Research Article

Pollution of Water Resources by Agrochemicals in the Agroindustrial Areas at the South Western Flank of Mount Cameroon.

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ABSTRACT

This study aimed to assess the contribution of certain constituents of soluble agrochemical residues to surface and groundwater pollution in the study area. The constituents studied included Dissolved Oxygen (DO), Nitrate (NO_3^-), Phosphate (PO_4^{2-}), Cadmium (Cd), Lead (Pb), and Nickel (Ni) in various water sources. Forty water samples were collected from both surface and groundwater. In-situ electronic meter measurements were used to determine the DO levels. The laboratory methods of Nitrogen Distillation and spectrophotometry were employed to measure the concentrations of NO_3^- and PO_4^{2-}, respectively. The concentrations of heavy metals were determined using Atomic Absorption Spectrometry. The results obtained during the wet season indicated that DO, NO_3^-, and PO_4^{2-} levels were within permissible limits. However, for Cd, Pb, and Ni, a significant proportion of values exceeded the permissible limits during this season (Cd: 95%, Pb: 95%, Ni: 35%), suggesting possible contamination of the water sources. Conversely, during the dry season, all parameters were within permissible limits, except for Pb, where 95% of its values exceeded the limit. These findings conclude that the application of agrochemicals in the agro-industrial areas has a notable impact on water resources, particularly during the wet season.

Keywords: Water resources, Pollution, Agrochemicals, Mount Cameroon.

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RESUME

Cette étude visait à évaluer la contribution de certains constituants des résidus agrochimiques solubles à la pollution des eaux de surface et des eaux souterraines dans la zone d'étude. Les constituants étudiés comprenaient l'oxygène dissous (OD), le nitrate (NO_3^-), le phosphate (PO_4^{2-}), le cadmium (Cd), le plomb (Pb) et le nickel (Ni) dans diverses sources d'eau. Quarante échantillons d'eau de surface et d'eau souterraine ont été prélevés. Les niveaux d'OD étaient mesurés sur place avec quelques compteurs électroniques. Les méthodes de laboratoire de distillation de l'azote et de spectrophotométrie ont été utilisées pour mesurer les concentrations de NO_3^- et PO_4^{2-}, respectivement. Les concentrations de métaux lourds ont été déterminées par spectrométrie d'absorption atomique.

Les résultats obtenus pendant la saison humide ont indiqué que les niveaux d'OD, de NO_3^- et de PO_4^{2-} se situaient dans les limites autorisées. Cependant, pour le Cd, le Pb et le Ni, une proportion significative des valeurs dépassait les limites autorisées pendant cette saison (Cd : 95%, Pb : 95%, Ni : 35%), ce qui suggère une contamination possible des sources d'eau. À l'inverse, pendant la saison sèche, tous les paramètres se situaient dans les limites autorisées, à l'exception du Pb, dont 95 % des valeurs dépassaient la limite. Ces résultats concluent que l'application de produits agrochimiques dans les zones agro-industrielles a un impact notable sur les ressources en eau, en particulier pendant la saison des pluies.

Mots-clés : Ressources en eaux, pollution, produits agrochimiques, Mont Cameroun.

INTRODUCTION

Water is essential for sustaining economic growth and meeting the increased demand for food (Mateo-Sagasta et al., 2017). Agriculture accounts for 70% of water abstractions worldwide and plays a major role in water pollution through the use of agrochemicals (UNEP, 2016). Agrochemicals have become vital components of modern agricultural systems. However, the extensive and indiscriminate use of these agrochemicals to meet the growing food demand caused by the increasing world population has led to the pollution of surface and groundwater resources (Khanna and Gupta, 2018). The use of agrochemicals saturates the soil with major ions (sodium, potassium, magnesium, nitrate, phosphate) and certain heavy metals (nickel, cadmium, lead, arsenic). These major ions and heavy metals are often discharged as runoff into nearby water bodies or leached into underground water, thereby causing water pollution. This pollution poses demonstrated risks to aquatic ecosystems (eutrophication), human health, and productive activities (UNEP, 2016).

There is global concern regarding the impact of agrochemicals on soil and water quality (Keshin, 2010). Different types of agrochemicals used in the fields have resulted in various forms of surface and groundwater pollution (Keshin, 2010). Agricultural activities directly and indirectly affect the concentrations of inorganic chemicals in surface and groundwater (Boehlke, 2002). The direct impacts include the dissolution and transport of excessive quantities of fertilizers and associated materials, as well as hydrological alterations related to irrigation and drainage. The indirect impacts involve changes in water-rock reactions in soils and aquifers due to increased concentrations of dissolved oxidants, protons, and major ions (Elhatip et al., 2003).

Previous studies have identified a range of chemicals found in fertilizers and agricultural pesticides, including major ions such as sodium, magnesium, calcium, potassium, chloride, sulfate, nitrate, phosphate, ammonium, and trace elements such as arsenic, cadmium, lead, nickel, chromium, copper, mercury, iron, zinc, and manganese (Alloway, 1990; Chen et al., 1997; Keshin, 2010). For instance, Moon et al. (1999) found the presence of cadmium, lead, nickel, and chromium in agricultural soils and adjacent river sediments in Northeast China. In another study conducted in the agricultural areas of Mersin Province, it was suggested that the levels of copper, cadmium, manganese, nickel, lead, chromium, and molybdenum detected in streams and irrigation channel samples were a result of agricultural pesticides used in the field (Kumbur et al., 2008). Baba and Ayyýldýz (2006) reported high levels of nitrate in the vicinity of Urla and Menemen, located in the Aegean region, and attributed it to the use of fertilizers and pesticides in agricultural activities. These studies indicate that the indiscriminate use of agrochemicals in agricultural fields poses significant pollution risks to surface and groundwater.

The study area comprises extensive plantations of palms and bananas, as well as individual farms that use different types of pesticides and fertilizers to improve crop yields. The water resources in this area are being exploited by the Cameroon

Development Corporation (CDC) for their plantations and by some private farm owners. However, these water resources, both surface and groundwater, face pollution risks primarily due to the use of pesticides and fertilizers in agriculture. The introduction of pollutants into water bodies deteriorates water quality and reduces its suitability for consumption (Melloul and Collin, 1994). Given this situation, it is necessary to study surface and groundwater pollution caused by agrochemicals in this area.

The main objective of this study is to assess the extent of agrochemical contribution to the pollution of surface and groundwater resources, with specific objectives to identify the different agrochemicals used and determine the level of agrochemical pollution using relevant indicators. This approach aims to establish baseline data for monitoring agrochemicals and protect the water resources in this area.

MATERIALS AND METHODS

Study Site

The study area is located on the southwestern flank of Mount Cameroon in the South West Region of Cameroon (Fig. 1). It includes the intense agro-industrial zones occupied by the CDC plantations, extending from Idenau to Debundschang, Limbe, and down to Tiko. The Mt. Cameroon area has a tropical seasonal climate with one rainy season (May – October) and one dry season (November – April) (Ako et al., 2013). The geology of the area is dominated by recent volcanic materials, including lava flows, terraced pyroclastic materials, basalts, lahars, and etindites. The area is well-watered, characterized by heavy precipitation that recharges the volcanic aquifer after percolating through scoriaceous rocks (Ako et al., 2011). The Mt. Cameroon volcanic structure represents a vast aquifer where groundwater circulates, thus making it a good location for this study.

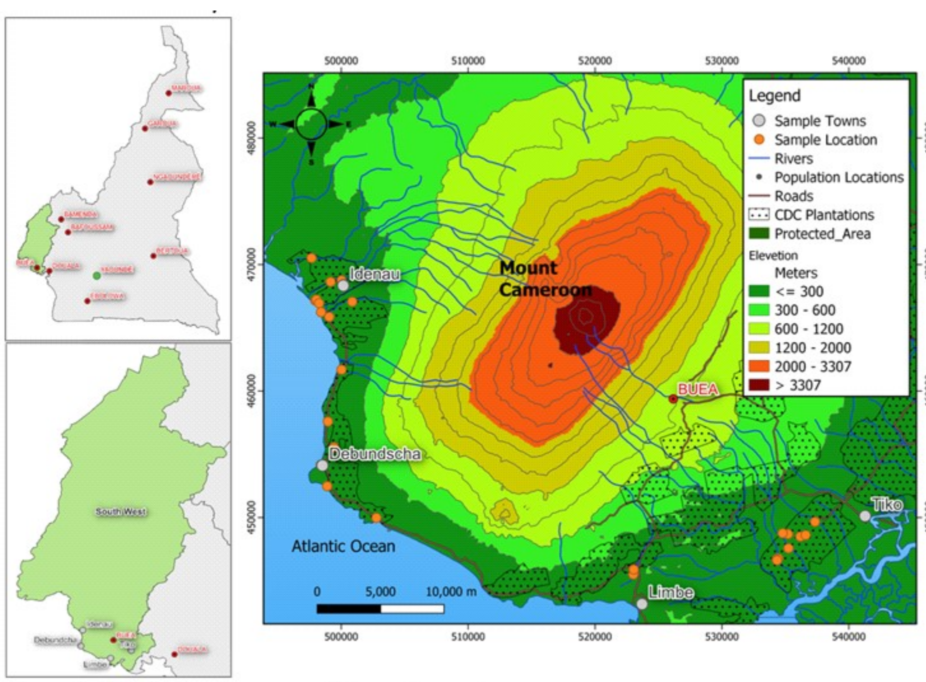

Figure 1: Sample location map of the entire study area

Methods

Prior to sampling and field measurements, a reconnaissance survey was carried out in February 2020. The survey aimed to identify sampling points within and around the active portion of the CDC plantations, based on the presence of water sources. During the survey, information was gathered from plantation managers of CDC and private farm owners regarding the types of agrochemicals used on the farms, as well as their frequency and purpose of use.

A total of 40 water samples were collected during the wet and dry seasons in August 2020 and February 2021, respectively. Twenty different water sources were sampled per season. All water samples were collected in sterilized 500ml polyethylene plastic bottles and transported to the FASA laboratory at the University of Dschang for analysis. The analysis included measurements of NO_3^-, PO_4^{2-}, and heavy metals (Cadmium, Lead, Nickel) using Nitrogen Distillation, Spectrophotometry, and Atomic Absorption Spectrometry (for heavy metals) techniques, respectively. Water samples for heavy metal analysis were acidified with 2 drops of 2% nitric acid, while those for NO_3^- and PO_4^{2-} analysis were collected without acidification. The collected water samples were immediately stored in coolers with ice blocks and transported to the laboratory within 24 hours.

The dissolved oxygen (DO) levels of the water sources were measured in situ using a portable YSI ProODO optical Dissolved Oxygen meter. The probe was inserted into the water, moved to release air bubbles, and ensure a fresh sample was in contact with the sensor. The equipment was held in the water for a few seconds until a stable value was detected, and the value was recorded. Data analysis was performed using SPSS version 20 for basic statistical analysis. QGIS Desktop version 3.20.3 was utilized for the production of maps and spatial distribution plots using interpolation.

RESULTS

1. Agrochemicals Frequently Used

The results obtained from field visits and interviews revealed that within the CDC plantations, organophosphate pesticides were frequently used, along with NPK and urea fertilizers. Specifically, glyphosate (C3H8NO5P) and glufosinate ammonium (C5H15N2O4P) herbicides were the most commonly applied organophosphate pesticides in both the banana and palm plantations. Glyphosate herbicides demonstrated high solubility in water at room temperature, with a solubility of 1.01 g/100 mL (20°C), while glufosinate ammonium herbicides exhibited lower solubility at 1,370 g/100 mL (22°C). The reaction of glyphosate with water can be represented by the equation:

$$2C_3H_8NO_5P + 4H_2O \longrightarrow O_2 + 6CH_4 + 2PO_4 + 2NO_2$$

According to this equation, when glyphosate herbicides dissolve in water, they produce nitrate and phosphate, which can potentially contaminate groundwater through leaching or enter surrounding water bodies as runoff, leading to water pollution. Similarly, NPK and urea fertilizers dissolve in water, resulting in the release of nitrate and phosphate. Elevated concentrations of nitrate and phosphate in drinking water can pose health hazards and contribute to eutrophication in nearby water bodies when they are carried by runoff (Jimoh et al., 2003).

For this study, the selected parameters of interest were nitrate, phosphate, dissolved oxygen, and heavy metals (cadmium, lead, nickel), which are commonly associated with the production of agrochemicals.

2. Agrochemical pollution

The concentrations of the 6 parameters of interest (Dissolved Oxygen (DO), Nitrate (NO_3^-), Phosphate (PO_4^{2-}), Cadmium (Cd), Lead (Pb), Nickel (Ni)) of the different water samples were used to determine the level of agrochemical pollution. A statistical summary of the concentration levels of these 6 parameters of interest in the different water samples for both seasons are presented on Table 1 and 2 respectively. A significant proportion of Ni, Pb and Cd exceeded the WHO (2011) maximum permissible limit for the wet season whereas only Pb exceeded the limit for the dry season.

Table 1: Statistical analysis for the 6 parameters of interest for the wet season compared with the WHO (2011) standard.

Parameter (Wet Season)	Min	Max	Mean	p-Value	WHO limit	Comment
DO	0.064	0.448	0.2304±0.089	$p<0.05$	3	OK
NO_3^-	1.24	19.85	9.08±6.620	$p<0.05$	50	OK
PO_4^{2-}	0.01	0.35	0.131±0.110	$p<0.05$	0.54	OK
Ni	0.00	0.110	0.053±0.035	$p>0.05$	0.07	Out of range
Pb	0.00	0.065	0.034±0.017	$p>0.05$	0.01	Out of range
Cd	0.00	0.02	0.012±0.005	$p>0.05$	0.003	Out of range

Table 2: Statistical analysis for the 6 parameters of interest for the dry season compared with the WHO (2011) Standard.

Parameter (Dry Season)	Min	Max	Mean	p-Value	WHO limit	Comment
DO	1.05	1.683	1.412±0.143	$p<0.05$	3	OK
NO_3^-	0.28	6.58	2.303±1.641	$p<0.05$	50	OK
PO_4^{2-}	0.10	0.41	0.18±0.087	$p<0.05$	0.54	OK
Ni	0.002	0.06	0.0282±0.014	$p<0.05$	0.07	OK
Pb	0.00104	0.0518	0.02144±0.015	$p>0.05$	0.01	Out of range
Cd	0.00042	0.0013	0.00078±0.0003	$p<0.05$	0.003	OK

A comparative summary of the 6 parameters of interest for both seasons was conducted using a histogram as shown on Figure 2 below. NO_3^- had the highest values for both seasons as compared to all other parameters, though its values were within the permissible limit, followed by DO, and then PO_4^{2-}.

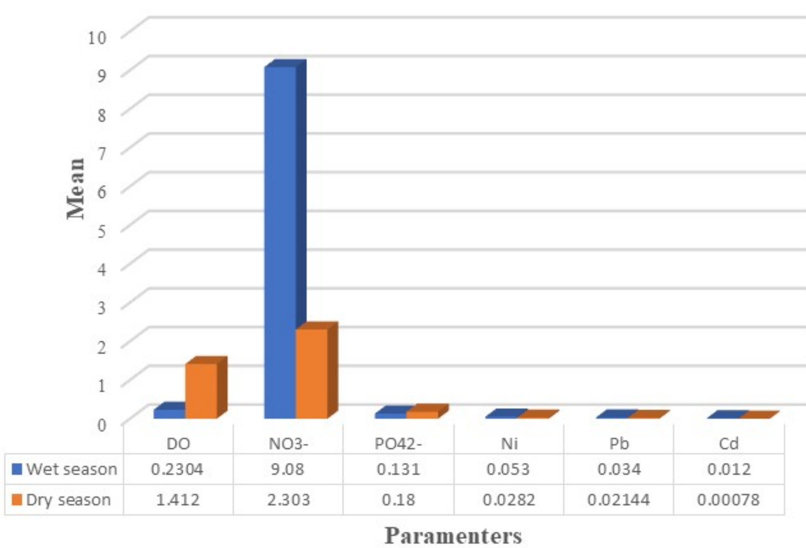

Figure 2: Mean concentrations of the 6 parameters of interest for both wet (blue) and dry (brown) seasons.

2.1 Dissolved Oxygen

The concentration of DO in the water samples for the wet season was very low ranging from 0.064mg/L to 0.448mg/L with a mean value of 0.2304±0.089mg/l. Its concentration for the dry season ranged from 1.05mg/L to 1.68mg/L with a mean value of 1.412±0.143mg/l. The DO values for both seasons were all within the permissible limit for water quality (Table 1 & 2 above). The results for both seasons were presented on a spatial distribution plot as shown on Figure 3a & 3b.

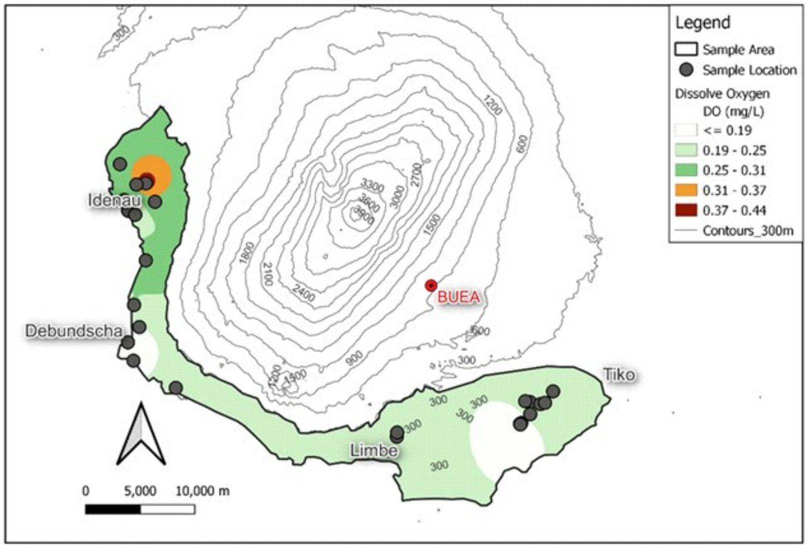

Figure 3a: Spatial distribution plots of DO for the wet season. ***Note: Highest values of DO at Idenau and lowest values at Debundscha and Tiko.***

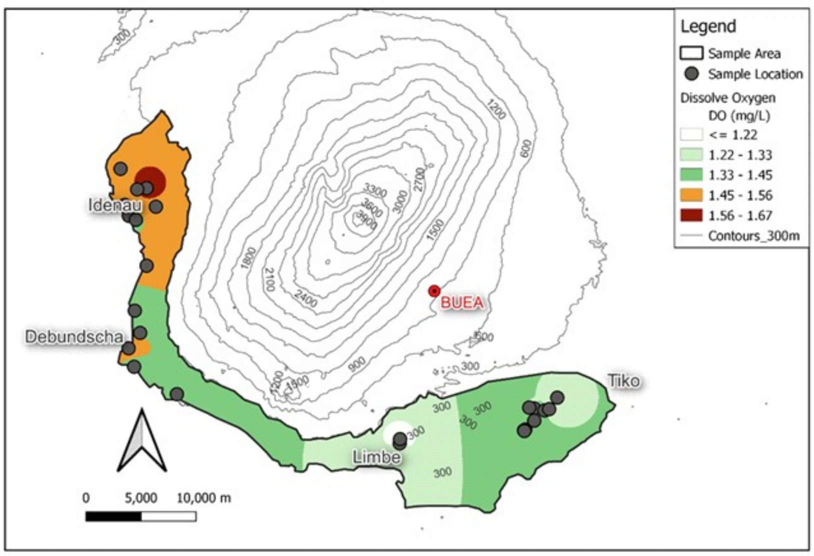

Figure 3b: Spatial distribution plots of DO for the dry season. ***Note: Majority of samples at Idenau has high values, and few samples with high values at Debundscha.***

2.2 Nitrate ion

The primary source of nitrate in water could be from agricultural runoff, urban runoff, and natural deposits (Brindha et al., 2017). The NO_3^- concentrations for both seasons all fell within the permissible limit for drinking water, with values ranging from 1.24mg/L to 19.85mg/L with a mean value of 9.08±6.620mg/l for the wet season, and 0.28mg/l to 6.58mg/L with a mean value of 2.303±1.64mg/l for the dry season. The NO_3^- values for the wet season were higher than the values for the dry season. The results were presented on a spatial distribution plot as shown on Figure 4a & 4b.

2.3 Phosphate ion

Naturally occurring levels of Phosphates in water are not harmful to humans or the environment, but high levels of Phosphates in water can cause digestive problems in humans and excessive amounts of phosphates in water bodies can cause eutrophication (Fadiran et al., 2008). The PO_4^{2-} concentrations for all samples were within the permissible limits for both the wet and dry seasons

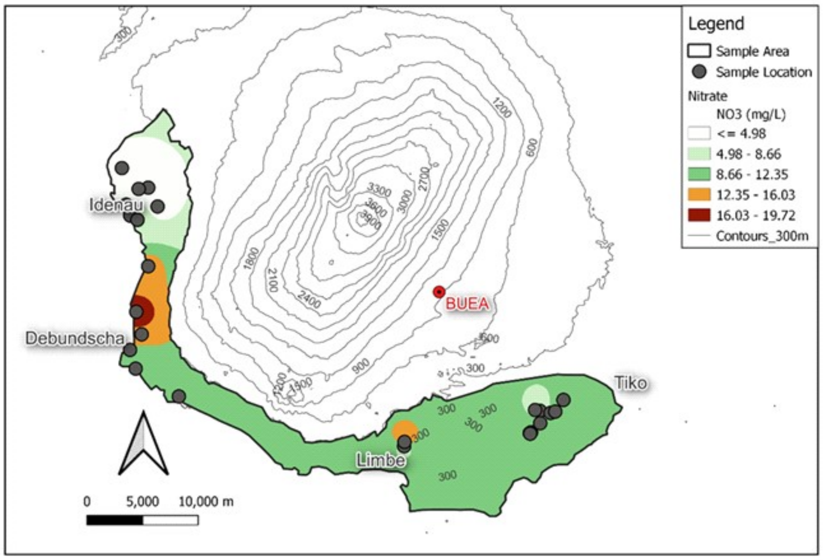

Figure 4a: Spatial distribution plot of NO_3^- for the Wet season. ***Note: Highest values of NO_3^- at Debundscha***

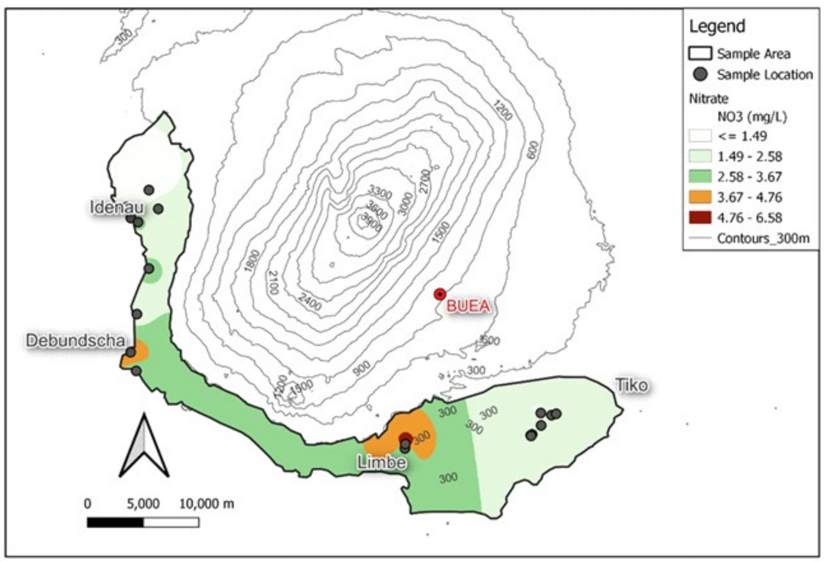

Figure 4a: Spatial distribution plot of NO_3^- for the Wet season. ***Note: Highest values of NO_3^- at Debundscha***

with values ranging from 0.01 to 0.35mg/l with a mean value of 0.131±0.110mg/l for wet season, and 0.10 to 0.41mg/l with a mean of 0.18±0.087mg/l for the dry season (Table 1 & 2 above). The PO_4^{2-} results for both seasons were presented on a spatial distribution plot as shown on Figure 5a & 5b.

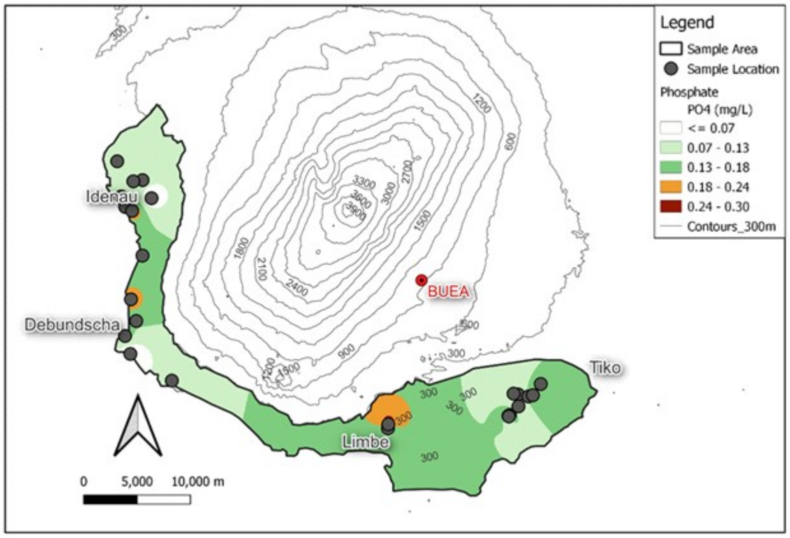

Figure 5a: Spatial distribution plot of PO_4^{2-} for the wet season. ***Note: Highest values at Limbe.***

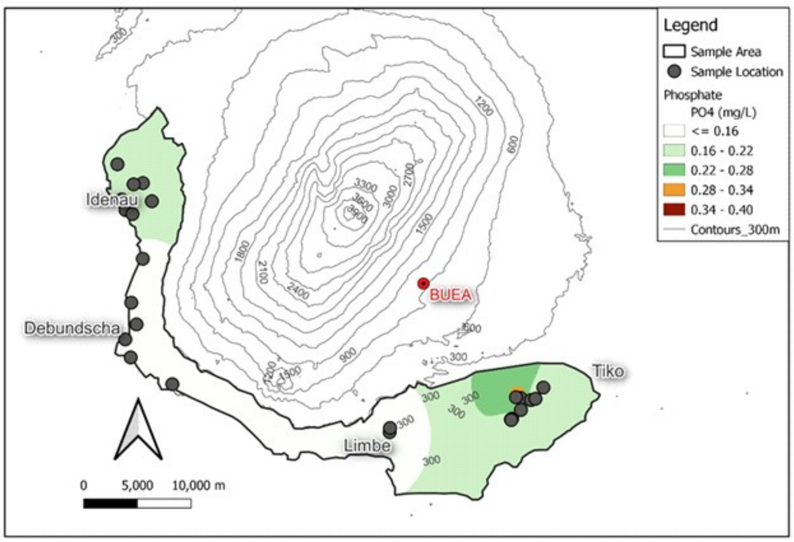

Figure 5b: Spatial distribution plot of PO_4^{2-} for the dry season. ***Note: Highest values at Tiko and lowest values at Limbe and Debundscha.***

2.4 Nickel (Ni)

The concentration of Ni for samples in the wet season ranged from 0.00mg/L to 0.11mg/L with a mean value of 0.053±0.035 mg/l as presented on Table 1. Thirty-five percent of the samples exceeded the permissible limit of 0.07mg/l for Nickel and the remaining 65% of the samples were within limit for the wet season. All water samples (100%) for the dry season were within the permissible limit with values ranging from 0.002mg/l to 0.06mg/l with a mean value of 0.0282±0.014 (Table 2). A distribution plot was used to represent these results as shown on Figure 6a & 6b.

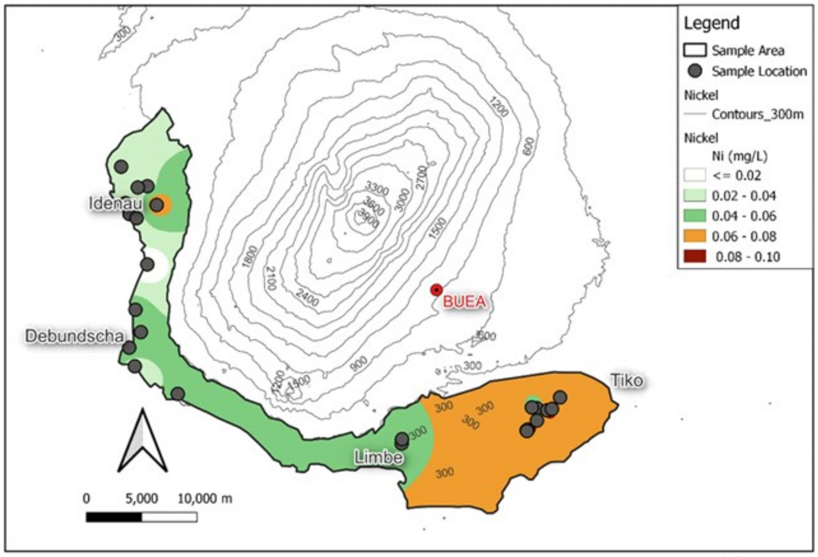

Figure 6a: Spatial distribution plot of Ni for the wet season. ***Note: Highest values at Tiko with a few high values at Idenau.***

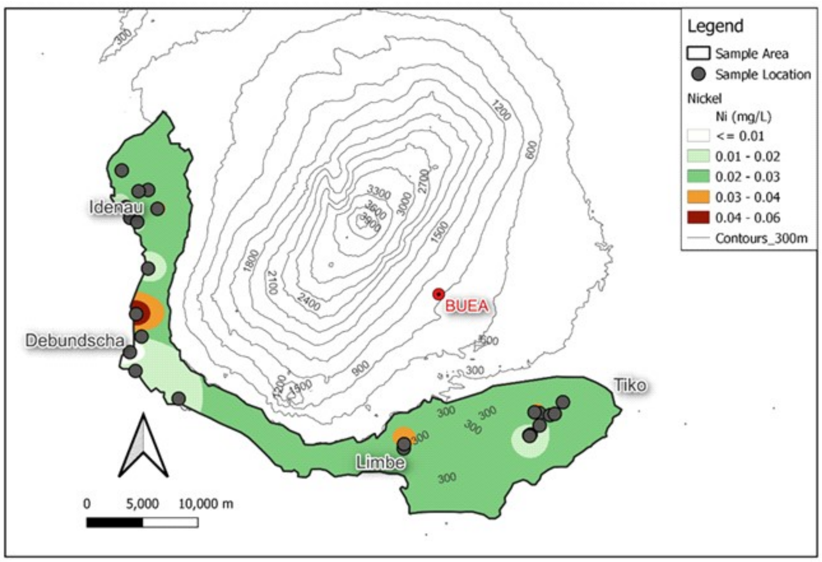

Figure 6b: Spatial distribution plot of Ni for the dry season. ***Note: Highest values at Debundscha with a few high values at Limbe and Tiko.***

2.5 Lead (Pb)

According to Keskin (2010) lead in surface and groundwater may occur from agricultural effluents with the excessive use of Phosphate fertilizers. Lead is one of the hazardous elements and has side effects on the human body such as hearing problems, neurological problems, anaemia, blood pressure, and kidney malfunction (Collin et al., 2022). The Lead (Pb) concentration for the wet season ranged from 0.00mg/l to 0.065mg/l and had a mean value of 0.034±0.017mg/l, with 95% of the water samples exceeding the permissible limit of 0.01mg/l. For the dry season, the Pb concentrations ranged from 0.001mg/l to 0.052mg/l with a mean value of 0.021±0.015mg/l, with 95% of the samples also exceeding the limit. These results were presented on a spatial distribution plot as shown on Figures 7a & 7b below.

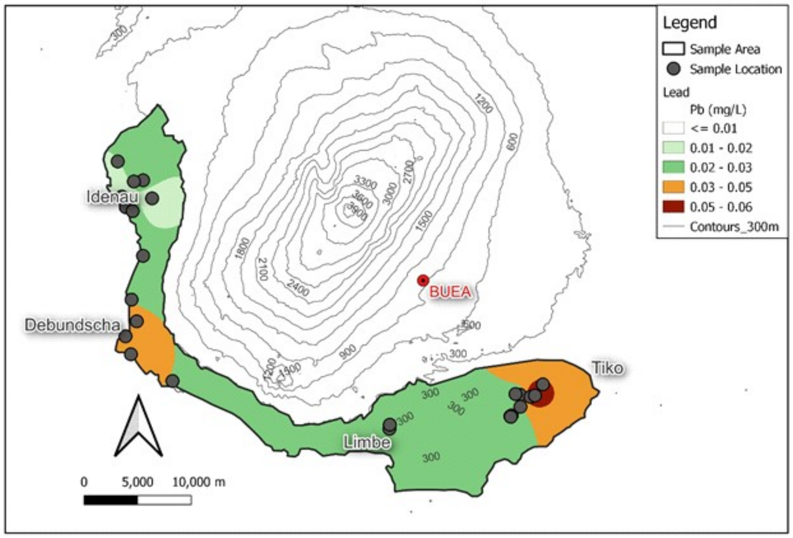

Figure 7a: Spatial distribution plot of Pb for the wet season. ***Note: Highest values at Tiko, and lowest values at Idenau.***

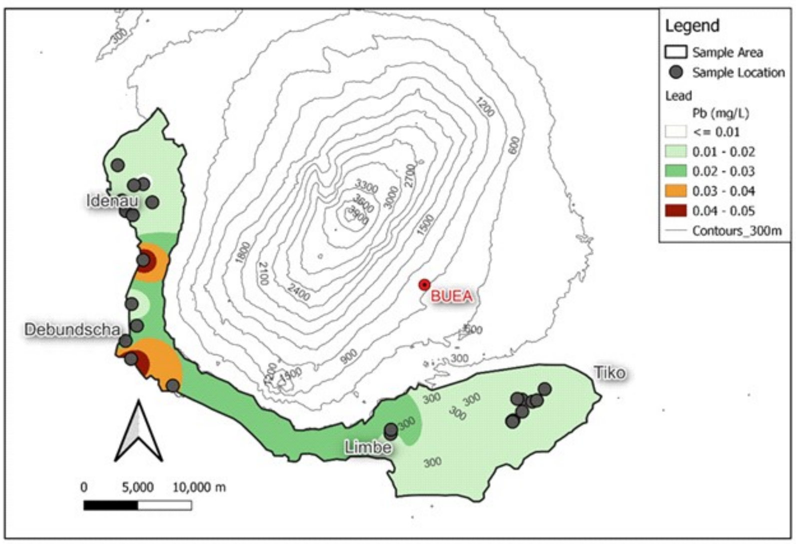

Figure 7b: Spatial distribution plot of Pb for the dry season. ***Note: Highest values at Idenau and Debundscha***.

2.6 Cadmium (Cd)

Cadmium concentrations for wet season samples ranged from 0.00mg/l to 0.02mg/l with a mean value of 0.012±0.005mg/l, with 95% of the samples exceeding the permissible limit of 0.003mg/l. All samples for the dry season were within the permissible limit, with values ranging from 0.00042mg/l to 0.0013mg/l with a mean value of 0.00078±0.0003mg/l. These results were presented on a spatial distribution plot as shown on Figure 8a & 8b.

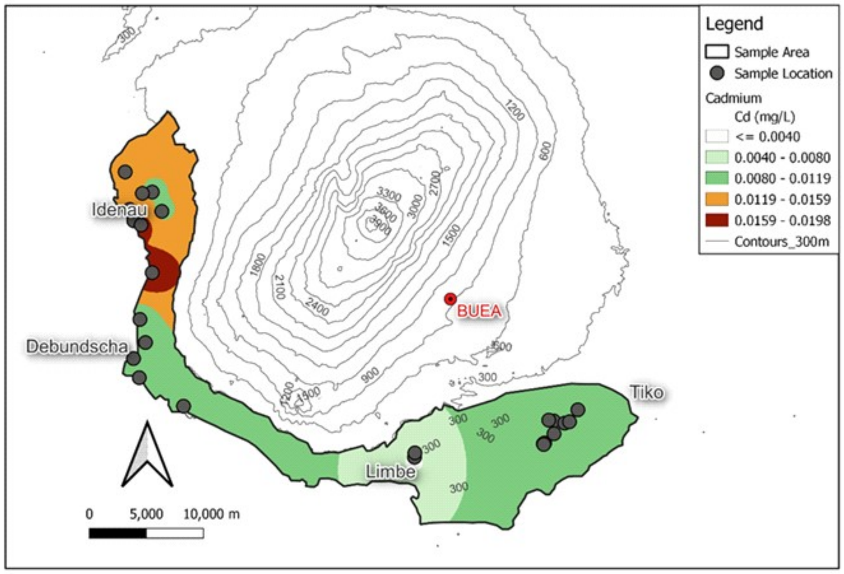

Figure 8a: Spatial distribution plot of Cd for the wet season. ***Note: Highest value at Idenau, and lowest values at Limbe.***

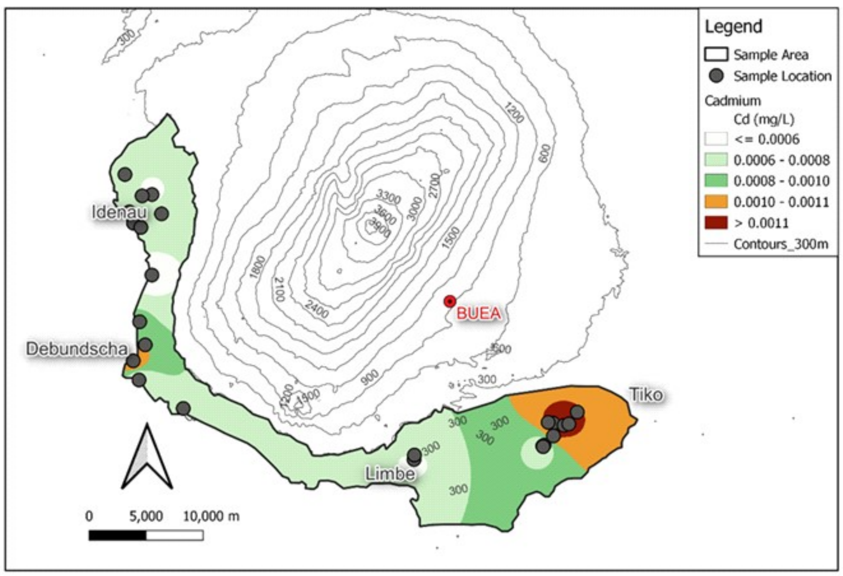

Figure 8b: Spatial distribution plot of Cd^{2+} for the dry season. ***Note: Highest values at Tiko.***

DISCUSSION

1. Agrochemicals Frequently Used

Organophosphate pesticides (glyphosate and glufosinate ammonium), **NPK** and **Urea** fertilizers are the soluble agrochemicals most frequently used by the CDC in its plantations. Based on their solubility, the parameters of interest for this study were: Nitrate, Phosphate, Dissolved Oxygen, Cadmium, Lead, and Nickel. The presence of Nitrate and Phosphate in drinking water above the permissible limit constitute a health hazard and can also cause eutrophication in nearby water bodies where it enters as runoff (Jimoh et al., 2003). The presence of nitrate in drinking water at concentrations greater than 50 mg/l could cause methemoglobinemia in babies aged less than 6 months (Parvizishad et al., 2017, WHO, 1998). Ni, Pb and Cd are non-essential heavy metals, meaning small quantity of any is poisonous (Adepoju-Bello et al., 2009).

According to Asogwa and Dongo (2009), farmers are exposed to some health effects due to incorrect application techniques for agrochemicals, poorly maintained spraying equipment, and inadequate storage practices for agrochemicals. As such, the community/farmers in the study area may also be exposed to some health effects as a result of the agrochemicals used in this area. Many widely used pesticides, such as organophosphates (frequently used in the study area), carbamates, pyrethroids, and chlorophenoxy herbicides are considered as neuro-developmental toxicants (Sudhangshu et al., 2014). In Cameroon, Roundup (glyphosate-based herbicide), Gramoxone and Atrazine are the most implicated pesticides based on their impacts on farmers health using the skin, inhalation, ingestion and eye contact as exposure routes (Pouokam et al., 2017). According to a study carried out by Justin et al. (2014) on three different ecological zones in Cameroon, stomach disorders, vomiting, skin irritations, dizziness, and watery eyes are some of the acute illnesses common with farmers in Cameroon in relation to the use of agrochemicals.

2. Agrochemical pollution

The level of DO in different water bodies depends on the physical, chemical and biological activity of the water body (Mulla et al., 2012; Imaobong and Ini, 2014). The low levels of DO in the study area especially during the wet season (0.064 to 0.448mg/L) could result from the presence of high organic content materials leading to Oxygen depletion (Gasim et al., 2007). These results imply a high degree of organic pollution (through runoff) of the water resources in the study area for the wet season. These findings are similar with the findings of Imaobong and Ini, 2014 in Akwa Ibom state of Nigeria who reported very low DO (0.1-0.2 mg/L), indicating an anaerobic and unhealthy state of Uruan surface and underground water.

Nitrate concentrations for both seasons were all below the maximum permissible limit of 50mg/l. High NO_3^- levels in water have been associated with methemoglobinemia, gastric ulcer, cancer, and urinary tract diseases (Wotany et al., 2013). Elevated values of NO_3^- were observed during the wet season (1.24 – 19.85mg/l) as compared to the dry season (0.28 – 6.58mg/l). This could be as a result of the runoff of nitrogen fertilizers into the waterbodies or by the leaching/seeping of these nitrogen fertilizers in to groundwater through irrigation and rainfall intensity in this area. These results are similar to the findings of Zuberi et al. (2019), in Tanzania. Ako et al. (2013) reported that the average groundwater nitrogen concentrations for Banana Plain (17.28mg/l) were higher as compared to that of the Mt. Cameroon area and attributed it mainly to anthropogenic activities (N-fertilisers, animal waste, organic manure).

The PO_4^{2-} concentrations for all samples were below the maximum permissible limit of 0.54mg/l for both the wet and dry seasons. Phosphate had elevated values for the dry season (mean value of 0.18±0.087mg/l) as compared to the values of the wet season (mean value of 0.131±0.110mg/l). This contradicts the results of Zuberi et al. (2019) in Tanzania, who reported high PO_4^{2-} concentration values in the wet season as compared to the dry season, as a result of increased runoff and leaching.

Heavy metals in surface and groundwater can occur either naturally as a result of the dissolution of rock materials or from anthropogenic activities such as the application of agrochemicals, industrial effluents, and inappropriate disposal of waste (Adepoju-Bello et al., 2009). All heavy metals (Ni, Pb, & Cd) for the wet season exceeded the maximum permissible limit, indicating high influence of agrochemical pollution during the wet season. These high values could be as a result of increased runoff and leaching due to the rainfall intensity. These results are similar with that of Keskin, (2010) and Zuberi et al. (2019). For the dry season, just one parameter (Pb) exceeded the limit (0.01mg/l), indicating lesser influence from agrochemical pollution. The high values of Pb (0.001mg/l to 0.052mg/l with a mean value of 0.021±0.015mg/l) in the dry season, could be as a result of the use of Phosphate fertilizers during this period brought in during irrigation.

CONCLUSION

Organophosphate pesticides (Glyphosate and Glufosinate ammonium herbicides), NPK and Urea fertilizers are the soluble agrochemicals frequently used in the study area. From these frequently used soluble agrochemicals, 6 parameters of interest (Dissolved Oxygen, Nitrate, Phosphate, Cadmium, Lead, and Nickel) were selected based on the reaction of these agrochemicals with water.

The results of agrochemical pollution showed that DO, NO_3^- and PO_4^{2-} were all within the permissible limits (values ranging from 0.01mg/L to 19.85mg/L) for both seasons. For Ni, Pb and Cd the majority of the concentrations exceeded the permissible limits (Ni:35%, Pb:95% and Cd:95%) for the wet season, indicating that the water resources in this area might be exposed to some agrochemical contamination during this season. Just one heavy metal Pb (with 95% of samples contaminated) was out of range for the dry season.

These results are indicative of the fact that, agrochemicals used in this agro-industrial area have a marked impact on the water resources during the wet season. It is therefore necessary to carry out an investigation on the health impact of these polluted water resources.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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