was used to compare the concentration and significance between seasons, while Pearson correlation was used to determine the relationship between NO_3^- and PO_4^{3-} , glyphosate, and NO_3^-, and glyphosate and PO_4^{3-}.

Results

The highest (0.27±0.01 mg/l) concentration of glyphosate was observed in July-September at station 2, while lowest (0.02±0.01mg/l) was recorded in January-March at 4 (Fig.2a). The months of April-June was also observed to record high concentration (0.15±0.02 mg/l; 0.1±0.01mg/l) at station 2 and 3 (Fig.2a). The seasonal concentration differed significantly (t=2.02; df=3; $P \leq 0.05$) with rainy season having a high (0.12mg/l) concentration compared to dry season that recorded (0.06 mg/l) (Fig.3a). The mean concentration of glyphosate in the stream throughout the study was 0.09±0.01 mg/l (Fig.3b). Correlation coefficient shows that $C_3H_8NO_5P$ correlates positively (r=0.43) with NO_3^- and $P0_4^{3-}$ (r=0.53) (Fig. 4 b and c).

The highest (1.82±0.01mg/l) concentration of NO_3^- was observed in June (rainy season) at

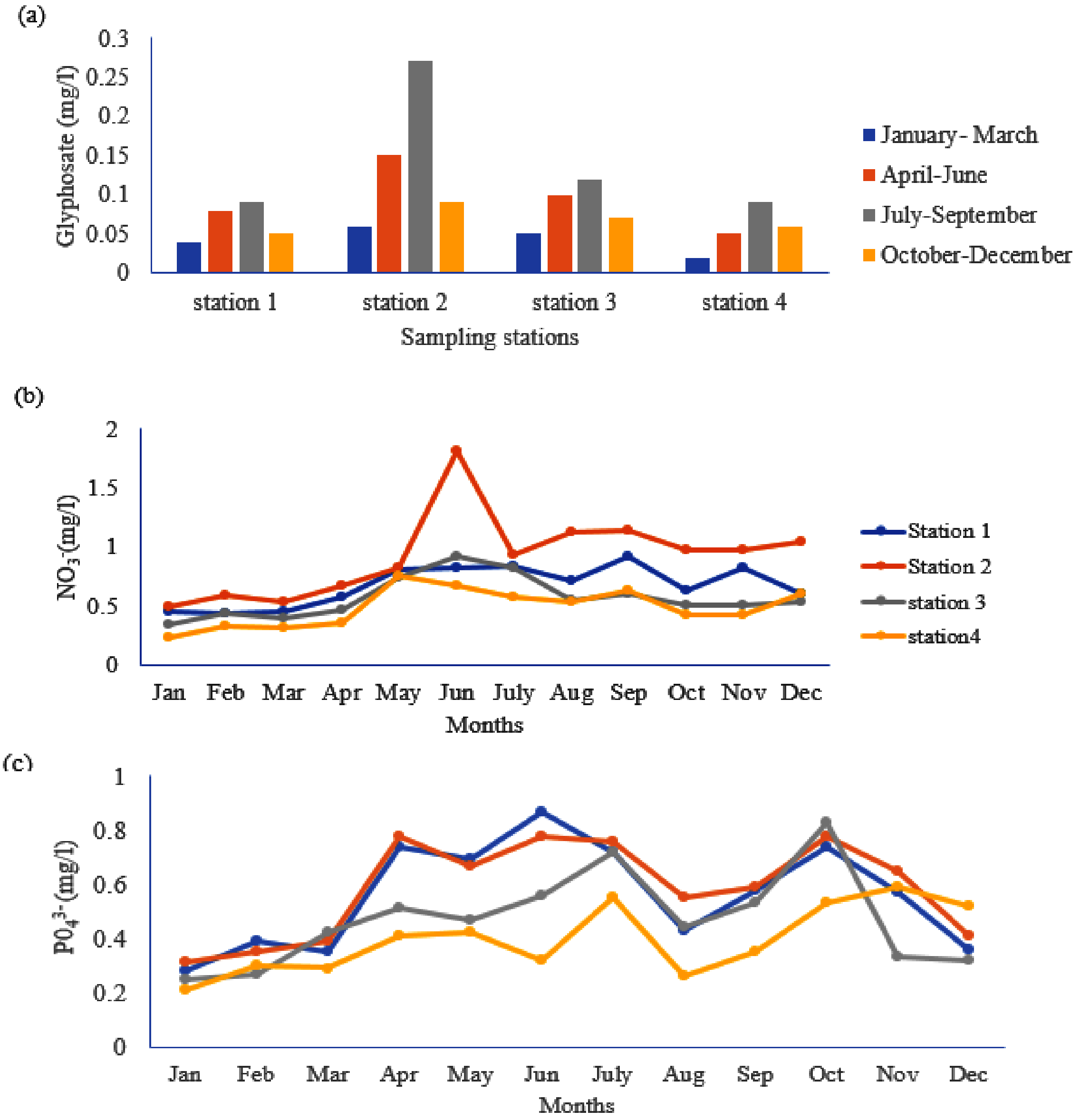

Figure 2 Mean variation of (a) glyphosate (b) nitrate (c) phosphate across months and stations of Kuti stream (KS), Abaji area council, FCT Abuja, Nigeria

station 2, while the lowest (0.23±0.06mg/l) was recorded in January (dry season) at station 4 (Fig.2b). Station 2 recorded the highest concentration across months, while station 4 had the lowest concentration except in December when station 3 recorded the lowest concentration (Fig. 2b). Student's t.test significantly (t=2.02; df=5; $P \leq 0.05$) showed that there was a high concentration (0.72±0.04mg/l) in rainy season compared to dry season (0.47±0.05mg/l) (Fig. 3a) while the mean concentration throughout the study was 0.59±0.04 mg/l (Fig. 3b), which was lower than the permissible of 9.1 mg/l for fisheries and recreation quality criteria standard by NERN (2011) and 50 mg/l by (WHO, 2004).

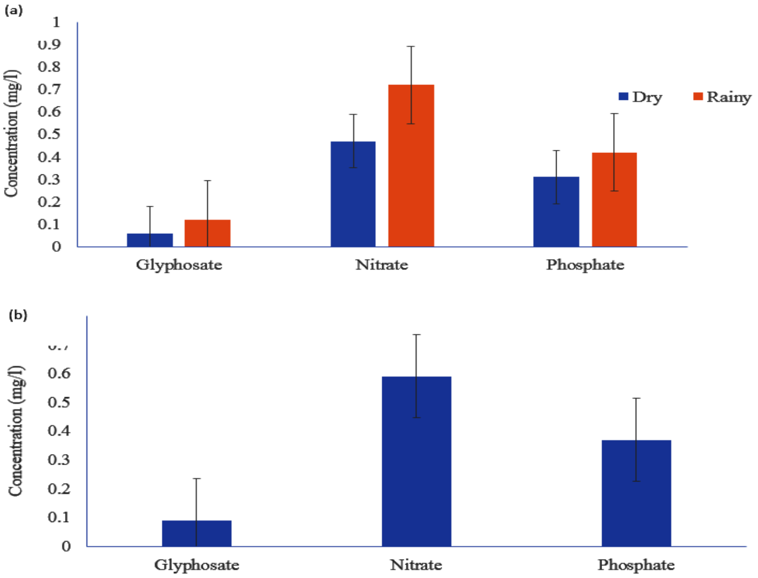

Figure 3 Mean variation of glyphosate, nitrate, and phosphate (a) between seasons (b) Throughout the study at Kuti stream (KS) Abaji area council, FCT Abuja, Nigeria

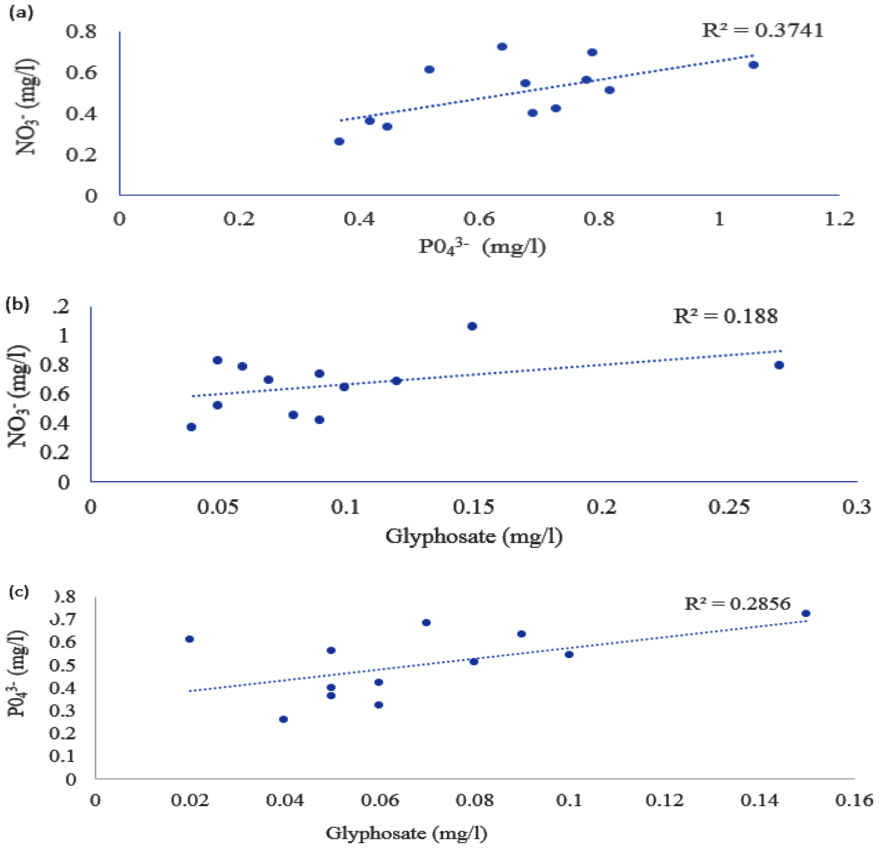

Figure 4 Correlation between (a) nitrate and phosphate (b) nitrate and glyphosate (c) phosphate and glyphosate of Kuti stream (KS) Abaji area council, FCT Abuja, Nigeria

Post-hoc Tukey test showed that the spatial variation of NO_3^- significantly differed ($P \leq 0.05$) across stations but not across months, between seasons, and interactions of months by stations, season by month, season by station, and season by month by station (Table 1). Correlation coefficient shows a strong positive (r=0.61) relationship with $P0_4^{3-}$ (Fig. 4c)

Phosphate ($P0_4^{3-}$) had it highest (0.87±0.01 mg/l) concentration in June (rainy season) at station 1 while the lowest (0.21±0.05mg/l) in December at station 3 (Fig.2b). Station 4 recorded the lowest concentration in January, March, April, May, June, July, September, and October while Station 3 had the lowest in November and December (Fig. 2b). Station 1 had the highest concentration in February and June, station 2 had the highest in January, April, July, August September, and November, while station 3 had the highest in December (Fig. 2b). Seasonal variation significantly (t=2.02; df=5; $P \leq 0.05$) showed that rainy season had high (0.47±0.05mg/l) compared to dry season (0.31±0.03mg/l) (Fig. 3a) but the mean concentration throughout the study 0.37±0.02 mg/l (Fig. 3b) which was lower than the permissible limit of 3.5 mg/l by NERN (2011) and 5.0mg/l (WHO, 2004). Post-hoc Tukey test showed the spatial and temporal variation of $P0_4^{3-}$ differed significantly ($p \leq 0.05$) across stations and seasons but not across months (Table 2).

Discussion

The high concentration of glyphosate observed in rainy season and station 2 could be attributed to agricultural runoff, drift, and proximity of farmlands to the stream. Rainy season is the peak of farming activities in Kuti which is characterized by heavy application of GBH to eliminate weeds before soil tillage. A heavy downpour can easily wash GBH from soil and parts of plants after application into the stream. Station 2 is surrounded by farmlands close to its bank which are in continuous usage both in rainy and dry seasons. Maize

TABLE 1

Analysis of Variance (ANOVA) for Nitrates (No_3^-) at KS

Source of variation	Df	Sum Sq	Mean Sq	F -value	Pr(>F)
Months	1	0.08	0.08	0.49	0.48^{Ns}
Station	4	7.47	1.87	10.97	0.05*
Season	1	0.01	0.01	0.07	0.79^{Ns}
Month by station	4	0.49	0.12	0.73	0.57^{Ns}
Season by month	1	0.17	0.17	0.98	0.33^{Ns}
Season by station	4	0.66	0.16	0.96	0.43^{Ns}
Season by month by station	4	0.07	0.02	0.10	0.98^{Ns}
Residuals	100	17.04	0.17		

TABLE 2

Analysis Of Variance (ANOVA) for Phosphate ($P0_4^{3-}$) at KS

Source of variation	Df	Sum Sq	Mean Sq	F -value	Pr(>F)
Months	1	0.02	0.02	0.13	0.72^{Ns}
Station	4	24.57	6.14	31.79	0.05^{***}
Season	1	0.73	0.73	3.75	0.05^{*}
Month by station	4	0.03	0.01	0.03	0.99^{Ns}
Season by month	1	0.24	0.24	1.24	0.26^{Ns}
Season by station	4	0.41	0.10	0.52	0.72^{Ns}
Season by month by station	4	0.13	0.03	0.17	0.95^{Ns}
Residuals	100	19.32	0.19		

***= Highly significant; ** =High significant; *= Significant; Ns= Not significant

(*Zea may*, L) was cultivated in rainy season, while in the dry season, rice (*Oryza sativa*, L) was cultivated. GBH can easily drift during application on farmland to kill weeds and the short distance travelled through run-off can deliver a high concentration of GBH into station 2, thereby increasing its concentrations compared to other stations. Similar observation was reported by Eduardo et al. (2020) in their work carried out in rural locality in Mexico to determine glyphosate residue in different sources of water. They reported that high concentration of glyphosate was observed in wells and surface water close to agricultural farmland in rainy season compared to dry season.

The mean concentration of glyphosate observed in this study was below the maximum contaminant level (MCL) of 0.7mg/l in drinking water (https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations). But if the intense agricultural practices taken place around Kuti stream continues, the concentration of glyphosate may exceed its maximum contamination level which may alter the ecosystem of the stream, stimulate eutrophication (anoxia and hypoxia), water degradation, and loss of biodiversity especially aquatic organisms and plankton which can create an imbalance in the food chain and web of the stream (Eduardo et al. 2020; Xia et al. 2020). Water from Kuti stream used during the dry season as a source of irrigation can be a source of glyphosate bioaccumulation in crops, which can be detrimental to human health when consumed (Xia et al. 2020).

The high concentration of nitrate observed at station 2 in June falls within the eutrophic level status of >1.500 mg/l for nitrates and >0.075mg/l for phosphate (Suteja and Purwiyanto, 2018). This could be attributed to agricultural runoff of nitrogenous and phosphorous fertilizers (NPK) from nearby farms. This observation conform with work of Dike et al. (2010) carried out at River Jakara in Kano state Nigeria, where they recorded high concentration of nitrate and phosphate in rainy season in a station close to agricultural farmlands. Adeola et al. (2015) report that the highest concentration of phosphate was observed in July in their study carried out at Nwaja creek, Port Harcourt, Niger Delta, Nigeria. They attributed the high concentration to the increasing rate of plant growth, changes in the species composition, and proliferation of planktonic and epiphytic, and epibenthic algae which can be attributed to the inflow of nutrients from nearby farms. Nidhi et al. (2017) report that the highest concentration of phosphate observed in one of their sites in their study carried out in River Narmada, Madhya Pradesh in India was observed in rainy season. Suteja et al. (2018) observed a high concentration of nitrates and phosphates in dry season compared to rainy season in their research carried out in Benoa Bay, Bali Indonesia which is contrary to the finding of this work. However, they concluded that the main source of water contamination is nitrogenous fertilizers from farmlands that practice intense application of agrochemicals. They concluded that the high concentrations of nitrate and phosphate is attributed to the low discharge of water during dry season and the accumulation of nutrients from wet season which emanate from domestic and farming activities that took place at the bank of other streams that serve as sources of water for Benoa Bay. Pranab et al. (2019) observed a high concentration of phosphate during the rainy season in their study carried out at Kailash Khal, a tropical wetland in India which they attributed to agricultural runoff from farms during the rainy season. Berhanu et al. (2020) report that the mean concentration of nitrate at Gilgel Gibe catchment, Southwestern Ethiopia was greater in agricultural and urban streams than in forest streams, which they attributed to intensive cultivation of crops which is characterized by heavy application of nitrogenous fertilizers. Qui-sheng et al. (2021) report that the high concentrations of NO3- recorded in the downstream area of River Jinsha in China were attributed to the contamination of nitrogenous fertilizers from farms on the bank of Jinsha River. Xia et al. (2020) in their review reports that agricultural runoff is responsible for 52 to 54% of nitrogen and phosphorous load in Taihu lake Basin in China. The mean concentration (0.59±0.04mg/l) of NO3- in the Kuti stream does not exceed the permissible limit of 50 mg/l while PO43- (0.37±0.02) exceeded 5 mg/l (NERN, 2011; WHO, 2017).

Conclusion

The application of agrochemicals in agricultural farmland has marginally increased crop yield and reduced the cost of labour, but its adverse effects outweigh its benefits. The concentration of glyphosate, nitrates, and phosphate in Kuti stream was below the maximum contamination level (MCL), but if the agricultural practices observed during this study continues, their concentration may exceed their MCL in the nearest future which may be detrimental to aquatic and human lives. Therefore, to avoid this scenario, eco-friendly agricultural practices such as conservation tillage, fertilization depth, and ecological ditches should be encouraged. Agricultural extension workers should sensitize rural farmers on the negative impacts of synthetic agrochemicals on the environment, agric environmental scheme should be implemented where farmers who practice conservation farming should be compensated for their trade-off for putting the environment into consideration.

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