Analysis of Nitrates and Phosphates in Drinking Water Samples Collected from Tea Growing Community, Nandi Hills, Kenya

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Authors' contributions

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ABSTRACT

Nitrates and phosphates are among the major inorganic pollutants in the environment, primarily contributed by nitrogenous and phosphate fertilizers, organic manures, human and animal wastes, and industrial effluents through biochemical activities of microorganisms. In Nandi Hills tea plantations, about 5,000 hectares of land are under mature tea and fertilizer is applied at a rate of 140 Kg /ha / year, with N: P: K being the commonly used fertilizer. Therefore, these inorganic ions can be discharged to water bodies through leaching and surface run-off. This study thus aimed at determining the concentration of nitrates and phosphate ions in borehole and stream water in Nandi Hills, Kenya. About 50 samples of drinking water (stream and borehole) were collected. The samples were analyzed to determine the concentration of nitrate ions, phosphate ions using cadmium reduction method and Uv-visible spectrophotometry. From the results obtained in the study, stream water recorded nitrate and phosphate concentrations of 2.91±0.74 and 0.30±0.08 mg/l respectively. In addition, there was a significant difference (P<0.05) in both nitrate and phosphate levels among the three sampling points in the three streams. However, there was no significant difference (P>0.05) in both nitrate and phosphate concentrations among the three streams used in

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the study. In borehole water, nitrate and phosphate levels were 1.69±0.79 and 0.29±0.07 mg/l respectively. Both nitrate and phosphate levels in stream and borehole water were found to be within the WHO acceptable limits. The study therefore concluded that concentrations of nitrate and phosphate ions in drinking water were within the WHO acceptable limits.

1. INTRODUCTION

According to Loucks et al. [1] water is an essential resource for living systems, industrial processes, agricultural production and domestic usage. The study further explained that water can be obtained from two main natural resources: groundwater and surface water. Groundwater includes borehole water and well water while surface water includes fresh water lakes, rivers, streams, etc. [2] recorded that water of good drinking quality is of basic importance to human physiology. The researchers further explained that an average man (of 53 kg – 63 kg body weight), requires about 3 litres of water in liquid and food daily to keep healthy. Therefore, water is regarded as one of the most indispensable substances in life and like air it is most abundant [3]. Increase in human population has exerted an enormous pressure on the provision of safe drinking water especially in developing countries [4]. Unsafe water is a global public health threat, placing persons at risk for a host of diarrheal and other diseases as well as chemical intoxication.

The current progression of human civilization has put serious concerns to the safety of ground and surface water for drinking purposes. This is mainly because of the current rate of water pollution. This form of environmental degradation occurs when pollutants are directly or indirectly discharged into surface and/or ground water bodies without adequate treatment to remove harmful compounds [4].

Water pollution is a major global problem mainly because of its serious effects on the entire biosphere [5]. The specific contaminants leading to pollution of water include a wide spectrum of chemicals, pathogens, and/or physical changes such as elevated temperature and discoloration [6]. While many of the chemicals and substances that are regulated may be naturally occurring (calcium, sodium, iron, manganese, etc.) the concentration is often the key in determining what is a natural component of water and what is a contaminant. High concentrations of naturally occurring substances can have negative impacts on aquatic flora and fauna [7].

Currently, the high water pollution load comes from chemicals which include detergents, disinfection by-products, food processing waste, insecticides, herbicides, petroleum, hydrocarbons, volatile organic compounds (VOCs), chlorinated solvents, perchlorate, pharmaceutical drugs and their metabolites, ammonia from food processing waste, chemical waste such as industrial by-products, fertilizers, heavy metals and silt [7,8].

Nitrates (NO_3^-) and phosphates (PO_4^{3-}) are among the major inorganic pollutants contributed by nitrogenous and phosphate fertilizers, organic manures, human and animal wastes and industrial effluents through the biochemical activities of microorganisms [9,10].

Excessive use of nitrogenous fertilizers such as Calcium Ammonium Nitrate (CAN) in agriculture has been one of the primary sources of high nitrate ions in water sources. Apart from nitrate ions, nitrogen is applied in ammonium (NH_4^+) and amide (NH_2^-) forms, which generates nitrate in soil system through mineralization, which is fairly rapid in tropical and subtropical soils. Livestock feeding, barnyards, septic tanks, animal and human contamination are the other important sources contributing high amounts of NO_3^- [10,11]. Due to its high solubility in water and low retention by soil particles, nitrate ions are prone to leaching to the subsoil layers and ultimately to the groundwater, if not taken up by plants or denitrified to N_2O and N_2 [12]. The rate of leaching is governed by the soil properties and amount of water present in the soil system. The arrival of nitrate to ground and surface water can be enhanced by shallow groundwater table; excessive application of nitrogenous fertilizers, manures and irrigation; and abundant rainfall.

Excessive use of phosphate fertilizers in agriculture has been known to be one of the major sources of high phosphates in water sources. In addition, waste-waters from

laundering agents contain phosphates; Most laundry detergents contain approximately 35% to 75% sodium triphosphate ($Na_5P_3O_{10}$) [13]. Phosphates exist in three forms: orthophosphate, metaphosphate (or polyphosphate) and organically bound phosphate with each compound bearing phosphorous in a different chemical arrangement [14]. Orthophosphates applied to agricultural or residential lands as fertilizers are carried into the surface water. In addition, leaching events can cause the vertical migration of the phosphates into the groundwater system causing pollution. Different organizations and countries have set standards for nitrates and phosphates in drinking water, to safeguard public health from the hazards associated with high concentrations of the chemicals.

In Nandi Hills tea plantations, about 5,000 hectares of land are under mature tea and fertilizer is applied at a rate of 140 Kg /ha/year, with N: P: K being the commonly used fertilizer [15]. Therefore, these inorganic ions can be discharged to water bodies through leaching and surface run-off. This study thus aims at determining the concentration of nitrates and phosphate ions in borehole and stream water in Nandi Hills, Kenya.

2. MATERIALS AND METHODS

2.1 Study Area

The research was conducted in Nandi Hills ward, Nandi County. The coordinates of Nandi Hills, are: 0°06'01.0"N, 35°10'35.0"E (Latitude: 0.100278; Longitude: 35.176389). Nandi Hills lies at an elevation of approximately 2,047 metres (6,716 ft), above sea level [16] and has a cool and wet climate with two rain seasons during the equinoxes. Temperatures vary between 18°C and 24°C which coupled with the rich volcanic soils make the area ideal for growing tea. Tea production in the Nandi Hills area uses high concentration of nitrogenous fertilizer. Nitrates can be discharged to water bodies through leaching and surface run-off and ends up in surface and ground water sources causing pollution [17].

2.2 Collection of Water Samples

A total of 50 water samples were collected from both surface water (stream) and ground water (boreholes) sources using plastic bottles. Out of the 50 samples collected, 40 of them were from boreholes while 10 were from streams. The samples collected were kept in a cooler containing ice and transported to the laboratory within a period of 24 hours. This was done to inhibit metabolic processes of microbes and biodegradation reactions that could significantly change the levels of nitrates and phosphates.

2.3 Analysis of Nitrate Concentration in Water

Analysis of nitrates was done using cadmium reduction method according to [18]. In this case, the sample was filtered using a filter paper, and passed through a column containing granulated copper-cadmium to reduce nitrate to nitrite. The nitrite (that originally present plus reduced nitrate) was determined by diazotizing with sulfanilamide and coupling with N-(1-naphthyl)-ethylenediaminedihydrochloride to form a highly colored azo dye which is measured colorimetrically using UV-Vis spectrometer. An absorbance measurement was made at 220 nm and corrected by subtracting a second measurement at 275 nm. This was done to compensate for the presence of organics.

2.4 Analysis of Phosphates Concentration in Water

Spectrophotometric method as described by [18] was employed in the analysis. The method involves the formation of molybdophosphoric acid, which is reduced to the intensely colored complex, molybdenum blue. This analytical method is usually extremely sensitive and is reliable down to concentration of 0.1mg of phosphorus per liter of water

Preparation of Standard Solutions: A 5 point calibration curve was prepared with concentrations ranging from 0 – 5 mg/L Phosphate from the stock standard solution. The standard solutions and the blank was treated according to the following "color development" procedure of [19]. After measuring the absorbance of these solutions, a plot of absorbance versus concentration was generated.

Color Development in Sample: A 25 mL water sample to be analyzed was placed in an Erlenmeyer flask (measured with a volumetric pipet). Approximately 1.0 mL of ammonium molybdate solution was added and the mixture swirled for 10 minutes to mix properly. To the flask, two drops of stannous chloride solution was added and mixed by swirling. Development

of a blue color within five minutes denoted the presence of phosphate ions. The measurements were recorded appropriately for each sample at 650 nm.

2.5 Data Analysis

Data was analyzed descriptively using Statistical Package for Social Science (SPSS), version 20. The differences among mean concentrations of phosphates and nitrates in water samples were determined using Analysis of variance (ANOVA). Results were presented using both Tables and Figs.

3. RESULTS AND DISCUSSION

3.1 Concentration of Nitrate Ions in Streams Water

From Table 1, the mean concentration for nitrate ions increased downstream in all the three streams. In the first stream, concentration of nitrate ions increased significantly (p<005) from 2.47 upstream to 3.35 mg/l downstream. Similarly, the concentration of nitrate ions increased significantly from 2.47 and 2.97 mg/l upstream to 3.17 and 3.46 mg/l downstream in the second and third stream respectively.

Table 1. Mean concentration of nitrate ions (mg/l) in stream water

Stream	Sampling point	Nitrate Mean$\pm$ SE (mg/L)
Stream 1	Upstream	$2.47^a \pm 0.044$
	Midstream	$2.53^a \pm 0.031$
	Downstream	$3.35^b \pm 0.012$
Stream 2	Upstream	$2.59^a \pm 0.041$
	Mid-stream	$2.64^a \pm 0.076$
	Downstream	$3.17^b \pm 0.092$
Stream 3	Upstream	$2.97^a \pm 0.051$
	Midstream	$3.05^a \pm 0.046$
	Downstream	$3.46^b \pm 0.089$

Mean values with different letters in a column are significantly different at p<0.05

Analysis of variance (ANOVA) results on differences in mean concentration of nitrate ions among streams and sampling points are summarized in Table 2. Mean concentration of nitrate ions among the three sampling points differed significantly (p<0.05). However, there was no significant difference (p>0.05) in nitrate ions concentration among the three streams. In addition, the interaction between stream and sampling point was insignificant (p>0.05).

Table 2. Effect of stream, sampling point and their interaction on nitrate ions concentration

Source of variation	F-Value	P- Value
Stream (S)	14.671	0.542
Sampling point (SP)	8.966	0.031**
Stream× Sampling point (S×SP)	37.421.	0.067

*** Denotes significance at P<0.05*

The levels of nitrate recorded at the study area could be as a result of certain natural processes like decomposition of vegetation and activities of nitrogen fixing bacteria and precipitation [20]. Most importantly, the major causes of high nitrate concentration could be due to the farming activities that go on around the catchment of the study area. [21] reported that after fertilizers are applied to fields, nitrogen not absorbed by crops nitrifies flows over the ground surface into the nearest stream. A study carried out by Biggs et al. [22] reported levels of nitrate ions that were within WHO acceptable standards in the Piracicaba stream in Brazil.

The findings from the study also reported an increase in concentration of nitrate ions downstream among the three streams used in the study. This is attributed to increase in human pollution downstream. These results are in harmony with others studies. Takem et al. [23] reported that the levels of nitrate ions in the downstream and upstream ranged between 24 and 21 mg/L respectively. Furthermore, Mladenov et al. [24] reported average NO^{3-} being more than two times higher in the downstream than upstream of Notwane stream in south-eastern Botswana. Earlier on, [25] reported NO_3 levels in the Osun stream in Nigeria to range between 20 and 14 mg/L downstream and upstream respectively.

3.2 Concentration of Phosphate Ions in Stream Water

Like nitrate ions concentration, the mean concentration of phosphate ions among the three sampling points differed significantly (p<0.05). (Table 3)

3.3 Concentration of Phosphate Ions in Stream Water

Like nitrate ions concentration, the mean concentration of phosphate ions among the three sampling points differed significantly (p<0.05). However, there was no significant difference (p>0.05) in the concentration of phosphate ions

among the three streams. Furthermore, there was insignificant (p>0.05) interaction between stream and sampling point as shown in Table 4.

Table 3. Mean concentration of nitrate ions (mg/l) in stream water

Stream	Sampling point	Nitrate Mean± SE (mg/L)
Stream 1	Upstream	2.47^a±0.044
	Midstream	2.53^a±0.031
	Downstream	3.35^b±0.012
Stream 2	Upstream	2.59^a± 0.041
	Mid-stream	2.64^a±0.076
	Downstream	3.17^b±0.092
Stream 3	Upstream	2.97^a±0.051
	Midstream	3.05^a±0.046
	Downstream	3.46^b±0.089

Mean values with different letters in a column are significantly different at p<0.05

Table 4. Effect of stream, sampling point and their interaction on the concentration of phosphate ions

Source of variation	F-value	P- value
Stream (S)	2.416	0.236
Sampling point (SP)	1.730	0.015**
Stream× Sampling point (S×SP)	14.120.	0.214

*** denotes significance at p<0.05*

Generally results in Table 5 recorded an increase in the concentration of phosphate ions downstream among the three streams. Basically in stream 1, 2 and 3, phosphates ions ranged between 0.19-0.37, 0.2-0.39 and 0.27-0.40 mg/L respectively.

These traces of phosphates ions could have been brought about by excessive use of readily available conventional chemical fertilizers on tea farms in the study area. Levallois et al. [26] recorded that use of chemical fertilizers is the major source of surface waters contamination. Apart from the use of chemical fertilizers, the use of detergents in car or cloth washing at the banks could be the possible source of high phosphate concentration in the stream. Furthermore, during natural process of weathering, rocks gradually release phosphorus as phosphate ions which are soluble in water and gradually mineralize phosphate compounds breakdown.

Similar findings were reported by [27] where phosphate concentration ranged from <0.001 to 0.321 mg/L in surface water in South Western Ghana.

Table 5. Mean concentration (mg/l) of phosphate ions in the Stream water

Stream	Sampling point	Phosphate ions Mean± SE (mg/L)
Stream 1	Upstream	0.19a±0.01
	Midstream	0.31^b±0.08
	Downstream	0.37^b±0.12
Stream 2	Upstream	0.20^a± 0.01
	Mid-stream	0.34^b±0.06
	Downstream	0.39^b±0.09
Stream 3	Upstream	0.27^a±0.03
	Midstream	0.29^a±0.04
	Downstream	0.40^b±0.08

Mean values with different letters in a column are significantly different at p<0.05

3.4 Nitrate and Phosphate Concentrations in Borehole Water

The mean phosphate and nitrate concentrations in borehole water were 0.298 and 1.697 mg/L respectively (Table 6). Generally, nitrate levels were higher than phosphate levels in borehole water.

Table 6. Means of concentrations of nitrate ions and phosphate ions in borehole water

Concentration of inorganic in water (mg/L)	
Phosphate ions	Nitrate ions
0.29±0.07	1.69±0.79

Fig. 1 clearly indicates that concentrations of phosphate ions in both borehole and stream water were within WHO acceptable limits (0.3 mg/L). Borehole water recorded phosphate ions that were slightly below the WHO acceptable limits (0.29 mg/L). On the other hand, stream water recorded a mean value of 0.302 mg/l which was found to be just within the WHO guidelines.

Water collected from boreholes in the study area recorded traces of nitrate ions that were found to be below the WHO acceptable limits. The traces of nitrate ions in borehole water are attributed to the fact that soil contains nitrate-rich rock minerals, which can dissolve gradually [27]. Another possible source of nitrate ions in borehole water in the region could be due to excessive use of chemical fertilizers by farmers given that tea farming is one of the main economic activities in the area. Furthermore, the depth of the boreholes in the study area could have contributed to the presence of nitrate ions in the water. According to Pulido-Bosch et al. [28] shallow boreholes which draw water from intensively cultivated superficial formations, yield waters with high nitrate ions. The study further

showed that when the boreholes are deeper and penetrate low-permeability cations in the superficial layers, the waters contain little nitrate ions. Similar results were also found in a study of groundwater quality by Munoz-Carpena et al. [29] in South Florida agricultural area U.S.A. who showed that some nitrate concentrations were below the WHO acceptable limits of 10 mg/L while others were above the limit. A study by [30] recorded NO_3-concentration ranging from 0.01 to 0.324 mg/L in ground water studied in the Ketu District. A study by Adekunle et al. [31] of groundwater quality in a typical rural settlement in Southwest Nigeria showed that Nitrate levels in some borehole water were within the WHO acceptable limits. [32] also recorded concentration ranging from <0.001 to 0.921 mg/L in surface water in South Western Ghana.

Fig. 2 indicates that the concentrations of nitrate ions in both borehole and stream were within WHO acceptable limits (10 mg/L). About 1.69 and 2.91 mg/L of nitrate levels in borehole and stream water were recorded respectively.

The low levels of phosphates ions in borehole water could be due to the fact that phosphate tends to sorb to soil and aquifer sediments and is not readily transported in groundwater. However, the presences of phosphate ion traces in borehole water within the study area could be attributed to what Salvato et al. [33] explained as excessive use of chemical fertilizers in agriculture. In addition, Tjandraatmadja et al. [34] proposed; cleaning products, cosmetics, medicated shampoos, food products, faeces and urine as sources of phosphate in groundwater. The principal source of phosphate ions in borehole water is established during natural process of weathering, rocks gradually release phosphorus as phosphate ions which are soluble in water and gradually mineralize phosphate compounds breakdown. Findings from the study are in agreement with those recorded by [25] where the concentrations in ground water ranged from 0.01 to 0.3 mg/l with a mean value of 0.11 mg/L. Another study by Dubrovsky et al. [35] reported that the estimated background concentration of
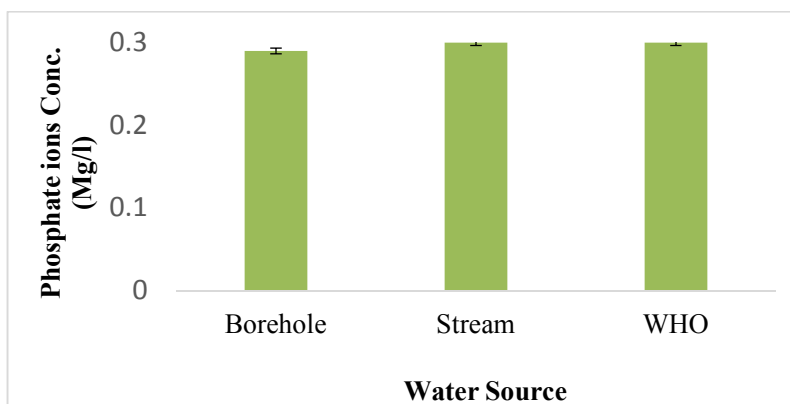

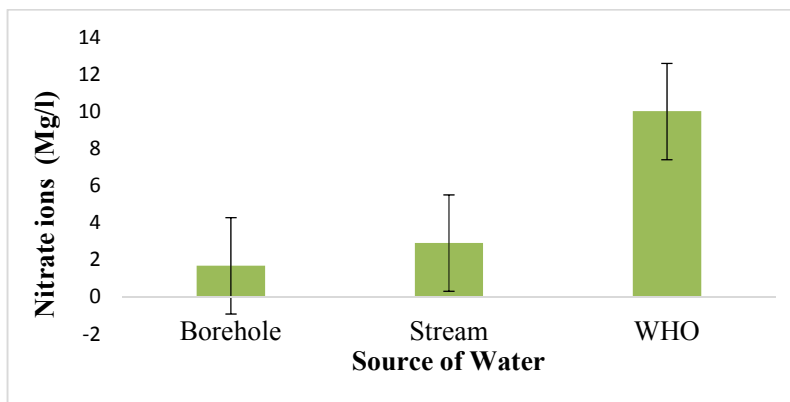**Fig. 1. Concentration of phosphate ions in drinking and WHO acceptable limits**

Fig. 2. Concentration of nitrate in drinking and WHO acceptable limits

orthophosphate for more than 400 shallow wells was 0.03 mg/L.

4. CONCLUSION

Both the concentration of nitrate ions and phosphate ions in borehole and stream water were within WHO acceptable limits, suggesting that the water sources in the study area are less polluted. There was significant difference in concentration of nitrate ions and phosphate ions among different sampling points in the three streams used in the study, suggesting that pollution of stream water in the study area increases downwards. Therefore, use of both borehole and stream water for drinking in the study area should continue. Also for stream water, upstream water should be used for drinking since the level of inorganic ions is low.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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