OPEN ACCESS

August 2021
ISSN 1996-0786
DOI: 10.5897/AJEST
www.academicjournals.org

ACADEMIC JOURNALS
expand your knowledge

About AJEST

African Journal of Environmental Science and Technology (AJEST) provides rapid publication (monthly) of articles in all areas of the subject such as Biocidal activity of selected plant powders, evaluation of biomass gasifier, green energy, Food technology etc. The Journal welcomes the submission of manuscripts that meet the general criteria of significance and scientific excellence. Papers will be published shortly after acceptance. All articles are peer-reviewed

Indexing

The African Journal of Environmental Science and Technology is indexed in:
CAB Abstracts, CABI's Global Health Database, Chemical Abstracts (CAS Source Index), China National Knowledge Infrastructure (CNKI), Dimensions Database, Google Scholar, Matrix of Information for The Analysis of Journals (MIAR), Microsoft Academic

AJEST has an h5-index of 14 on Google Scholar Metrics

Open Access Policy

Open Access is a publication model that enables the dissemination of research articles to the global community without restriction through the internet. All articles published under open access can be accessed by anyone with internet connection.

The African Journal of Environmental Science and Technology is an Open Access journal. Abstracts and full texts of all articles published in this journal are freely accessible to everyone immediately after publication without any form of restriction.

Article License

Article Copyright

Self-Archiving Policy

The African Journal of Environmental Science and Technology is a RoMEO green journal. This permits authors to archive any version of their article they find most suitable, including the published version on their institutional repository and any other suitable website.

Please see http://www.sherpa.ac.uk/romeo/search.php?issn=1684-5315

Digital Archiving Policy

The African Journal of Environmental Science and Technology is committed to the long-term preservation of its content. All articles published by the journal are preserved by Portico. In addition, the journal encourages authors to archive the published version of their articles on their institutional repositories and as well as other appropriate websites.

https://www.portico.org/publishers/ajournals/

Metadata Harvesting

The African Journal of Environmental Science and Technology encourages metadata harvesting of all its content. The journal fully supports and implement the OAI version 2.0, which comes in a standard XML format. See Harvesting Parameter

Memberships and Standards

Academic Journals strongly supports the Open Access initiative. Abstracts and full texts of all articles published by Academic Journals are freely accessible to everyone immediately after publication.

All articles published by Academic Journals are licensed under the Creative Commons Attribution 4.0 International License (CC BY 4.0). This permits anyone to copy, redistribute, remix, transmit and adapt the work provided the original work and source is appropriately cited.

Crossref is an association of scholarly publishers that developed Digital Object Identification (DOI) system for the unique identification published materials. Academic Journals is a member of Crossref and uses the DOI system. All articles published by Academic Journals are issued DOI.

Similarity Check powered by iThenticate is an initiative started by CrossRef to help its members actively engage in efforts to prevent scholarly and professional plagiarism. Academic Journals is a member of Similarity Check.

CrossRef Cited-by Linking (formerly Forward Linking) is a service that allows you to discover how your publications are being cited and to incorporate that information into your online publication platform. Academic Journals is a member of CrossRef Cited-by.

Academic Journals is a member of the International Digital Publishing Forum (IDPF). The IDPF is the global trade and standards organization dedicated to the development and promotion of electronic publishing and content consumption.

Contact

Editorial Office: ajest@academicjournals.org

Help Desk: helpdesk@academicjournals.org

Website: http://www.academicjournals.org/journal/AJEST

Submit manuscript online http://ms.academicjournals.org

Academic Journals
73023 Victoria Island, Lagos, Nigeria
ICEA Building, 17th Floor,
Kenyatta Avenue, Nairobi, Kenya.

Table of Content

Vol. 15(8), pp. 298-302, August 2021
DOI: 10.5897/AJEST2021.3015
Article Number: 127DC3C67427
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

ACADEMIC JOURNALS
expand your knowledge

African Journal of Environmental Science and Technology

Full Length Research Paper

Physicochemical Assessment of a Hand-dug Well and the Kamakubuna Stream in the Sella Limba Chiefdom, Kamakwie, Northern, Sierra Leone

Augustine Cole[2*], Mohamed Pujeh Junior[1], Yahaya Kudush Kawa[1] and Jonathan Kpaka[1]

[1]Department of Chemistry, School of Environmental Sciences, Njala University, Sierra Leone.
[2]Department of Agricultural Engineering, School of Technology, Njala University, Sierra Leone.

Received 14 April, 2021; Accepted 6 July, 2021

This research accesses the physical and chemical parameters of Ministry of Agriculture, Forestry and Food Security (MAFFS) hand dug well and the Kamakubuna Stream in the Sella Limba Chiefdom, Kamakwie Town. The physical parameters such as total dissolved solid (TDS), turbidity, pH, temperature, conductivity; and the chemical parameters such as residual chlorine, ammonium, ammonia, bromine, copper, fluoride, iron, nitrite, potassium, phosphate, sulphate, nitrogen-nitrate and bicarbonate. The samples were collected from the MAFFS hand dug well and the Kamakubuna stream, and transported to the water quality laboratory within thirty minutes. A physicochemical analysis was done on the water samples. The results analysed shown that the parameters were within the WHO accepted guidelines, except for low pH values and high mean value in turbidity for the MAFFS hand dug well.

Key words: Hand dug well, WHO, parameters, samples and stream.

INTRODUCTION

Worldwide, three in ten people, or 2.1 billion, lack access to safe, readily available water at home, and six in ten, or 4.5 billion, lack safely managed sanitation, according to a new report by WHO and UNICEF (2017). According to the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation, at least 1.2 billion people worldwide are estimated to drink water that is not protected against contamination from faeces. Even more drink water, which is delivered through a system without adequate protection against sanitary hazards. A similar report published by WHO/UNICEF 2017, estimated that, over half of the global population or 4.2 billion people lack safely managed sanitation services. According to WHO, safely managed drinking water and sanitation services means drinking water free of contamination, that is available at home when needed, and toilets whereby excreta are treated and disposed of safely. In many developing countries, the availability of quality water has become a crucial and urgent problem and a matter of concern to families and communities (Maduka et al., 2014).

*Corresponding author. E-mail: augustines.cole@gmail.com.

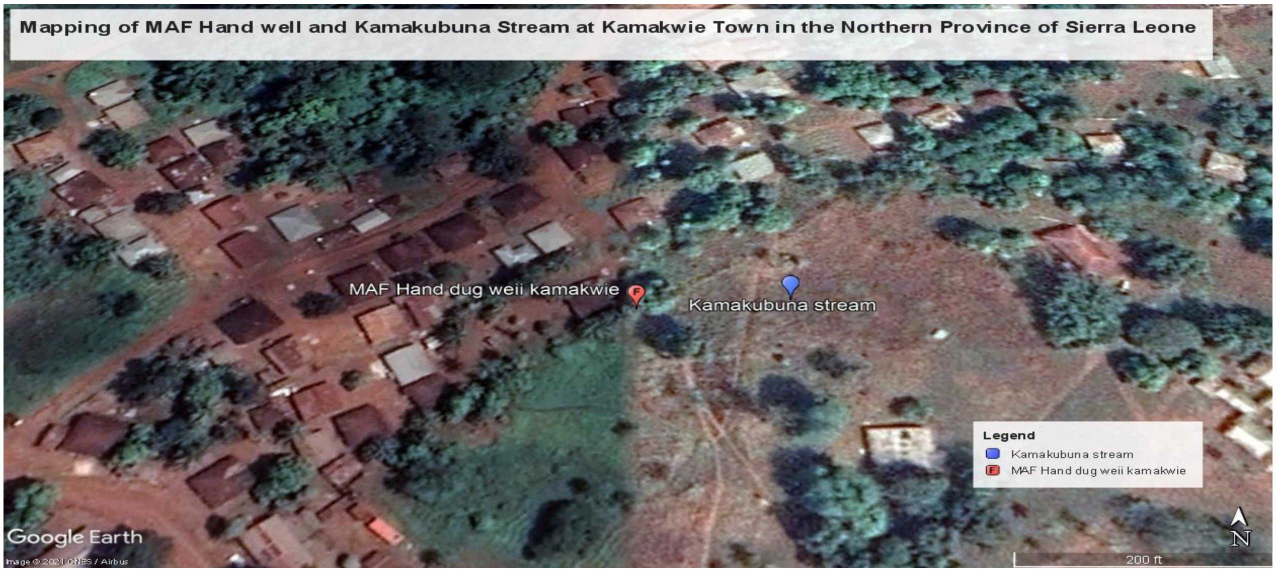


Figure 1. Mapping of MAFFS hand dug well and the Kamakubuna Stream, in the Sella Limba Chiefdom, Kamakwie Town.

In 1961, the Sierra Leone Guma Valley Company was established to provide safe drinking water to inhabitants in greater Freetown. In 1981, a rural water supply unit was established within the division. This division was later transformed into the Sierra Leone Water Company (SALWACO) in 2001. The main objective was to provide safe and affordable water to principal towns, such as Bo, Kenema, Koidu, Kabba, and Makeni and all urban areas except Freetown.

In Sierra Leone only 2% of the population has access to clean, readily available drinking water, and most households lack basic sanitation (https://ww.cdc.gov). Access to safe and clean drinking water remains a challenge for the past and present government. At Sella Limba, the primary sources of drinking water are; hand dug wells, rivers, streams and swamp water which are most times unprotected. A reliable supply of clean wholesome water is highly essential in a bid to promote healthy living among the inhabitants of a defined geological region in addition to being key to sustainable development, health, food production and poverty reduction (Balogun et al., 2014). Unhygienic water is a global public health concern, putting people at risk for a host of diarrheal diseases and chemical intoxication (Emenike et al., 2017).

The poor and marginalized people living in rural and peri-urban settlements are most in need of improved and safe drinking water, appropriate forms of sanitation and access to water for other domestic purposes (Crow, 2001).

According to WHO/UNICEF 2017 report, every year, 361 000 children under 5 years of age die due to diarrhoea. Poor sanitation and contaminated water are also linked to transmission of diseases such as cholera, dysentery, hepatitis A, and typhoid.

A recent report published by Statistics Sierra Leone (WHO/UNICEF 2017), with the technical support of UNICEF, conducted a Multiple Indicator Cluster Survey (MICS) to collect internationally comparable data on a wide range of indicators. The survey revealed that almost 90% of the drinking water at household level contained *Escherichia.coli* bacteria, presenting a serious health threat to citizens.

The objective of this study is to determine, the physicochemical properties of MAFFS hand dug well and the Kamakubuna Stream in the Sella Limba chiefdom, Kamakwie, and hence find suitable solutions to help improved the quality of these waters.

MATERIALS AND METHODS

Description of study area

Sella Limba is a chiefdom within the Bombali District in the Northern Province of Sierra Leone. It has its principal town located in Kamakwie Town. It is located on Latitude 9.5013º or 9º 30' 4.6" north and Longitude -12.2227º or 12º 13' 21.8" west; it is situated at an elevation of 117 m (384 feet). Salla Limba has a population of 58,401 (SSL, 2015).

The MAFFS hand dug well and the Kamakubuna Stream used to collect samples for this study is located at the Sella Limba chiefdom in Kamakwie Town, Karena district of Sierra Leone. The MAFFS hand dug well, and the Kamakubuna stream is utilised by the locals, inhabiting that environment. Sella Limba is a densely populated area. The main activity of the locals in that environment is agricultural activities (Figure 1).

Sampling

Eleven (11) cleaned and sterilized plastic bottles were used to carried out this research. These sterilised plastic bottles were carefully labelled to easy identification. The volume for each plastic bottle is 500 ml. The plastic bottle was rinsed three times with the water sample, before the sample was collected. The samples were collected for three months (October, November and December). The sample was placed in an icebox and transported to the water directorate of the Ministry of Water Resources for quality analysis.

Procedure for sample analysis

Physical analysis

Temperature examination: A clean plastic bottle was rinsed three times with the water sample, and filled to 500ml mark, a digital thermometer with electrode was placed in the beaker, and the electrode button turned on. The temperature was read and recorded in duplicate and the mean temperature taken in ºC. This method was used to examine the remaining samples.

pH determination: A digital pH meter with electrode was gently inserted into the plastic bottle containing 500ml of the water sample, and the electrode switched on. The concentration of the pH was recorded in duplicates and the averaged mean value taken.

Total dissolved solid (TDS) and Electrical conductivity (EC): A digital conductivity meter with electrode was used to examine the level of total dissolved solid (mg/L) and electrical conductivity (µS/cm). The electrode was inserted into the beaker containing the water sample, and the electrode turned on. The values were read and recorded.

Turbidity: A Photometer 7100 was used to assess the turbidity level of the water sample. The Photometer was calibration using a blank solution. A test tube filled with 10ml water sample was placed in the cuvette and then covered with light black shield cap. The button was turned on and the readings recorded in nephelometric turbidity unit (NTU).

Analysis of chemical parameters: WAGTECH PHOTOMETER 7100 was used to examine the Chemical quantity of the water sample. Each sample was analysed according to instructional manual for excellent quality result. A blank sample was first prepared as a reference (0.00mg/L) for each of the sample to be analysed. The test tube was filled with 10ml water sample, and one tablet (chemical) dropped into the test tube, it was then crushed and stirred to dissolve in the 10ml of the water sample, and allowed to stand for 10 minutes. The test tube was placed in the cell container and lid closed. The appropriate wavelength was turned on; the concentration level of each chemical was recorded in mg/L.

RESULTS AND DISCUSSION

Physical parameters

Temperature

From Table 1, the mean temperature recorded for all the water samples are within the World Health Organisation (WHO) acceptable standards for safe drinking water. WHO has no value for temperature of drinking water, however, WHO recommends that safe drinking water must have a temperature of 25.00ºC at the pH of 7.00. Temperature played a fundamental role in water quality analysis, since it influences both the physicochemical and bacteriological processes, such as absorption of chemicals and microbial growth.

pH

From Table 1, the mean pH values for all the water samples analysed fell below the WHO standard for drinking water. WHO permissible pH ranges for safe drinking water is 6, 5-8, 5. The low pH value of the water could be associated with the presence of CO_2. An increased carbon dioxide concentration will therefore lower pH, whereas a decrease will cause it to rise. Temperature will also affect the equilibria and the pH, in pure water, a decrease in pH of about 0.45 occurs as the temperature is raised by 25ºC, (WHO, 2003). The pH of water is mostly being influenced by environmental conditions. Careful assessment of pH control system is fundamental at all levels of water treatment plants, to ensured disinfection and clarification, and also to minimize low pH of water entering water producing machines in other to help control or minimize corrosion of pipes (WHO, 2003).

Turbidity

From Table 1, the mean turbidity concentration recorded for the hand dug well fell outside the WHO accepted range that is < 5.00 (NTU).The high value in turbidity for the MAFFS hand dug well could be as a result of low water table (aquifer), with little volume of water in the well, which might have been widely opened and exposed to contamination. However, the Turbidity value for Kamakubuna Stream is within the WHO permissible range(< 5 NTU). Materials that sometimes encourage turbid in water include dead organic matter and clay particles.

Electrical conductivity (EC) and Total dissolved solid (TDS)

From Table 1, the electrical conductivity and the total dissolved solid for all the samples analysed fell within the WHO acceptable range for safe drinking water. WHO recommended standard for E.C and TDS is < 450mg/L and < 248mg/L respectively. Conductivity values are influenced by temperature (the cooler the water, the lower the conductivity, and the warmer the water, the higher the conductivity value)

Chemical parameters

The results of this research showed that, the chemical concentration of all the water samples analysed fell within the WHO acceptable range for safe drinking water. The

Table 1. Shows the physicochemical mean values obtained from the MAFFS hand dug well and the Kamakubuna Stream.

Parameter	Hand dug well			Mean	Variance	SD	Kamakugbuna stream			Mean	Variance	SD	WHO
	Oct.	Nov	Dec.				Oct.	Nov.	Dec.				
Temperature (^{0}C)	25.00	26.00	25.00	25.33	0.33	0.58	25.00	27.00	23.00	25.00	4.00	2.00	No Value
pH	5.85	5.85	5.85	5.85	0.00	0.00	5.98	5.45	6.10	5.84	0.12	0.35	6.50-8.50
Turbidity (NTU)	1.18	1.18	50.00	17.45	807.63	28.42	3.80	4.80	3.80	4.13	0.33	0.57	< 5NTU
Conductivity (µS/Cm)	241.00	241.00	242.00	241.33	0.33	0.58	28.10	70.10	28.10	42.10	588.00	24.24	< 450µS /cm
TDS (ppm)	121.00	121.00	123.00	121.67	1.33	1.15	14.00	100.00	14.00	42.67	2465.32	49.65	< 248.00ppm
R. Chlorine (mg/L)	0.01	0.01	0.00	0.01	0.00	0.00	0.09	0.00	0.09	0.09	0.00	0.00	0.30-0.50
Ammonia (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	No value
Bromine (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	No value
Total hardness (mg/L)	121.00	121.00	121.00	121.00	0.00	0.00	60.00	100.00	60.0	73.33	533.33	23.09	< 500.00 mg/L
Copper (mg/L)	0.19	0.19	0.19	0.19	0.00	0.00	0.08	0.08	0.08	0.08	0.00	0.00	< 1.00 mg/L
Fluoride (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	< 1.50 mg/L
Magnesium (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	4.00	4.00	4.00	4.00	0.00	0.00	< 200.00mg/L
Nitrite (mg/L)	0.01	0.01	0.01	0.01	0.00	0.00	0.02	0.02	0.02	0.02	0.00	0.00	<3.00 mg/L
Nitrate- nitrogen (mg/L	2.40	2.40	2.40	2.40	0.00	0.00	0.08	0.08	0.08	0.08	0.00	0.00	< 10.00 mg/L
Potassium (mg/L)	1.80	1.80	1.80	1.80	0.00	0.00	3.50	3.50	3.50	3.50	0.00	0.00	< 6.00 mg/L
Phosphate (mg/L)	0.15	0.15	0.15	0.15	0.00	0.00	0.15	0.15	0.15	0.15	0.00	0.00	< 20.00 mg/L
Sulphate (mg/L)	10.00	10.00	10.00	10.00	0.00	0.00	9.00	9.00	9.00	9.00	0.00	0.00	< 400.00 mg/L
Arsenic (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<0.01 mg/L
Sulphide (mg/L)	0.17	0.17	0.17	0.17	0.00	0.00	0.03	0.03	0.03	0.03	0.00	0.00	< 0.50 mg/L
Chlorine (mg/L)	0.05	0.05	0.05	0.05	0.00	0.00	0.20	0.20	0.20	0.20	0.00	0.00	< 250 mg/L
Bicarbonate (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	No value
Chromium (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	< 0.05 mg/L

following are the results obtained for the MAFFS hand dug well and the Kamakubuna stream respectively; Residual Chlorine (0.01 mg/L, 0.09 mg/L), Ammonia (0.00 mg/L, 0.00 mg/L), Bromine (0.00 mg/L, 0.00 mg/L), total hardness (121.00 mg/L, 73.3 mg/L), Copper (0.19 mg/L, 0.08 mg/L), Fluoride (0.00 mg/L, 0.00 mg/L), Magnesium (0.00 mg/L, 0.00mg/L,), Nitrite (0.01 mg/L, 0.02 mg/L), Nitrate- Nitrogen (2.40 mg/L, 0.08 mg/L), Potassium (1.80 mg/L, 3.50 mg/L), Phosphate (0.15 mg/L, 0.15 mg/L), Sulphate (10.00 mg/L, 9.00 mg/L,), Arsenic (0.00 mg/L, 0.00 Mg/L), Sulphide (0.17 mg/L, 0.03 mg/L), Chlorine (0.05 mg/L, 0.20 mg/L), Bicarbonate (0.00 mg/L, 0.00 mg/L) and Chromium (0.00 mg/L, 0.00 mg/L).

Conclusion

Water plays a vital role in the development of all living organisms on earth, as it is needed by all organisms for normal functioning of the body. However, consuming contaminated water can be detrimental to human health. A sample of water collected from the MAFFS hand dug well and the Kamakubuna stream was analysed and results compared to the World Health Organisation guidelines. The results for all the chemical parameter analysed fell within the WHO acceptable range. However, a low pH value was recorded in all the water samples analysed, with a high mean turbidity concentration for the MAFFS hand dug well. It can therefore be concluded that water is safe for drinking. It is however, recommended that the surrounding of the well be kept clean, cover and locked after use and sample tested periodically to enhance quality assurance.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Balogun SA, Akingbade AO, Oyekunle MA, Okerentugba PO (2014). Physiochemical and Microbiological profile of drinking water sold in Abeokuta, Ogun State, Nigeria. Nature and Science 12(3):103-105.

Crow B (2001). Water: gender and material inequalities in the global south. University of California, Santa Cruz.

Emenike PC, Tenebe TI, Omeje M, Osinubi DS (2017). Health risk assessment of heavy metal variability in sachet water sold in Ado-Odo Ota, South-Western Nigeria. Environmental Monitoring and Assessment 189(9):1-16.

Maduka HCC, Chukwu NC, Ugwu CE, Dike CC, Okpogba AN, Ogueche PN, Maduka AA (2014). Assessment of commercial bottled table and sachet water commonly consumed in Federal University of Technology, Owerri (FUTO), Imo State, Nigeria using Microbiological indices. Journal of Dental and Medical Sciences 13(1):86-89.

World Health Organization (WHO) (2003). Guidelines for drinking-water quality, 2nd ed. Vol. 2. Health criteria and other supporting information. World Health Organization, Geneva, 1996.

WHO/UNICEF Joint Monitoring Programme (2017). Report Sierra Leone Multiple Indicator Cluster Survey 2017.

Vol. 15(8), pp. 303-319, August 2021
DOI: 10.5897/AJEST2021.3035
Article Number: B8DF67D67471
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

ACADEMIC JOURNALS
expand your knowledge

African Journal of Environmental Science and Technology

Full Length Research Paper

Behavior of major ions and heavy metals risk assessment in spring and surface water on the southwest slope of Mount Cameroon (Western Africa)

Gustave Raoul Nkoue Ndondo[1*], Gloria Eneke Takem Eyong[2], Josephine Ndjama[2], David Eric Komba[1], Suzanne Ngo Boum[1], Bertil Nlend[1], Pascale Mouto Makongo[1], Zachari Mfonka[1], Marie-Joseph Ntamak Nida[1] and Jacques Etame[1]

[1]Departement of Geosciences, Faculty of Science, University of Douala, Douala, Cameroon.
[2]Hydrological Research Centre, Institute of Geological and Mining Research, Yaounde, Cameroon.

Received 16 June, 2021; Accepted 28 July, 2021

The coastal flanks of Mt Etinde is wedged between the sea and the southwestern slope of Mt Cameroon. The only fresh water resources available for multipurpose uses in this area are mountain springs and streams that drain volcanic materials. To access the sources, processes and assess the ecological risk associated with hydrochemicals and heavy metals in these mountain water resources, 18 water samples were collected in different seasons at 4 locations between may 2009 and december 2010 for major ions and heavy metals determination. The sampled waters ranged from neutral to slithly alkaline, weakly mineralized and dominated by Ca–Mg–HCO_3 water type irrespective of season. The hydrochemical ratios revealed ions chemistry mostly influenced by geogenic source of silicate rock weathering and atmospheric inputs. Sampled waters had low concentration of heavy metals which are less mobile in the aqueous phase, controlled by hydraulic condition. Geochemical processes of mineral dissolution and reverse ion exchange coupled with hydrodynamic processes of flushing at the weathering front and soil leaching are the main controls on the water chemistry in the area. Despite agricultural and other anthropogenic activities, quality indices in the study area indicate the absence of anthropogenic inputs.

Key words: Major ions, heavy metals, rocks weathering, soil leaching, water quality assessment.

INTRODUCTION

The determination of major and trace elements in surface and groundwater is necessary to ascertain geochemical profiles that differentiate natural and human influences on water chemistry. Rock weathering, anthropogenic and atmospheric inputs are the most important processes controlling the water quality. The natural hydrogeochemical

*Corresponding author: E-mail: raoulnkoue@yahoo.fr.

characteristics of spring and stream water in a given region is the reflection of the chemical composition of minerals of rocks, as well as the physico-chemical process of chemical weathering and erosion, which cause mineral dissolution (Braun et al., 2005; Nkoue et al., 2021). Depending on the nature of the dissolved minerals, the chemical composition of surface and groundwater may be enriched with metals, metalloids or ions involved in geochemical processes such as sorption, redox reactions, ion exchange, and complexation, which may control it's hydrogeochemistry and subsequently affect the water quality (Ako et al., 2012; Asare‑Donkor et al., 2018). Hydrogeochemical characterisation can be understood via several methods, among which, the typical hydrogeochemical ratios, which can evaluate the origin and processes of water resources and the factors that influence the water chemistry (Zhu et al., 2007).

In recent years, there has been an increasing interest in heavy metal contamination and toxicity in aquatic systems (N'guessan et al., 2009; Yi et al., 2011; Li et al., 2014; Khan et al., 2013; Asare‑Donkor et al., 2018; Ibanga et al., 2018; Raafat, 2020; Sharmin et al., 2020). A number of studies have found that spring and stream water may contain elements such as arsenic, cadmium, chromium, lead, selenium, and mercury for which contamination is a major environmental concern due to their toxicity, carcinogenicity, and mutagenicity even at low concentration (Moore et al., 2011; Ifegwu and Anyakora, 2012; Mandeng et al., 2019). Heavy metals in rivers could be related to agricultural and industrial waste and by-products (Naveedullah et al., 2013; Zhou et al., 2020), significant inputs may result from geogenic-lithogenic sources from rock weathering, volcanic activities and geothermal processes (Serelis et al., 2010; Ali et al., 2019).

Rivers which receive volcanic inputs and/or hydrothermal hot springs at flanks of the volcanoes may be heavily affected. Viviroli et al. (2020) highlighted the importance of mountain water resources at global scale and the dependence of lowland inhabitants on theses ressources, which often deliver high runoff to the sub-adjacent lowlands used for irrigation, industry, drinking and domestic purposes. Evaluation of the quality of water at flanks of the volcanoes is essential since these waters could be rich in elements owing to the rock-water interaction (Durowoju et al., 2019). The situation calls for concern in the coastal slope of Mt Cameroon where spring water and torrential runoff at flanks are the only freshwater resources available for drinking and other uses especially in the localities of Batoke, Etinde and Bakingili. Indeed, because of its high touristic attraction and fertile soils, this area is experiencing fast growing population and strong agricultural developments which has not been matched by the provision of basic service infrastucture for potable water supply and sanitation. Several studies dealing with water quality problems have been done in the Mt Cameroun area (Endeley et al., 2001; Riotte et al., 2003; Benedetti et al., 2003; Ako et al., 2012). However, there is still little known about the assessment of water resources in relation to heavy metals, particularly in the area of Mt Etinde where water–rock interaction and hydrothermalism could contribute heavy metals supply in grounwater and control the spring and stream water chemistry. Because water quality is mainly concerned with the combined effects of heavy metals, measuring the concentration of heavy metals and determining the multi-element indices (heavy metal pollution index (HPI), Heavy metal evaluation (HEI), contamination factor (Cd) and modified contamination factor (mCd)…) is essential in monitoring water quality (Vu et al., 2017; Ghaderpoori et al., 2018).

The coastal slope of Mt Cameroon is an ideal target to conduct hydrochemical assessment of heavy metals in view of sustainable management and protection of freshwater resources. This humid tropical area is characterized by extreme rainfalls and elevated temperatures all year long, which enhances intense weathering conditions and soil erosion, promoting the release of hydrochemicals and heavy metals in outflowing waters from torrential runoff and springs of the flanks of Mt Etinde volcano (1713 m a.s.l). This justifies the long monitoring that has been initiated in the framework of this study, in order to characterize the water chemistry, ascertain the sources and processes of ions and heavy metal concentrations to assess the water quality status.

MATERIALS AND METHODS

Study area

The study area is a coastal strip at the foot of the of Mt Etinde (1713 m.a.s.l) between Batoke and Bakingili, located on the slope of the SW oceanic border of Mt Cameroon Volcano (4100 m.a.s.l). It lies between latitude 4°1'and 4°7'N and longitude 9°1'and 9°9'E (Figure 1). The climate is tropical humid type with two distinct seasons: a dry season from November to April and a wet season from Mai to October (Olivry, 1986). Normal annual rainfall varies from about 5000 to 9000 mm (Etame et al., 2009b). The mean annual temperature is 26°C. The vegetation changes with altitude from a dense semi-deciduous forest at the base of Mount Etinde (<800 m asl) to a less dense mountain forest towards the summit (Letouzey, 1985; Thomas and Cheek, 1992; Tchouto, 1996).

Geology and geomorphology

Mt Etinde is a volcano, belonging to the volcanic Line of Cameroon (Central Africa). Lava flows of Mt Etinde are dated at from 1.1 Ma (Fitton, 1987) to 0.65 Ma (Nkoumbou et al., 1995). Geologically, it is

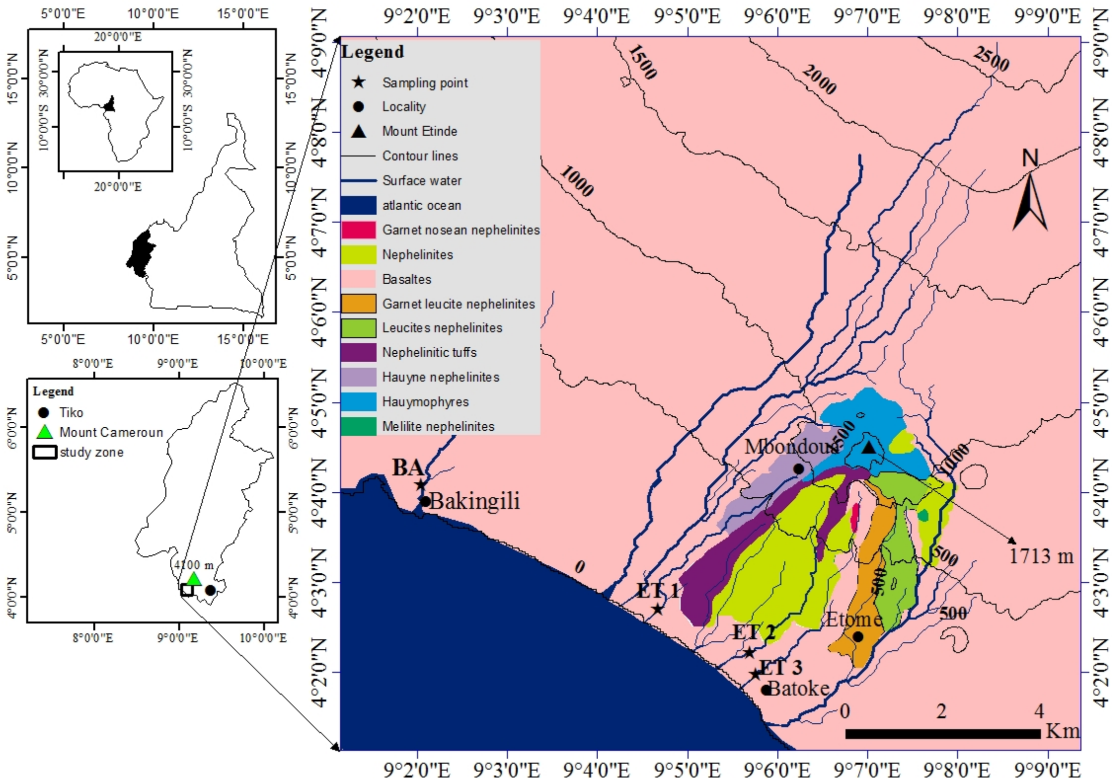


Figure 1. Studied area and sampling sites.

composed under-saturated series in silica mainly composed of layered nephelinitic tuffs, nephelinites, nephelinites to hauyne melilite or garnet-red, leucito-nephelinites to aenigmatite and haunophyres (Mouafo, 1988; Nkoumbou et al., 1995; Benedetti et al., 2003; Etame et al., 2009a; Rospabé, 2014), which do not seem comagmatiques with alkali basalts of Mt Cameroon. Soils on the flanks of Mt Etinde are weathered haplic cambisoil, typical of most mountanous humid equatorial climatic zones. Such weathered soils are high in clay content and residual elements such as Fe, Al, and Si and low in alkali metals and alkaline earth metals (Etame et al., 2009a). These cambisoil are less than 2 m thick in the slopes and are derived from in-situ weathering of underlain nephelinitic parent rocks (Etame et al., 2009a,b). The slopes of Mt Etinde have deeply incised V-shape valleys separating sharp crests. These valleys commonly have seasonal streams that run dry in the dry season.

Hydrology and hydrogeology

The stydy area is located in the moist tropics close to the equator where annual rainfall exceeds evapotranspiration. This southwestern atlantic border of Cameroon is the rainiest in the country and among the wettest regions in the world (Olivry, 1986), with an average precipitation of about 8000 mm/year. About 90% of annual precipitation falls during May–October, followed by a dry season from November to April. This seasonality is illustrated in Figure 2, which shows the rainfall record for the period between 2003 and 2013 at the monitoring station of Issongo that the Cameroon Development Coorporation (CDC) maintains on the west slope of the Mt Cameroon at 3 km from Mt Etinde. Precipitation peaks during July-August when the Intertropical Convergence Zone (ITCZ) is passing across the region, with little rain falling during the dry season between December and February. Orographic enhancement of precipitation by the Mt Cameroon is pronounced, with the western slope receiving approximately 70% of annual rainfall in the region. The hydrographic network of Mount Etinde is characterized by streams that flow through the various "v" shaped surrounding the massif. The runoff in this area is observed to be dominated by torrential streams that springs on the flanks of the mountain. Runoff from storm events tend to rise and decay very rapidly consequently, streams are seasonal at high altitudes, while at low altitudes they are permanent. Nephelinitic lavas surrounding the Mt Etinde cone are generally fractured forming the potential aquifers. High precipitation and fracturing supported by steep slope cause most of the springs to emerge on this formation particularly in the flanks of the mountain. In fact, in the dry season, high-altitude rivers acquire a buried regime due to low hydraulic gradient (Nkoumbou, 1990).

Sampling and laboratory analysis

The sampling points were selected based on their accessibity and their use by the population (Fig. 1). Surface waters were sampled at tree points (ET1, ET2 and ET3) representing the outlets of torrential streams. Spring water was sampled at a single point at the foot of the Mt Etinde at Bakingili (BA), used for drinking purpose. The characteristics of these points are presented in Table 1.

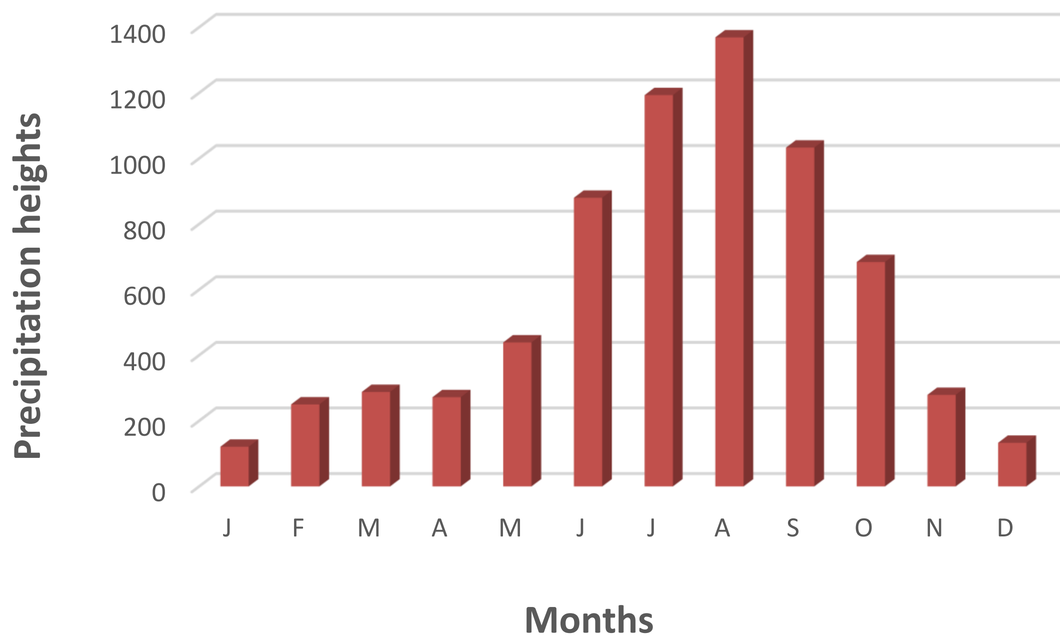


Figure 2. Average monthly rainfall (2003-2013) at Issongo station 3 km from Mt Etinde.

The sampling bottles (polyethylene bottles and glass vials) were pre-washed with ultrapure nitric acid at 15 N and rinsed repeatedly with deionized water, then oven dried and stored in plastic bags until sampling. The samples were taken on different dates in the dry and wet season. Total number of 18 samples were collected in 0.5 L polyethylene bottles for the analysis of major ions and physicochemical parameters and total number of 9 samples were colleted for heavy metals in 0.60 ml glass bottles. The syringe filters were rinsed with the sampling water before the collection of water samples. Each bottle was rinsed three times with the sampling water before being completely submerged to collect the sample. 2 drops of nitric acid were added to each sample for heavy metals analysis. All the samples thus collected were stored in a cooler until the tranport to the laboratory.

pH was measured by a precision WTW-PH 330i/SET probe, while conductivity was determined using a precision WTW-LF 325-B/SET probe. Alkalinity was determined by headline volumetric titration with hydrochloric acid using Grant method, with an analytical error of <3%. Major anions were determined by ion chromatography, High Performance Liquid Chromatography (HPLC - Dionex ICS-90) with a precision of ±2% at the Laboratory of Water Analysis (LAGE), Cameroon Institute of Geological and Mining Research (IRGM). Major cations and heavy metals were determined by ICP-MS, at the laboratory of « IRD-CEREGE, Institut de Minéralogie et Physique des Milieux Condensés, Paris, France ». The accuracy of the method was assessed by the analysis of reference materials (SLRS4) with deviation of < 0.07%.

Heavy metal indices calculations

Heavy Metal Pollution Index (HPI) was proposed by Mohan et al. (1996). It is an index which allows to assess the overall water quality with regard to heavy metals. It is determined by Equation 1.

$$\mathrm{HPI} = \frac{\sum_{i=1}^{n} \mathrm{WiQi}}{\sum_{i=1}^{n} \mathrm{Wi}} \quad (1)$$

Where n is the number of samples considered, Wi is the inverse of the standard value (Si) of the i^{th} metallic element, Qi is the sub-index of the i^{th} metallic element. Qi is determined by Equation 2.

$$\mathrm{Qi} = \sum_{i=1}^{n} \frac{|\mathrm{Mi} - \mathrm{Ii}|}{\mathrm{Si} - \mathrm{Ii}} \times 100 \quad (2)$$

Where Mi is the average concentration of element i in a given sample, Ii is the maximum ideal concentration for element i.

The HEI method like the HPI gives an overall quality of the water with respect to heavy metals (Edet and Offiong, 2002). The HEI is computed as :

$$HEI = \sum_{i=1}^{n} C_i / MAC \quad (3)$$

where C_i is the monitored value of the i^{th} parameter and *MAC* the maximum permissible concentration of the i^{th} metal parameter.

Contamination degree of heavy metals was calculated using the formula prescribed by Hakanson (1980):

$$C_d = \sum_{i=1}^{n} C_f \quad (4)$$

Table 1. Location and description of the sampling points.

Sampling point name	GPS coordinates	Types of uses and influences
ET1	09°46'48''E-04°02'42''N	It is located in a marshy area in which there are also plantations. The people of this area use the water from this stream, called onkogobong, for drinking.
ET2	9°05'42''E-04°02'13''N	It is located below the main road connecting Batoke to Bakingili (South-West). Its water is used by local populations to wash clothes and cars. It is also used as bath water and dishes.
ET3	09°05'45''E-04°01'59''N	It is located in the city of Batoke. The populations use it as water for the dishes, the linen but also the bath.
BA	09°02'6''-04°04'05''N	It is located near the station of Bakingili and is used for drinking, laundry, dishes and bathing.

Where C_d is the contamination degree, and C_f the contamination factor, n the number of analysed elements. The contamination factor is expressed as follows:

$$C_f = \frac{C_i}{C_n} \qquad (5)$$

Where C_f is the contamination factor of the i^{th} parameter, C_i is the monitored value of the i^{th} parameter, and C_n is the standard value of the i^{th} parameter.

RESULTS AND DISCUSSION

Hydrochemical characteristics

Table 2 presents the physicochemical parameters and the summary descriptive statistics of the major ions in the water samples (mg/L) of the studied area. Concentrations of hydrochemical constituents are illustrated in box plots (Figure 3). Most parameters occur in narrow ranges with little standard deviations (SD), indicating chemical composition affected by homogenous processes and single source. pH values ranged between 7.03 and 9.03 with a mean of 7.76±0.53, indicating that the surface waters are neutral to slightly alkaline. In general, pH values were within the range of the WHO (6.5-8.5) limits for drinking water, except a single sample (11/06/2009 at ET1). Electrical Conductivity (EC) ranges between 50.9 and 89.6 µS/cm with an average value of 74.94±12.05 µs/cm, which indicates that water is weakly mineralized. Lowest EC and pH were recorded near the peak of the precipitation, indicating dilution process by weakly acidic and low mineralized meteoric waters. Akalinity ranged between 278 and 832 µeq/L with a mean value of 623±180 µeq/L. Total suspended sediments (TSS) was between 2.2 and 18.2 mg/L, averaging 6.38±5.17 mg/L.

In all the water samples, the total cation charge ($TZ^+ = Na^+ + K^+ + 2Mg^{2+} + 2Ca^{2+}$) inbalanced the total anion charge ($TZ^- = Cl^- + 2SO_4^{2-} + 2CO_3^{2-} + HCO_3^-$). For the normalized inorganic charge balance ($NICB = (TZ^+ - TZ^-)/TZ^+$), all samples had an NICB < -70%, reflecting a cationic deficit, mainly due to the abundance of bicarbonates. Major ion concentrations were low (Table 2) and were in the order of $HCO_3^- >> NO_3^{2-} > Cl^- \geq SO_4^{2-} > PO_4^{3-} > F^-$ for major anions. HCO_3^- ranged from 16.96 to 50.75 mg/L and accounted for more than 92% of the TZ^-. Nitrate varied from 0.00 and 1.98 mg/L with an average value of 0.89 mg/L. Chlorine ranged from 0.69 to 1.97 mg/L and sulfate ranged from 0.47 to 1.28 mg/L with average of 0.88 mg/L. Phosphorous had the lowest concentration, ranges between 0.00 and 0.27 mg/L with averages value of 0.07 mg/L. Average cation concentration where in the following order: $Ca^{2+} > Mg^{2+} > K^+ > Na^+$. Ca^{2+} represented on average 31.04% of the TZ^+ While Na^+ only accounted for 2.06% of the TZ^+. The concentration of calcium and magnesium ranged between 3.94-7.94 mg/L and 1.55-6.65 mg/L respectively. Sodium and potassium values ranged respectively from 0.17 to 1.62 mg/L and 0.82 to 4.57 mg/L. The concentrations of cation were found to be slightly higher in spring water (BA) than in streams (Table 2). The levels of ions in all the spring and stream water samples fall below the WHO (2017) maximum acceptable limits. Temporal variations of major ions (Figure 4) showed a slight decrease in concentration towards the period of precipitate peak, which was explained by dilution owing to the heavy rainfall during this period. However, highest nitrate concentrations were observed during this period, which linked the origin of this element to the leaching of the soil. Such seasonal variations is typical of poorly saturated and highly leached milieu in which springs and surface water are diluted during the rainy season (Viers et al., 2000).

Table 2. Summary data of Hydrochemical and physicochemical parameters of the study area.

Site	Sampled date	pH	EC µs/cm	Alk	TSS mg/L	Na^{+} (mg/L)	K^{+} (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	F^{-} (mg/L)	Cl^{-} (mg/L)	NO_3^{-} (mg/L)	PO_4^{3-} (mg/L)	SO_4^{2-} (mg/L)	HCO_3^{-} (mg/L)
ET1	04/05/09	7.81	77.1	765	10.8	0.35	1.47	3.12	7.85	0.14	1.05	0.15	0.00	0.61	46.7
	11/06/09	9.03	76.0	730	18.2	0.34	1.59	2.99	7.87	0.09	1.25	0.00	0.00	0.87	44.5
	15/09/09	7.03	54.6	278	4.2	0.17	0.82	1.55	3.94	0.00	1.00	1.96	0.00	0.47	17.0
	23/03/10	7.66	80.4	690	2.8	0.34	1.25	2.88	7.02	0.07	0.83	0.25	0.06	0.68	42.1
	29/05/10	7.76	81.2	691	2.4	0.40	2.51	2.61	6.98	0.03	0.69	0.58	0.03	1.12	42.2
	16/09/10	nd	nd	nd	nd	0.36	2.50	2.06	5.84	nd	nd	nd	0.05	nd	nd
ET2	11/06/09	8.35	77.7	755	11.6	0.44	2.39	2.94	7.41	0.10	1.97	0.00	0.08	0.84	46.1
	15/09/09	7.43	50.9	352	7.4	0.25	1.39	1.97	4.95	0.00	0.80	1.63	0.14	0.70	21.5
	23/03/10	7.56	85.1	720	5.2	0.43	1.77	2.79	6.66	0.08	0.89	1.12	0.24	0.97	43.9
	29/05/10	7.71	70.5	490	2.2	0.35	1.83	2.54	6.04	0.02	0.89	1.16	0.07	0.83	29.9
	16/09/10	nd	nd	nd	nd	0.32	1.73	2.39	6.10	nd	nd	nd	0.06	nd	nd
	05/12/10	nd	nd	nd	nd	0.45	2.28	2.81	7.02	nd	nd	nd	0.06	nd	Nd
ET3	23/03/10	7.50	89.6	832	3.0	0.48	2.34	2.59	7.03	0.07	0.78	0.96	0.27	1.27	50.8
	29/05/10	7.47	81.2	550	2.4	0.21	2.58	2.12	7.28	0.10	0.85	1.98	0.00	1.3	33.6
	16/09/10	nd	nd	nd	nd	0.36	2.15	2.06	5.84	nd	nd	nd	0.05	nd	nd
	05/12/10	nd	nd	nd	nd	0.43	2.79	2.36	6.62	nd	nd	nd	0.07	nd	nd
BA	16/09/10	nd	nd	nd	nd	1.26	3.87	4.84	6.23	nd	nd	nd	0.08	nd	nd
	05/12/10	nd	nd	nd	nd	1.62	4.57	6.65	7.94	nd	nd	nd	0.08	nd	nd
Min		7.03	50.9	278	2.2	0.17	0.82	1.55	3.94	0.00	0.69	0.00	0.00	0.47	17.0
Max		9.03	89.6	832	18.2	1.62	4.57	6.65	7.94	0.14	1.97	1.98	0.27	1.28	50.8
Mean		7.76	74.9	623	6.4	0.48	2.89	6.63	6.59	0.06	1.00	0.89	0.07	0.88	38.0
Med		7.66	77.7	691	4.2	0.36	2.15	2.61	6.98	0.07	0.89	0.96	0.06	0.84	42.2
Sd		0.53	12.1	181	5.2	0.38	0.93	1.19	1.06	0.05	0.36	0.75	0.08	0.26	11.0

nd:not determined.

Major anions and cations data obtained for the spring and stream water samples were plotted on the Piper trilinear diagram (Piper, 1944) to classify the water according to the hydrochemical facies. The relative abundance of the anions and cations are shown in Figure 5. The plot reveals a single type of water, predominantly influenced by the Ca-Mg-HCO_3 hydrochemical facies. This facies remains the same at all sampling point whatever

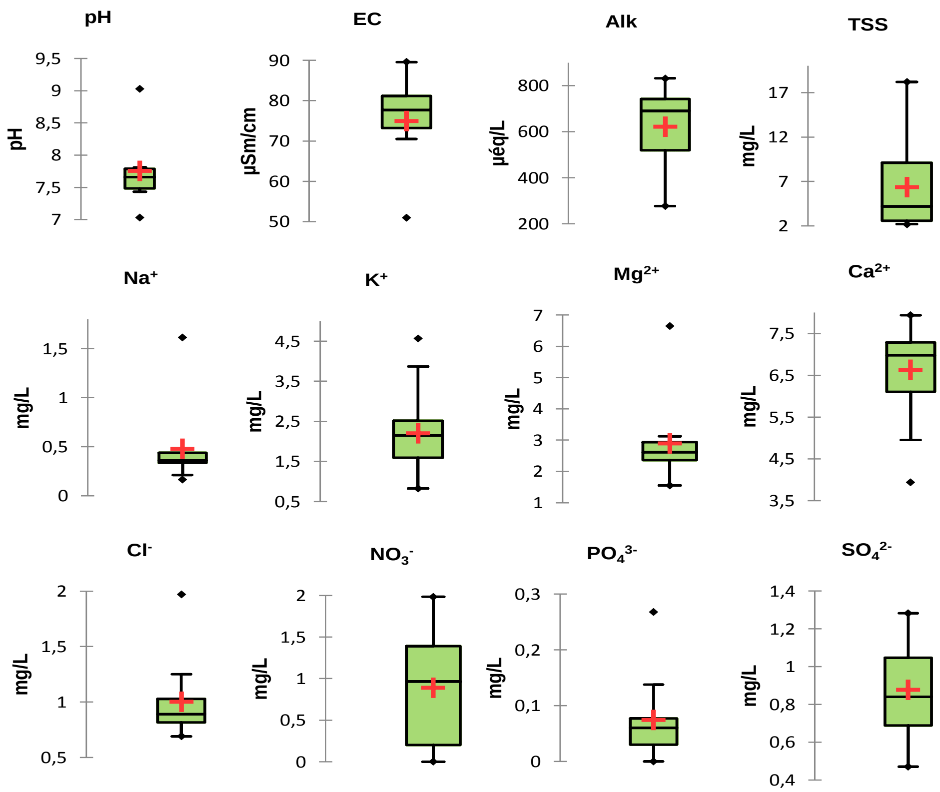


Figure 3. Box plots illustration of the hydrochemical characteristics of water in the study area.

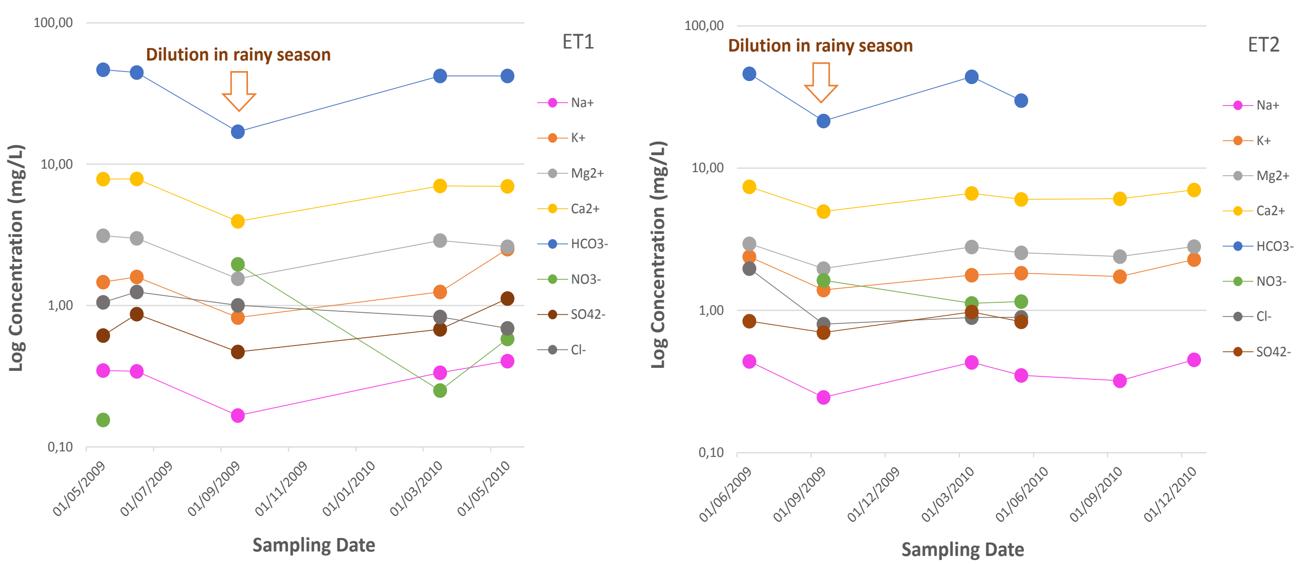


Figure 4. Temporal variation of major ions in stream water of Mt Etinde.

the period of the year. The combined distribution of both cations and anions showed dominance of alkaline earth (Ca+Mg > Na+K) and weak acids (CO_3+HCO_3 > Cl + SO_4) indicating the temporary hardness of these waters.

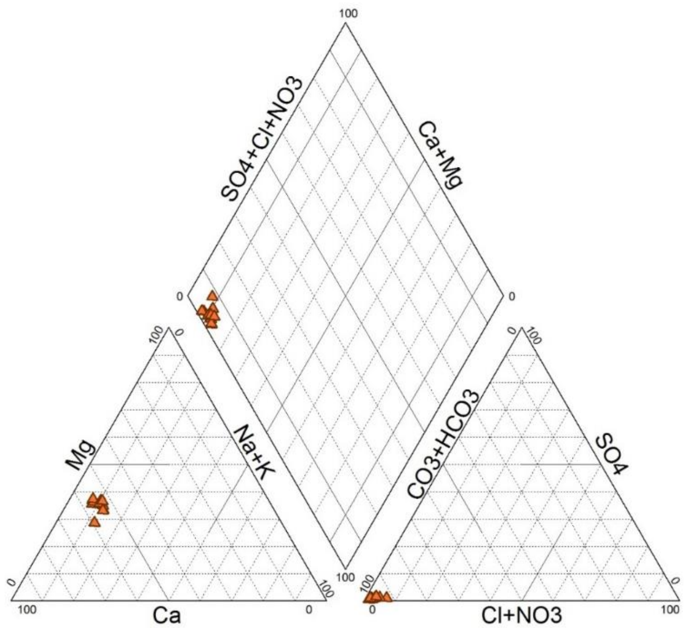


Figure 5. Piper trilinear diagram (Piper, 1944) showing the classification based on the hydrochemical facies of the water samples.

This result is similar to other research conducted by Ako et al. (2012) on the hydrogeochemical investigation of groundwater in the Mount Cameroon area.

Controls processes of major ions in water

By using the chemical components in water and relationships between the ionic species, the sources of the ions and chemical processes that generate them can be determined. These include salt dissolution, seawater intrusion, silicate weathering and ion exchange (Hounslow, 1995; Fisher and Mullican, 1997; Han and Liu, 2004; Diaw et al., 2012).

The Na^{+}+ K^{+} versus Cl^{-} + SO_4^{2-} was plotted (Figure 6A) to determine the origin of these parameter in spring and stream waters. The plot shows samples falling on and below the 1:1 line. This observation suggest mineral dissolution as the process controlling the major ion chemistry. Cl^{-} and SO_4^{2-} acounted for less than 5% of the TZ^{-}, which indicates that evaporite dissolution is not a possible source of these ions. This finding is consolidated by the dominance of Ca^{2+} over SO_4^{2-} in 100% of the samples (Table 3), confirming that Ca^{2+}source was other than gypsum dissolution (Hounslow, 1995). Althouth chloride content exceeding sodium expresses the predominance of marine influence for which the Na^{+}/Cl^{-} molar ratios is equal to 0.55 (Meybeck, 1987; Stallard and Edmond, 1983), the average Na^{+}/Cl^{-} molar ratio of 0.57 (Table 2) obtained here could be explained by precipitations of marine origin or fixation of Na^{+} in the form of clay minerals (Kolahchi and Jalali, 2006).

In order to ascertain the influences of rock-water interaction, evaporation and precipitation on the water chemistry, we plotted the total dissolved solids (TDS) versus the weight ratio of $(Na^{+}+K^{+})/(Na^{+}+K^{+}+Ca^{2+})$ and Cl-/ $Cl^{-}+HCO_3^{-}$ according to Gibbs (1970). The data points suggest chemical weathering of rock and rainwater supplies as the main factors controlling the water chemistry in this area (Figure 7). This observation is supported by the Cl^{-} and K^{+}concentrations exceeding Na^{+}, which confirms the contribution by rainwater resulting from the evaporation of seawater. The low dissolved ions content coupled with nearly neutral to alkaline pH suggest short to average water-rock interaction time. This is further supported by the Gibbs plot with the data points plotted near the rainfall dominance feld. This short water–rock interaction time can be attributed to the fractured nature of the nephelinitic formation on the slope of Mt. Etinde coupled with high hydraulic gradient due to high rainfall. During the dry season, there is a decrease in hydraulic gradient due to low rainfall. This leads to an increase in the water rock interaction time, enhansing alkaline conditions (Makoba and Muzaka, 2019).

The molar ratios of Mg^{2+}/Ca^{2+} and Na^{+}/Ca^{2+} have been

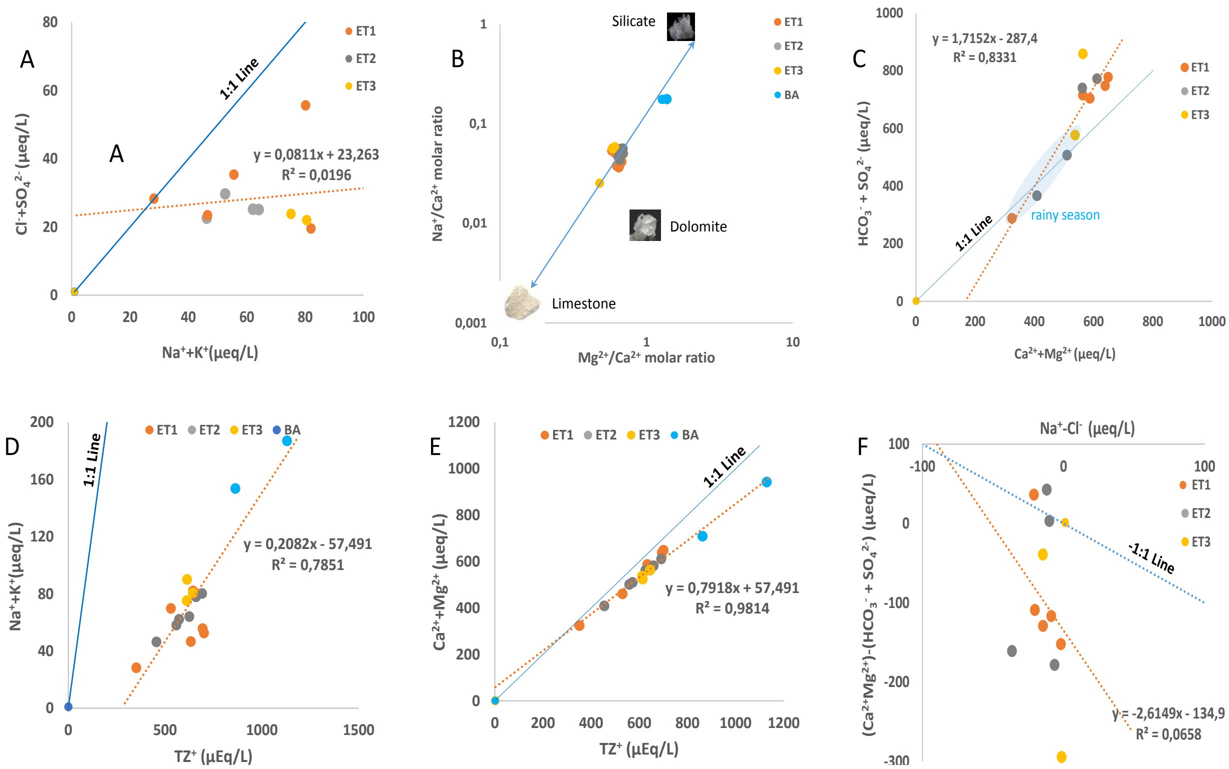


Figure 6. The ionic ratio plots for plot (A) Na^++ K^+ versus Cl^- + SO_4^{2-}, (B) Mg^{2+}/Ca^{2+} versus Na^+/Ca^{2+}, (C) Ca^{2+} + Mg^{2+} versus HCO_3^- + SO_4^{2-}, (D) Na^++K^+ versus TZ^+, (E) (Ca^{2+}+Mg^{2+}) versus TZ^+, (F) (Na^+ - Cl^-) versus (Ca^{2+} + Mg^{2+}) – (HCO_3^- + SO_4^{2-}).

Table 3. Molar ratios of chemical species in surface water**.**

	ET1				ET2				ET3		Mean	Min	Max	Std.
Na^+/Cl^-	0.51	0.43	0.26	0.64	0.35	0.47	0.76	0.62	0.95	0.39	0.57	0.26	0.95	0.23
Cl^-/HCO_3^-	0.04	0.05	0.09	0.03	0.07	0.06	0.03	0.05	0.03	0.03	0.05	0.03	0.09	0.02
Ca^{2+}/SO_4^{2-}	30.15	21.83	19.7	25	21.76	16.46	16.6	17.7	13.5	15.13	19.78	13.5	30.15	5.05
Mg^{2+}/Ca^{2+}	0.65	0.62	0.64	0.68	0.65	0.65	0.69	0.69	0.61	0.62	0.65	0.61	0.69	0.03
Na^+/Ca^{2+}	0.77	0.76	0.73	0.83	1.03	0.87	1.13	1.01	1.18	1.01	0.932	0.73	1.18	0.16
CAI	-5.4	-4.5	-2.4	-6.8	-3.6	-5.3	-8.4	-7.1	-11.3	-11.8	-6.66	-11.8	-2.4	3.10

CAI : chloro-alkali index.

used to determine the sources of calcium and magnesium ions in surface water. These molar ratios are distinct in waters draining limestone, dolomite and silicates basement, in which there are respectively about 0.03 ; 1 and 1 for Mg^{2+}/Ca^{2+} and 0.005 ; 0.01 and 1.73 for Na^+/Ca^{2+} (Han and Liu, 2004 ; Mtoni et al., 2013). In this study, all samples had Mg^{2+}/Ca^{2+} and Na^+/Ca^{2+} molar ratios ranging from 0.61 to 0.69 and 0.73 to 1.18, respectively (Table 3). On the plot of Mg^{2+}/Ca^{2+} versus Na^+/Ca^{2+} according to Han and Liu (2004), all water samples fall on the axis between the limestone and silicate poles, getting closer to the silicate pole (Figure 6B). This indicates the dominance effect of silicate minerals with little effect from calcite dissolution. To further determine the likely influence of silicate dissolution, Ca^{2+}+Mg^{2+} versus SO_4^{2-}+HCO_3^- was plotted. Fisher and Mullican (1997) established that a charge balance with a linear slope of 1:1 will exist between the Ca^{2+}+Mg^{2+} and SO_4^{2-}+HCO_3^- if they are derived from basic dissolution of carbonate and evaporate minerals (calcite, dolomite and gypsum). In this study, majority of data plot fall above the equiline 1:1 (Figure 6C)

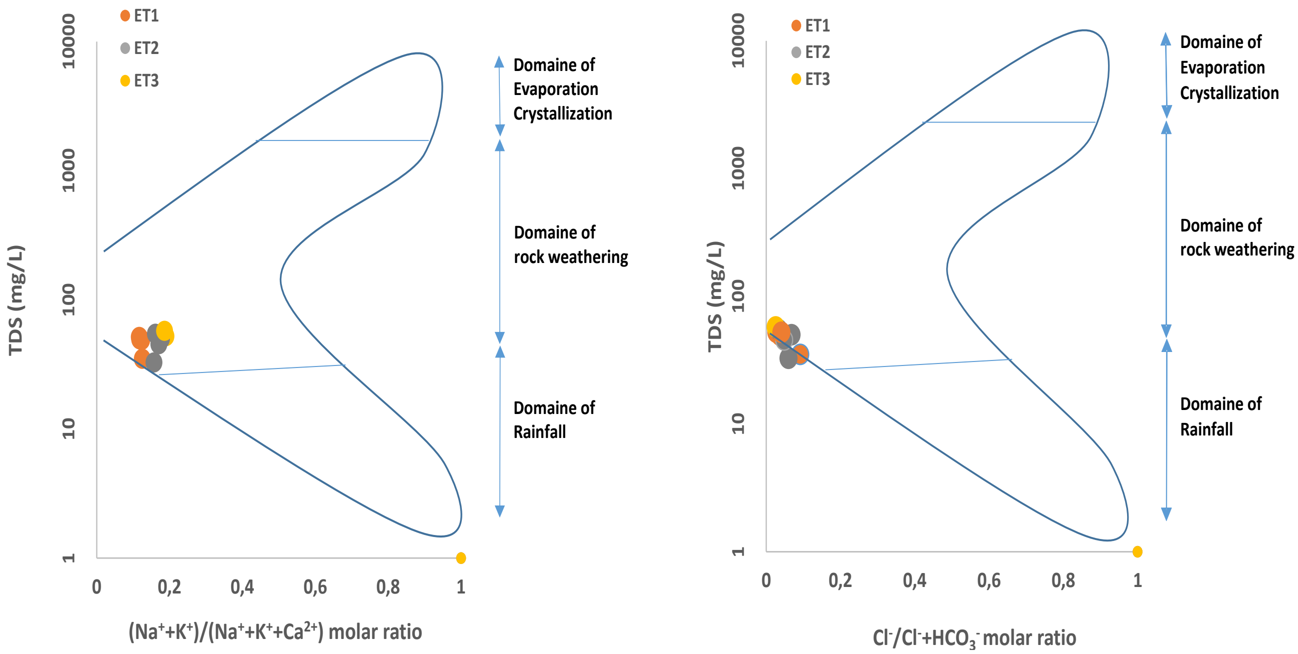


Figure 7. Gibbs diagrams presenting a simple plot of TDS versus the weight ratio of $(Na^+ + K^+)/(Na^+ + K^+ + Ca^{2+})$ and Cl-/ Cl^- $+HCO_3^-$ in stream waters.

suggesting a deficiency of alkaline earth elements $(Ca^{2+}+Mg^{2+})$ over $SO_4^{2-}+HCO_3^-$ which reflects additional sources of HCO_3^- supplied by silicate weathering (Mortatti and Probst, 2003 ; Wirmvem et al., 2013). However, some few samples from the rainy season were plotted along the equiline 1:1. This could illustrate the dissolution of calcite mineral that was found associated to phillipsite in this area (Etame et al., 2009b). The plot of $Na^+ + K^+$ versus TZ^+ (Figure 6D) shows all points far below 1:1 line with a strong positive correlation (R^2=0.8), indicating a higher ratio of alkaline cations from silicate weathering relative to saline cations (Stallard and Edmond, 1983; Srinivasamoorthy et al., 2014). Furthurmore, the plot of $(Ca^{2+}+Mg^{2+})$ versus TZ^+ (Figure 6E) fall on and below the line 1:1 with very strong positive correlation (R^2=0.98), reflecting an increasing contribution of Na^+ and K^+ as TDS increases. This confirms that Na^+ and K^+ are almost exclusively from silicate weathering.

Previous geochemical studies (Nkoumbou et al., 1995; Etame et al., 2009a,b) revealed that the main primary mineral assemblage in the study area are dominated by Clinopyroxene, feldspathoids and phillipsite. Etame et al. (2009a) showed that the weathering process of these minerals, which involves the release of HCO_3^- in the water, leads to the formation of halloysite, hematite and gibbsite. Although the presence of these secondary minerals in the soil rather reflects congruent weathering, the significance of cation-exchange in controlling ionic concentrations in solution was tested. The relationship between Na^+ and Cl^- (representing the amount of Na^+ gained or lost compared to that provided by salt dissolution) and $(Ca^{2+} + Mg^{2+}) - (HCO_3^- + SO_4^{2-})$ was plotted (Figure 6F). The latter represents the amount of Ca^{2+} and Mg^{2+} gained relative to that provided by carbonate or sulphate mineral dissolution. If ion exchange is a significant process in the surface water, the relationship between these variables should be linear with a slope of -1:1 (Fisher and Mullican 1997). In this study, 90% of sample fall bellow the -1:1 line, showing decreases of $(Ca^{2+} + Mg^{2+}) - (HCO_3^- + SO_4^{2-})$ without any increase of $Na^+ + Cl^-$, thus indicating that ion exchange was not dominant, but played a significant role in controlling the ionic content of the surface water. This finding is confirm by the ratio between $(Ca^{2+} + Mg^{2+})$ versus $(HCO_3^- + SO_4^{2-})$ of figure 6C, in which the majority of the samples fall left to the 1:1 line highlighting ion exchange process in this area (Fisher and Mullican, 1997). Chloro-alkali indices (CAI) also known as an index of base exchange were used to determine the nature of ion exchange in water system. Positive indices indicate the exchange of Na^+ and K^+ in water with Ca^{2+} and Mg^{2+} in soil mineral (chloro-alkaline equilibrium), while negative indices depict the reverse situation (chloro-alkaline disequilibrium). In the volcanic area of Etinde, all the water samples gave negative CAI (Table 3) suggesting reverse ion exchange process of Ca^{2+} and Mg^{2+} in water

Table 4. Statistical sommary of heavy metals in the study area.

Site	Sampling date	Al µg/L	V µg/L	Cr µg/L	Mn µg/L	Fe µg/L	Co µg/L	Ni µg/L	Zn µg/L	Cu µg/L	As µg/L	Rb µg/L	Sr µg/L	Zr µg/L	Mo µg/L	Cd µg/L	Ba µg/L	Pb µg/L	U µg/L
ET1	29/05/2010	10.63	1.60	0.47	0.26	107.41	0.04	0.37	0.38	0.58	0.04	5.56	124.01	bdl	0.31	bdl	1.94	0.01	0.01
	16/09/2010	13.18	7.34	0.09	0.42	nd	bdl	0.02	0.36	0.13	0.07	5.38	103.88	0.01	nd	bdl	2.07	0.01	0.01
ET2	29/05/2010	6.26	1.71	0.45	0.63	95.89	0.03	0.32	0.33	0.49	0.05	6.91	115.88	bdl	0.31	bdl	5.11	bdl	bdl
	16/09/2010	12.31	6.91	0.04	0.74	nd	bdl	0.08	1.28	0.17	0.05	7.70	119.36	0.01	nd	bdl	5.48	0.02	0.01
	05/12/2010	6.34	9.67	0.01	bdl	nd	bdl	0.02	bdl	0.03	0.06	9.19	143.31	bdl	nd	bdl	6.85	bdl	bdl
ET3	29/05/2010	1.27	3.72	1.15	0.11	151.96	0.05	0.46	1.06	1.12	0.06	11.38	78.09	bdl	3.23	bdl	1.23	0.01	bdl
	05/12/2010	12.93	9.32	0.02	0.17	nd	bdl	0.03	bdl	0.30	0.07	6.66	134.87	0.01	nd	bdl	2.18	0.05	0.01
BA	16/09/2010	2.56	16.98	0.58	bdl	nd	bdl	2.61	1.04	0.20	0.18	9.10	43.37	0.01	nd	bdl	0.82	0.02	0.06
	05/12/2010	2.16	17.14	0.63	bdl	nd	bdl	0.04	0.05	0.07	0.19	11.17	59.22	0.02	nd	bdl	0.85	0.02	0.12
Min		6.34	1.60	0.01	0.11	95.89	0.03	0.02	0.05	0.03	0.05	5.38	43.37	0.00	0.31	bdl	0.82	bdl	bdl
Max		13.18	17.14	1.15	0.74	151.96	0.05	2.61	1.28	1.12	0.19	11.38	143.31	0.02	3.23	bdl	6.85	0.05	0.12
Mean		7.52	8.27	0.38	0.39	118.42	0.04	0.44	0.64	0.34	0.11	8.12	102.44	0.01	1.28	bdl	2.95	0.02	0.03
Med		6.34	7.34	0.45	0.34	107.41	0.04	0.08	0.38	0.20	0.07	7.70	115.88	0.01	0.31	bdl	2.07	0.02	0.01
SD		4.86	5.79	0.38	0.25	29.61	0.01	0.83	0.47	0.34	0.06	2.23	34.65	0.01	1.69	bdl	2.25	0.02	0.05
WHO				50	100	200		20	3000	2000	10					3		10	30

nd: Not determined ; bdl : below the detection limit.

with Na^+ and K^+ in soil mineral.

Heavy metals in water samples

Concentrations of metals in surface water and spring water are shown in Table 4. The highest metal concentrations between 95.89 to 151.96 µg/L and 43.37 to 143.31 µg/L were observed for Fe and Sr respectively. Al, V, Rb, Ba and Mo have concentrations between 6.34 - 13.18 µg/L, 1.60-17.14 µg/L, 5.38-11.38 µg/L, 0.82- 6.85 µg/L and 0.31- 3.23 µg/L respectively. Heavy metals ranged between 0.00-2.61 µg/L and showed a decreasing order as follows: Zn>Ni>Mn>Cr>Cu>As>Co>U>Pb. Cd was below de detection limit. Heavy metals were all lower than the guideline for drinking water (WHO, 1993) and the standard levels regulated content of the environmental quality standards for surface water (UNCED, 1992; UNECE, 1994). Rb, Sr, and Ba concentration were higher and did not show significant temporal variation while the trend of Al, Mn was irrespective of seasons. Concentrations of Cr, Ni, Cu and Co, in surface water were higher at the begining of the rainy season in May-Jun and decreased in September with the declining rainfall to further decreases to a minimum in December in the dry season. On the other hand, V, Zn, and As concentration increases with the declining rains (Figure 8). Ni, Zn an Cu showed temporal variation in spring water, with a decreasing trend in concentrations during the dry season. This trends show that the behaviour of these metals in water is mainly related to hydrodynamic processes and may be due to flushing of the metal immobilized at the weathering front. According to Etame et al. (2009a), the accumulation of these metals in soils of the studied area is meanly due to adsorption on secondary minerals (haematite, goethite, halloysite). Leaching of these soils during the

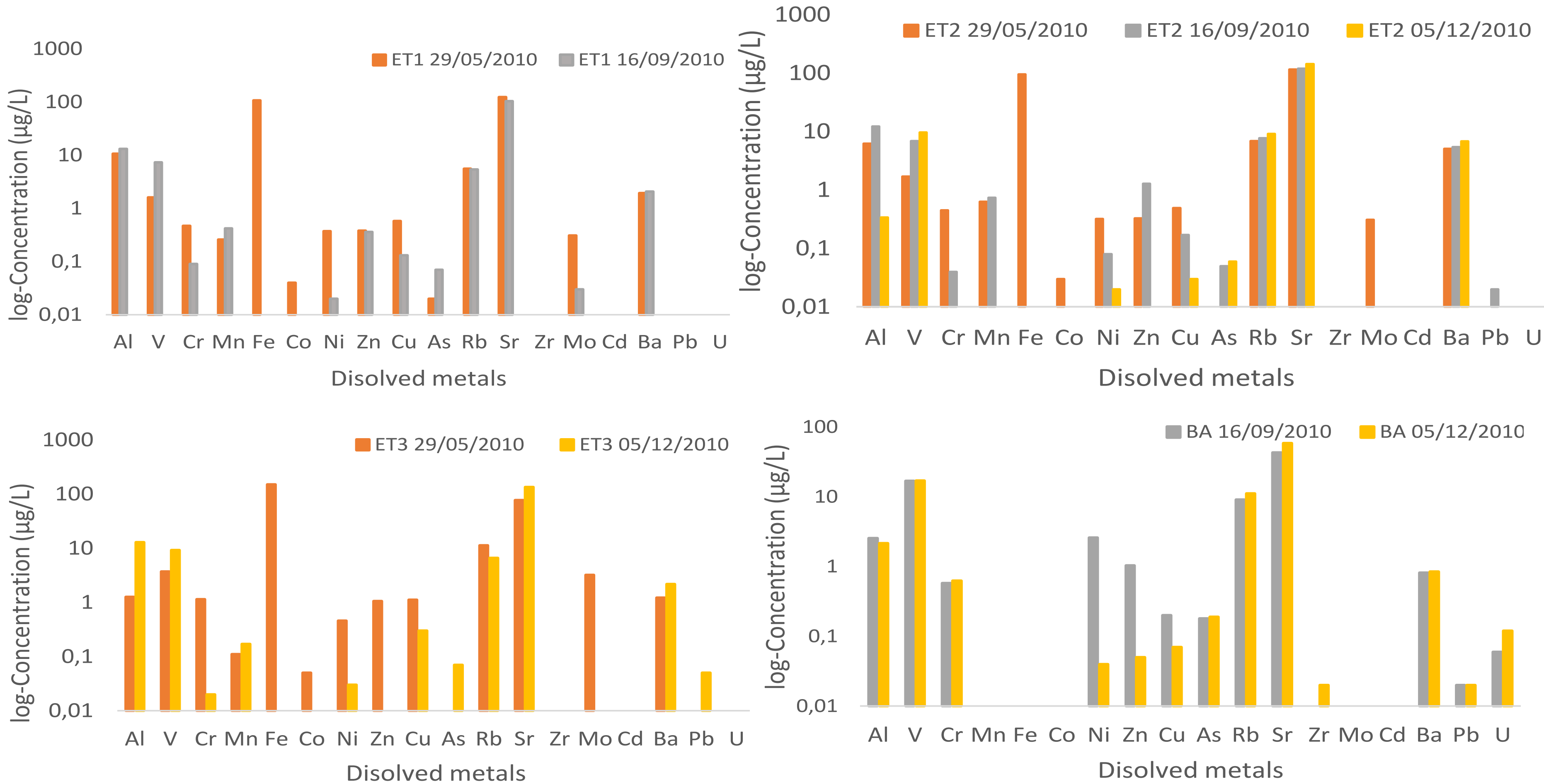


Figure 8. Comparaison of heavy metals concentration at different sampling periods (29/05/2010 = begining of the rainy season; 19/09/2010 = declining of the rainy season; 05/12/2010 = dry season).

rainy season is the primary source of Cr, Ni, Cu, Co, V, Zn, Pb and As in surface water. Metals are also associated to iron oxy- hydroxide, which are controlled by the precipitation- dissolution process as function of physico- chemical (Eh, pH, adsorption) and hydrodynamic changes (Braun et al., 2005). The neutral to slightly basic pH recorded in this study, which reflects the weathering of basic rock of this area, lead to the precipitation of heavy metals. The pH versus metal load were plotted in the diagram to adapt the classification of water samples in the study

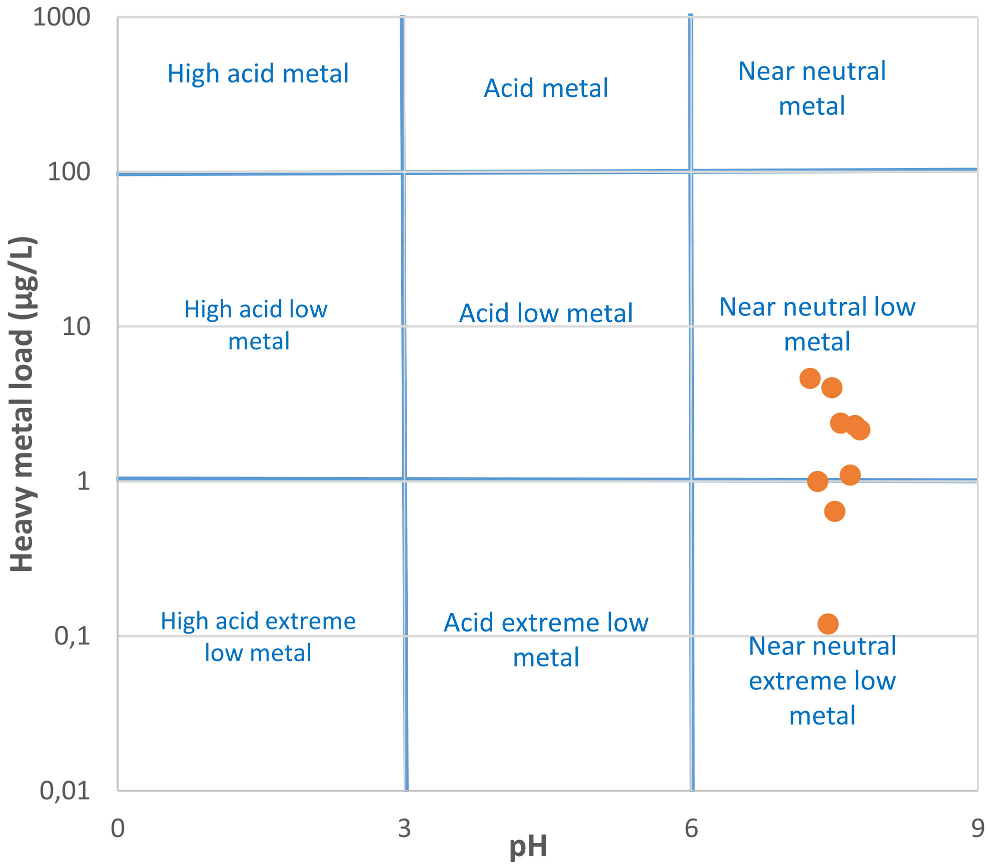


Figure 9. Ficklin-Caboi diagram shows the groundwater classification based on total heavy metal load vs pH of the study area.

area according to Ficklin et al. (1992) and Caboi et al. (1999). This diagram is suited to differentiate the various geological aspects of water chemistry. The metal load (ML) for each sample was calculated as follows :

$$ML\ (\mu g/L) = \sum_{i=1}^{n} Conc._{metal} = Conc._{Cr} + Conc._{Mn} + Conc._{Co} + Conc._{Ni} + Conc._{Zn} + Conc._{Cu} + Conc._{As} + Conc._{Cd} + Conc._{Pb}$$

Figure 9 presents the plotted data in the diagram, in which 60% of water samples are classified as near neutral low metal class, while 40% are classified as near neutral extreme low metal class. Thus, it can be inferred that metals present in waters of the Mt Etinde area are comparatively low and less mobile in the aqueous phase. This assertion were further verified by comparing the average dissolved heavy metal with the average pedogeochemical content. The mean heavy metal contents in soil and parent rock was considered based on data from Etame et al. (2009b). As shown in Table 5, the percentage of Cr, Co, Ni, Zn, Cu and Pb was very low in the sampled waters, between 8.10^{-4} and 10^{-2}%, confirming the very low mobility of these metals due to precipitation in soil and sediments. This process could justify the enrichment of these metals in the soil profile compared to the parent rock and appears to be the main controlling process of heavy metals in this milieu.

Risk assessment of heavy metals

The carcinogenic risk assessments were calculated for the average concentration of heavy metals in surface water (ET1, ET2, ET3) and spring water (Ba). Heavy metal pollution index and heavy metal evaluation index (HPI and HEI) represents the composite influence of metals on the overall quality of water. These methods has been widely used in the evaluation of surface water quality (Mohan et al., 1996; Prasad and Bose, 2001; Edet

Table 5. Comparaison of the mean heavy metals content in soil and water.

Site	Cr	Co	Ni	Zn	Cu	Pb	
Parent rock (ppm)	13.66	27.36	13.14	197.50	67.87	7.90	Etame et al. (2009a)
Soil (ppm)	59.20	52.38	42.24	174.80	177.89	8.99	Etame et al. (2009a)
Water (ppb)	0.38	0.04	0.44	0.64	0.34	0.02	This study
Water/Soil ratio (%)	0.00064	0.00008	0.00104	0.00037	0.00019	0.00022	

Table 6. Mean HPI of stream waters and spring water.

Heavy metal	Mean value [Mi] (µg/L)	Standard permissible value [Si] (µg/L)	Highest desirable value (µg/l) [Ii]	Unit weightage (Wi)	Mean HPI	
Al	6.053	200	30	0.005	Surface waters of Etinde	**2.66**
Cr	0.69	50	50	0.02		
Mn	0.33	300	100	0.003333		
Fe	118.42	300	200	0.003333		
Mo	1.28	70	-	0.014286	Spring water of Bakingili	**7.56**
Cd	0	10	3	0.1		
Ba	0.59	700	-	0.001428		
Ni	0.383	20	20	0.05		
Cu	0.363	1500	50	0.000667		
Zn	0.59	15000	5000	0.000067		

Table 7. HPI, HEI and Cd values at different sampling sites.

Sampling site		HPI	Mean deviation (%)	Deviation with mean HPI value	HEI	Cd
Etinde	ET1	2.37	-10.96	-0.29	0.66	0.48
	ET2	2.29	-13.93	-0.37		
	ET3	3.34	25.89	0.69		
Bakingili	Rainy season	11.55	52.83	3.99	0.23	0.16
	Dry season	3.59	-52.52	-3.97	0.09	0.03

and Offiong, 2002; Ghaderpoori et al., 2018). The HPI and HEI for the study area are determined by incorporating the mean concentration values of recorded heavy metals and using the standards (Table 6). The mean HPI resulting from surface water and spring water were 2.66 and 7.56 respectively. The HPI was also calculated separately for each individual sample site and the deviation and deviation percentage of individual HPI values compared to the mean were expressed (Table 7). The result of indices showed that the HPI for all the sampling sites were far below the critical limit of 100 reported by Prasad and Bose (2001). By following the approach of Edet and Offiong (2002), the proposed HEI criteria for the samples are as follows: low HEI < 10 indicates high-quality water ; medium HEI = 10-20 indicates medium contamination risk and high HEI > 20 indicates high contamination risk. The mean value of HEI was 0.66±14 for surface water and 0.16±0.1 for spring water. The present level of HEI shows that the water quality falls within the first category of low zone of pollution. The degree of contamination (Cd) was used as reference to estimate the extent of metal pollution (Al-Ami et al., 1987). Cd may be grouped into three categories as follows: low (Cd<1), medium (Cd = 1 - 3) and high

(Cd>3). The mean Cd values were 0.48±0.24 for surface water and 0.095±0.09 for spring water, suggesting high-quality water for drinking with regard to heavy metals. The HPI, HEI and Cd calculated for spring water were slighly low in dry season compare to the rainy season, reflecting the importance of hydrodynamic on the release of metal in the water column. The calculated carcinogenic risk assessments has good stability and indicates a unique and natural source of metals in this area, rather related to the soil-geochemical background than to anthropogenic origin. This study demonstrated 'nil to very low' degree of water contamination with respect to the analyzed heavy metals. Thus, the studied area is not subjected to pollution with regard to heavy metals and hence has low potential for carcinogenic risk.

Conclusion

This paper identified possible sources and processes controlling the mineralization of spring and surface water, quantified the level of heavy metals and assessed the human health risks associated with drinking water resources in the Batoke-Etinde-Bakingili coastal strip. Generally, water from the study area is weakly mineralized, chemical ions and heavy metals being associated to natural pedogeochemical source. Findings revealed that these low concentrations of major ions were typical of poorly saturated and highly leached soil resulting from the weathering of silicate mineral rock. The average values of molar ratios revealed that saline and alkaline ions in this area derived from silicate mineral dissolution and precipitations of marine origin, with little effect of calcite mineral dissolution that was found assosiated to phillipsite mineral. Ions exchange, although not dominant, was found to play a significant role in controlling the ionic content of the surface water, especially the reverse ion exchange process. Heavy metals in the waters were within the acceptable limits of the WHO. Concentrations of heavy metals in this area are mainly controlled by the flushing of metal at the weathering front and the leaching of soil during the rainy season. Precipitation-dissolution process, heavy metal adsorption on secondary minerals and iron oxy-hydroxides can be pointed as major factors regulating the heavy metals in waters of this area. Based on the WQI, the waters of the study area are classify as excellent. The HPI, HEI and Cd were far below the critical limit, indicating high-quality water for drinking with regard to heavy metals.

Mean value for all studied heavy metals was far below the reference guidelines, suggesting that heavy metal contamination and ecological risk needed not be a major concern for pollution control and management plans for spring and surface waters of the study area. However, since the metal concentrations in the soil are quite high, changes in hydraulic conditions and soil acidity can at times lead to the release of heavy metals from soil and sediments to the water column. This paper is a baseline study and could be expanded to sediment geochemical analysis, redox potential analysis, and their roles in enhancing the release of heavy metals in water. Hence in the future, by collecting more samples across the study area could help for effective monitoring and control plans of heavy metal behaviour.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors sincerely appreciate Martine Gerard of the « IRD-CEREGE, Institut de Minéralogie et Physique des Milieux Condensés (IMPME) » of the Pierre and Marie Curie University, Jussieu, Paris – France for cations and heavy metals analysis. Our thanks also goes to Henriette Ateba Bessa of the Laboratory of Water Analysis (LAGE) of the Cameroon Institute of Geological and Mining Research (IRGM) for ions analysis.

REFERENCES

Ako AA, Shimada J, Hosono T, Kagabu M, Akoachere RA, Elambo GN (2012). Spring Water Quality and Usability in the Mount Cameroon Area Revealed by Hydrogeochemistry. Environmental Geochemistry and Health 34(5):615-639.

Al-Ami MY, Al-Nakib SM, Ritha NM, Nouri AM, Al-Assina A (1987). Water Quality Index Applied to the Classification and Zoning of Al-Jaysh Canal, Bagdad, Iraq. Journal of Environmental Science and Health 22(4)::305-319.

Ali H, Khan E, Ilahi I (2019). Environmental Chemistry and Ecotoxicology of Hazardous Heavy Metals: Environmental Persistence, Toxicity, and Bioaccumulation. Journal of Chemistry 4:1-14. https://doi.org/10.1155/2019/6730305

Asare‑Donkor NK, Ofosu OJ, and Adimado AA (2018). Hydrochemical characteristics of surface water and ecological risk assessment of sediments from settlements within the Birim River basin in Ghana. Environmental Systems Research 7:9.

Benedetti MF, Dia A, Riotte J, Chabaux F, Gérard M, Boulègue J, Fritz B, Chauvel C, Bulourde M, Déruelle B, Ildefonse P (2003). Chemical weathering of basaltic lava flows undergoing extreme climatic conditions: the water geochemistry record. Chemical Geology 201(1-2):1-17.

Braun JJ, Ndam Ngoupayou JR, Viers J, Dupre B, Bedimo Bedimo JP, Boeglin JL, Robain H, Nyeck B, Freydier R, Sigha Nkamdjou L, Rouiller J, Muller JP (2005). Present weathering rates in a humid tropical watershed: Nsimi, South Cameroon. Geochimica et Cosmochimica Acta 69(2):357-387.

Diaw M, Faye S, Stichler W, Maloszewski P (2012). Isotopic and geochemical characteristics of groundwater in the Senegal River delta aquifer: implication of recharge and flow regime. Environmental Earth Sciences 66(4):1011-1020.

Durowoju OS, Butler M, Ekosse GIE, Odiyo JO (2019). Hydrochemical Processes and Isotopic Study of Geothermal Springs within Soutpansberg, Limpopo Province, South Africa. Applied Sciences 9(8):1688.

Edet AE, Offiong OE (2002). Evaluation of Water Quality Pollution Indices for Heavy Metal Contamination Monitoring. A Study Case from Akpabuyo-Odukpani Area, Lower Cross River Basin (Southeastern Nigeria). GeoJournal 5(4):295-304.

Endeley RE, Ayonghe SN and Tchuenteu F (2001). A preliminary hydrochemical baseline study of water sources around Mount Cameroon. Journal of the Cameroon Academy of Sciences 1(3).

Etame J, Gerard M, Bilong P, Suh CE (2009a). Behaviour of elements in soils developed from nephelinites at Mount Etinde (Cameroon): Impact of hydrothermal versus weathering processes. Journal of African Earth Sciences 54(1-2):37-45.

Etame J, Gerard M, Suh CE, Bilong P (2009b). Halloysite neoformation during the weathering of nephelinitic rocks under humid tropical conditions at Mt Etinde, Cameroon. Geoderma 154:59-68.

Moore F, Esmaeili K, Keshavarzi B (2011). Assessment of heavy metals contamination in stream water and sediments affected by the Sungun porphyry copper deposit, East Azerbaijan Province, Northwest Iran. Water Quality, Exposure and Health 3(1):37-49.

Fisher RS, Mullican WF (1997). Hydrochemical evolution of sodium-sulfate and sodium-chloride groundwater beneath the northern Chihuahuan Desert, Trans-Pecos, Texas, USA. Hydrogeology Journal 5(2):4-16.

Ghaderpoori M, kamarehie B, Jafari A, Ghaderpoury A, Karami M (2018). Heavy Metals Analysis and Quality Assessment in Drinking Water-Khorramabad City, Iran. Data in Brief 16:685-692.

Gibbs RJ (1970). Mechanisms Controlling World Water Chemistry. Science 170(3962):1088-1090.

Hakanson L (1980). Ecological risk index for aquatic pollution control. A sedimentological approach. Water Research 14(8):975-1001.

Han G, Liu C-Q (2004). Water geochemistry controlled by carbonate dissolution: A study of the river waters draining karst-dominated terrain, Guizhou Province, China. Chemical Geology 204:1-21.

Hounslow AW (1995). Water quality data: analysis and interpretation. CRC Press LLC, Lewis Publishers, Boca Raton 416 p.

Ibanga LB, Nkwoji JA, Usese AI, Onyema IC, Chukwu LO (2018). Hydrochemistry and heavy metals concentrations in sediment of Woji creek and Bonny estuary, Niger Delta, Nigeria. Regional Studies in Marine Science 25:100436.

Ifegwu C, Anyakora C (2012). Screen for eight heavy metals from groundwater samples from a highly industrialized area in Lagos, Nigeria. African Journal of Pharmaceutical Sciences and Pharmacy 3(1):1-16.

Khan MU, Malik RN, Muhammad S (2013). Human health risk from heavy metal via food crops consumption with wastewater irrigation practices in Pakistan. Chemosphere 93(10):2230-2238.

Kolahchi Z, Jalali M (2006). Effect of water quality on the leaching of potassium from sandy soil. Journal of Arid Environment 68(4):624-639.

Letouzey R (1985). Notices et cartes phytogéographique du Cameroun au 1/500 000. IRA/Institut de la carte internationale de la végétation, Toulouse, Fasc. 1-5, 240p+cartes.

Li Z, Ma Z, Jan van der Kuijp T, Yuan Z, Huang L (2014). A review of soil heavy metal pollution from mines in China: pollution and health risk assessment. Science of the Total Environment 468-469:843-853.

Makoba E, Muzuka ANN (2019). Water quality and hydrogeochemical characteristics of groundwater around Mt. Meru, Northern Tanzania. Applied Water Science 9(120).

Mandeng EPB, Bidjeck LMB, Bessa AZE, Ntomb YD, Wadjoua JW, Doumo EPE, Bitom LD (2019). Contamination and risk assessment of heavy metals, and uranium of sediments in two watersheds in Abiete-Toko gold district, Southern Cameroon. Heliyon 5(10):e02591.

Meybeck M (1987). Global chemical weathering of surficial rocks estimated from river dissolved loads. American Journal of Science 287(5):401-428.

Mohan SV, Nithila P, Reddy SJ (1996). Estimation of Heavy Metal in Drinking Water and Development of Heavy Metal Pollution Index. Journal of Environmental Science and Health 31:283-289.

Mouafo L (1988). Volcanologie et pétrologie du Mont Etinde. Thèse de doctorat 3ème cycle Université de Yaoundé, Cameroun 134 p.

Mortatti J, Probst JL (2003). Silicate rock weathering and atmospheric/soil CO_2 uptake in the Amazon basin estimated from river water geochemistry: seasonal and spatial variations. Chemical Geology 197(1-4):177-196.

Mtoni Y, Mjemah IC, Bakundukize C, Van Camp M, Martens K, Walraevens K (2013). Saltwater intrusion and nitrate pollution in the coastal aquifer of Dar es Salaam, Tanzania. Environmetal Earth Sciences 70(3):1091-1111.

Naveedullah N, Hashmi MZ, Yu C, Shen H, Duan D, Shen C, Lou L, Chen Y (2013). Risk assessment of heavy metals pollution in agricultural soils of siling reservoir watershed in Zhejiang province, China. BioMed Research International 2013:1-10.

N'guessan YM, Probst JL, Bur T, Probst A (2009). Trace elements in stream bed sediments from agricultural catchments (Gascogne region, S-W France): Where do they come from? Science of the Total Environment 407:2939-2952.

Nkoue NGR, Ngo BS, Song F, Takem GE, Komba DE, Nlend B, Etame J (2021). Hydrogeochemical Characteristics and Quality Assessment of Surface Water in an Agricultural Area in Equatorial Africa: The Mungo River Basin, South West Cameroon, Central Africa. Journal of Geoscience and Environment Protection 9:164-181.

Nkoumbou C (1990). Etude géologique des monts Roumpi ; un ensemble. Plutonique et volcanique de la ligne du Cameroun. Données pétrologiques sur les néphilinites du Mont Etinde, thèse, Université de Nancy I, 352 p.

Nkoumbou C, Deruelle B, Velde D (1995). Petrology of Mount Etinde nephelinites series. Journal of Petrology 36(2):373-395.

Olivry JC (1986). Fleuves et rivieres du Cameroun. In Collection Monographie Hydrologique 9:733 p Paris: MESRES-ORSTOM.

Prasad B, Bose JM (2001). Evaluation of Heavy Metal Pollution Index for Surface and Spring Water Near a Limestone Mining Area of the Lower Himalayas. Environmental Geology 41(1):183-188.

Raafat A (2020). A preliminary study of heavy metals pollution risk in water. Applied Water Science 10(1):1-4.

Riotte J, Chabaux F, Benedetti M, Dia A, Gérard M, Boulègue J, Etamé J (2003). Uranium colloidal transport and origin of the 234U–238U fractionation in surface waters: New insights from Mount Cameroun. Chemical Geology 202(3-4):365-381.

Rospabé M (2014). Pétrologie et géochimie des laves du Mont Etinde, Ligne Volcanique du Cameroun. Mémoire de Master, Univ. de Bretagne Occidentale 55 p.

Serelis KG, Kafkala IG, Parpodis K, Lazaris S (2010). Anthropogenic and geogenic contamination due to heavy metals in the vast area of Vari, Attica. Bulletin of the Geological Society of Greece 43(5):2390-2397.

Sharmin S, Mia J, Shohidullah MM, Zakir HM (2020). Hydrogeochemistry and heavy metal contamination in groundwaters of Dhaka metropolitan city, Bangladesh: Assessment of human health impact. HydroResearch 3:106-117.

Srinivasamoorthy K, Gopinath M, Chidambaram S, Vasanthavigar M, Sarma VS (2014). Hydrochemical characterization and quality appraisal of groundwater from Pungar sub basin, Tamilnadu, India. Journal of King Saud University-Science 26(1):37-52.

Stallard RF, Edmondn JM (1983). Geochemistry of Amazon: 2. The influence of geology and weathering environment on the dissolved load. Journal of Geophysical Research 88(C14):9671-9688.

Tchouto MGP (1996). Forest inventory report of the proposed Etinde rainforest reserve, Mt. Cameroon, Mt. Cameroon project. Limbe, Cameroon 64 p.

Thomas DW, Cheek M (1992). Vegetation and plant species on the south side of Mt. Cameroon in the proposed Etinde Rainforest Reserve. Report to Cameroon Government, RBG, Kew, ODA.

United Nations Conference on Environment and Development

(UNCED) (1992). Agenda 21, Chapter 18. Protection of the Quality and Supply of Freshwater Resources: Application of Integrated Approaches to the Development, Management and Use of Water Resources. UNCED, Rio de Janeiro.

United Nations Economic Commission for Europe (UNECE) (1994). Standard Statistical Classification of Surface Freshwater Quality for the Maintenance of Aquatic Life. In: Readings in International Environment Statistics. UNECE, New York and Geneva.

Viers J, Dupré B, Braun JJ, Deberdt S, Angeletti B, Ndam Ngoupayou JR, Michard A (2000). Major and trace element abundances and strontium isotopes in the Nyong basin rivers (Cameroon): constraints on chemical weathering processes and elements transport mechanisms in humid tropical environments. Chemical Geology 169(1-2):211-241.

Vu CT, Lin C, Shern CC, Yeh G, Le VG, Tran HT (2017). Contamination, ecological risk and source apportionment of heavy metals in sediments and water of a contaminated river in Taiwan. Ecological Indicators 82:32-42.

Viviroli D, Kummu M, Meybeck M, Kallio M, Wada Y (2020). Increasing dependence of lowland populations on mountain water resources. Nature Sustainability 3(11):917-928.

Wirmvem MJ, Ohba T, Fantong WY, Ayonghe SN, Suila JY, Asaah ANE, Tanyileke G, Hell JV (2013). Hydrochemistry of shallow groundwater and surface water in the Ndop plain, North West Cameroon. African Journal of Environmental Science and Technology 7(6):518-530.

World Health Organization (WHO) (2017). Guidelines for drinking-water quality. Fourth edition Incorporating the first addendum pp. 1-631.

Yi Y, Yang Z, Zhang S (2011). Ecological risk assessment of heavy metals in sediment and human health risk assessment of heavy metals in fishes in the middle and lower reaches of the Yangtze river basin. Environmental Pollution 159(10):2575-2585.

Zhou QQ, Yang N, Li YZ, Ren B, Ding XH, Bian HL, Yao X (2020). Total concentrations and sources of heavy metal pollution in global river and lake water bodies from 1972 to 2017. Global Ecology and Conservation 22:e00925.

Zhu GF, Li ZZ, Su YH, Ma JZ, Zhang YY (2007) Hydrogeochemical and isotope evidence of groundwater evolution and recharge in Minqin Basin, Northwest China. Journal of Hydrology 333(2-4):239-251.

Vol. 15(8), pp. 320-329, August 2021
DOI: 10.5897/AJEST2020.2883
Article Number: E05A74767496
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

African Journal of Environmental Science and Technology

Full Length Research Paper

Remote sensing applications in buildings' information system (BIS) for the University of Nigeria, Enugu Campus

Okwuchukwu Christopher Nwaka*, Somtoochukwu Chukwunonso Okafor, Amarachukwu Odumodu, Ndukwe Emmanuel Chiemelu and Chisom Okwuchi Emeghiebo

Department of Geoinformatics and Surveying, Faculty of Environmental Studies, University of Nigeria Enugu Campus, Enugu 4000001, Enugu State, Nigeria.

Received 9 July, 2020; Accepted 15 September, 2020

The creation of an information system for various facilities is crucial as it is a vital instrument for effective urban management, especially in the areas of monitoring the state of such facilities to ensure adequate maintenance, ease of access, etc. This paper focuses on how remote sensing and other modern techniques can aid in developing a buildings' information system (BIS) for the University of Nigeria Enugu Campus. It comprised mapping the university environment, particularly the buildings within its boundary as well as developing a database containing the attributes of these buildings. Satellite images of the campus were downloaded and a map of buildings in the campus was developed through geo-referencing and digitizing. A database for the attribute information related to these buildings was also developed and finally the database was linked to the map. This project was carried out using application packages such as Microsoft Excel, QGIS 2.4.0, PostgreSQL 9.3.1, and a Hand-held global positioning system (GPS) receiver for ground-truthing. It is recommended that the accurate identification of buildings in the campus, especially in the residential quarters be improved by placement of number tags as this was a challenge encountered during the course of this project. Beyond this project, it is also of great essence to develop an information system for all other utilities on campus so as to achieve a harmonized and complete information system inventory for the university as it will greatly aid the management and maintenance of these utilities.

Key words: Buildings' information system (BIS), spatial data, attributes data, database management system (DBMS), geographic information system (GIS).

INTRODUCTION

An information system is an organized system for collecting, organizing, storing and communicating information (Rainer et al., 2007). Information is a very vital tool to man as it is an important necessity in our

*Corresponding author. E-mail: christopher.nwaka@unn.edu.ng.

everyday life. It brings about knowledge and is an indispensable tool for effective planning. Several facilities co-exist within the university environment, and there is need to have information about these facilities on demand. The knowledge of the spatial and non-spatial (attribute) characteristics of these facilities are of valuable essence in their utilisation, management, development as well as the addition of new facilities.

A variety of technologies exist for the acquisition of geospatial data for an information system; Hardcopy maps (Meyers, 2000), aerial photographers, land surveyors, census takers, as well as an average person using a cell phone that is Global Positioning System (GPS)-enabled, can collect geospatial data, and this can be entered into a Geographic Information System (GIS) environment. The diverse attributes of several kinds of geospatial data can individually be used as a separate theme or layer within the GIS. Such attributes include ownership of land, buildings, rivers and lakes, roads, bridges, congressional districts, or counties. Therefore, utilizing the power of GIS analysis, it is possible to create a new path to interpreting information which otherwise, would be difficult to analyse and understand (Folger, 2009).

Utilities and facilities all over the world are changing in an unprecedented manner and this has added to the work of facility managers (Meyers, 2000). The development and expansion of the constructed facilities of an institution aggravate the difficulties of managing them. Before the advent of the computer technology, most institutions especially in developing nations relied on hardcopy maps and records to manage their facilities. This has proven inadequate because with time, physical maps deteriorate, get lost or are misfiled. Where available, similar records are kept at different departments (thus creating a waste of storage space); accessibility to data becomes insecure or impossible. These shortcomings therefore, call for new tools and strategies, not only to reduce management costs, but also to improve on space management. GIS can be seen as an indispensable instrument that facilitates the integration of information relating to these facilities and also proffers solution to the shortcomings stated earlier.

GIS has been defined as a computer-based system that enables users to collect, store, process, analyse and present spatial and non-spatial information about areas of the earth (Folger, 2009; Cete et al., 2010). The term GIS can also be seen as a system comprising software, hardware, people, data, organizations and institutional arrangements that aid the acquisition, storage, analysis, dissemination and presentation of both spatial and non-spatial information pertaining to portions of the earth (Chrisman, 2002).

In the 21st century, there has been a heightened understanding of the role of GIS by many facility managers especially within the universities. Campus Information Systems (CIS) that are GIS-based, have been utilized by a lot of these facility managers to achieve various aims, thereby making it a tool effective for planning, ease of administration and management.

The Building Information System (BIS, an offset of the GIS) is one information system that is designed to capture, store, manipulate, analyse, manage and present spatial as well as non-spatial information about buildings. It provides the means for inquiry, analysis and information updating after information about the facility must have been transferred to the computer environment (Konsol, 2001). The need for Building Information System is rapidly increasing as it improves the ease of maintenance and reduces the risk of error (Topay et al., 2004).

The University of Nigeria, Enugu Campus, though has automated some of its procedures, is still dependent on the old analogue system for recording, retrieving, updating, and documenting information of all facilities (surface and sub-surface) within her boundary, thus, developing a Campus Information System for University of Nigeria, Enugu Campus will therefore provide a substantial contribution to its future planning and management. Owing to the fact that the institution is situated in a very large space with a lot of facilities, and coupled with the limitations of resources and time constraint, this study focuses on using GIS as a tool to create a Building Information System for the campus. The result of which will aid the proper and effective management of these buildings, which will be of immense benefits to university administrators, other staff members, students, etc., thereby improving in the quality of teaching and learning.

Although there are platforms such as Google Earth and other internet based applications with which individuals from any part of the country can locate the university, the information derivable from these platforms are very limited as attributes of individual buildings cannot be extracted. This paper therefore shows that creating a Building Information System facilitates the availability of detailed information about every building in the university and thus allows for:

(1) Proper planning for future constructions within the campus.
(2) Easily navigating within the university while avoiding the inconvenience of questioning strangers.
(3) Knowledge about the current state of the buildings so as to ascertain those that need to be maintained and the urgency of maintenance.

LITERATURE REVIEW

A successful information system is essential for a successful business (Savoie, 2012). Scholarly articles exist on the creation or implementation of information system through the use of GIS for utilities such as buildings, roads, power-lines and a whole lot more. A lot of these works were carried out for different purposes such as in campuses for effective planning and management, for the government to aid the proper allocation of amenities and so on. These works have been carried out using diverse application programs (ArcGIS, Erdas Imagine, etc.), database management systems, data acquisition methods as well as several means of presentation.

Motuka (2008) in his work developed an integrated GIS database system of the U-block of the Kenya Polytechnic University College which sought to enable the institution's management to have better methods of resource utilization (e.g. space) at the institution. Due to the fact that the college relied on the old system of organizing, retrieving and updating hardcopy facility drawings, where available, there was no coordinated system for storing, accessing and updating the available documents related to the physical infrastructure of the institution. Thus, the aim of his study was to develop, using an existing GIS tool kit, a means for developing a regular geo-database that organises digital data in order that illustration and visualization, information management, project organization and decision making are facilitated, thereby producing a geodatabase for facilities management for the U-Block of the Kenya Polytechnic University College, Nairobi. The two methods he used were digitization of the existing architectural drawings followed by the linking of the resulting spatial data with the non-graphic data using Microsoft Excel, ArcGIS, ArcView, and Microsoft Access software, being that they provide major procedures for the input and conversion of data. The functions of the project includes graphic processing abilities which give the users the means for map digitization and editing, geo-database management; including the capacity to introduce and manage data (non-graphic) joined with map features, and conversion, in order to transfer and work with files of diverse formats (e.g. from Ms Access to ArcView).

Aysel et al. (2015) carried out a project to develop an information system for the future and current planning of Mustafa Kemal University Tayfur Ata Sökmen Campus by integrating spatial information within a GIS environment. The objectives of the project were to develop geographic information system of the campus (both attribute and spatial data), establish inquiry system of the campus and model a 3D system of the campus. This was achieved by collecting the spatial and non-spatial data of the campus, which consists of topographic structure (slope, aspect, elevation), infrastructure (clean water lines, electrical lines, wastewater line), roads (main and secondary), buildings (administrative buildings, educational facilities, health units, community facilities, etc.) and thereafter, digitizing all data, creating attribute tables and creating a 3D model of the campus. For this project, they made use of an image data of the campus with 50 cm resolution comprising three bands and 16 bits, and the other data used for analyses and reference included topographic maps with scale of 1:25,000, detailed infrastructure maps obtained from Mustafa Kemal University Construction Works and Technical Department, ground reference data obtained from land survey by GPS, and non-spatial data about academic and administrative staff members and students. ERDAS 9.1 Imagine, ArcGIS 9.3, AutoCAD and Sketch up computer applications were used for image classification and data analyses.

Fajemirokun et al. (2006) employed the technique of GIS in mapping and managing crime in Nigeria, using Victoria Island (in Lagos State) as a population sample. The objective of his study was production of a map to show Victoria Island, containing its streets and plots as well as create a database for attributes such as addresses of buildings, types of buildings, purposes of buildings, address, and street names for the purpose of assisting the police in mapping out crime scenes and its surrounding in order to make it easier and quicker to respond to distress calls. He also incorporated the analysis of road network in order to aid the police arrive faster to the scene of the crime through the shortest route possible for the purpose of facilitating quick intervention to such distress calls. Findings revealed that GIS can be used to map and analyse crime occurrences with a view to determining the factors leading to such crimes and how they can be effectively managed.

In an article written in the Global Information Management (GIM) International, a BIS was created in Lombardy (Italy), based on archived and surveyed data for the risk-assessment of buildings that possess historic and architectural value. The BIS was created for the Maria Maggiore building in Bergamo, built in 1137. Essentially, a multisensory approach was utilized to carry out observations of the monument both inside and outside, Terrestrial Laser Scanning being the primary technology utilized. The procedures involved in developing the BIS includes collecting, classifying and transferring all the graphical and descriptive information that were found in Bergamo's historical archives, to digital format; the most recent documents dating to the early 1900's were first digitized, while the older ones were processed. The data collection survey was carried out with reflectorless and motorised total-stations instead of indirectly extracting them through the processing of the laser-scanned data owing to reasons of accuracy and reliability. A survey was also conducted using advanced techniques of geo-data acquisition to produce a model of the multi-level structure of the building, this was used to check the uncertainty in the position of points and remove points that are erroneous; a lot of horizontal distances were measured by means of hand-held lasers. The outer shape of the building (stored as a polyline in CAD) was used to show where the walls intersect with the ground level. The BIS was ArcView-based and the Lombardy authorities adopted the GIS as standard.

Tarhan et al. (2006) conducted a study targeted at achieving uniformity between non-spatial and spatial data through creating a campus information system that is based on GIS for the Izmir Institute of Technology (IIT). Due to the fact that IIT is a developing campus environment with new dormitories, sports area, faculty buildings, and its topography, geology and soil capability requires careful attention, a GIS-based Campus Information System will be of help for the new decisions. The objectives of the study were to store the non-spatial and spatial information on the campus to enable update, plan, or use for the purposes of administration, carry out hazard analysis to help understand the limitations of the campus site geography, and create an interactive access to information in the campus giving rise to easy access to sharable and personal information about the campus with the aid of an effective BIS. The non-spatial (attribute) and spatial (images) data about the campus were first collected, after which the database, maps, queries, and spatial analyses about the collected data were produced via ArcGIS which have been useful for administrative purposes.

Arif and Tashin (2002) also engaged GIS capabilities and developing web technologies in building a web-based campus information system for Karadeniz Technical University (KTU). The Karadeniz Technical University Information System (KTUBIS) provides information exchange for the university owing to the building of a database and presenting its data on the internet. Graphic as well as non-graphic data were collected. The graphic data comprising road, infrastructure, building, parking lot, geodetic point, illumination plant (point), and terrain configuration were collected from maps at a scale of 1:1000 and constitutes the major geographical features of KTU's main campus. The buildings were grouped according to usage into dormitory or living quarters, educational, managerial, house, library, culture, sport, food, etc. The graphic data were edited and digitized using AutoCAD, while ArcIMS 3.2 application program from ESRI was utilised in serving the KTUBIS data and services. Some of the benefits of the KTUBIS includes the fact that maps of the campus required in any format, is easily created and can be collected in an updated environments, easy access to files that are organized by the system, the database created pertaining the university department can be accessed and utilized by the managerial services of the university and users such as campus planners, students, personnel, managerial officers, as well as others not within the university, can access the system via the internet.

It is also useful to state that whereas most of the applications of BIS executed in literatures were done using commercial software, we demonstrate that open source application programs (QGIS and PostgresSQL) can also be deployed efficiently for the creation of the BIS.

This paper is majorly aimed at demonstrating that a building information system for the University of Nigeria Enugu Campus was produced with open source application programs, which creates enabling platform for visualization and interaction; and upon conclusion, provided information about the physical structure, both spatial and non-spatial information as well as opportunity to make an inquiry about the buildings. Thus, the procedures described can also be used as a template to carry out further works on Building Information System for other areas as it is not yet a well-researched subject in Nigeria.

METHODOLOGY

Study area

Enugu State is situated in Nigeria's South-East geo-political zone. It lies 6°30' North of Equator, and 7°30' East of Latitude. On the world time zone, it is plus one hour (+1 h) of the GMT. To the south, it is bounded by Imo and Abia states, to the East, Ebonyi State, to the North-East, Benue State, to the North-West, Kogi State and to the West, Anambra State, covering about 7,161 km^2 (2,765 m^2) in area (Figure 1).

The specific area selected for this study is University of Nigeria Enugu Campus, in Enugu North Local Government Area of Enugu State. It is bounded by latitude 6°24'58'' to 6°25'51'' and longitude 7°29'50'' to 7°30'43'' with an area of approximately 200 ha (Figure 2).

Materials used

The materials utilized are HP laptop computer with the following specifications: Intel(R) Core(TM) i3-4005U CPU at 1.70GHz, RAM: 4.00GB and System type: 64-bit Operating System and a 32GB Flash drive while the computer application programs are QGIS 2.4.0, PostgresSQL 9.3.1 and Microsoft Excel.

Method

The methods are the reconnaissance survey, data acquisition, data processing, and finally, the integration of the processed data.

Since the project area is a familiar one, the reconnaissance survey was skipped and the major preliminary investigation was to evaluate various application programs so as to ascertain which best suits the project execution. It was resolved that the QuantumGIS (QGIS) software will be used alongside PostgreSQL as the database management system with PostGIS as its spatial database extender. The decision to execute the project using the QGIS software was influenced by the fact that it is open source and the PostgreSQL (which is also open source) was also chosen because it is very compatible with the QGIS software, and it is an object-oriented database management system, thus, having an edge over other regular relational database management systems.

Two major data types were utilized; spatial and non-spatial. The spatial data source was a geo-referenced image of the campus captured by aerial photography which showed locations of all buildings in the campus. Due to the fact that this image is old and does not display current developments within the study area, a more recent Google Earth image of the campus was also downloaded and utilized during the execution of the project. The non-spatial (attribute) data of the buildings was gotten from the Department of Works, University of Nigeria, Enugu Campus as well

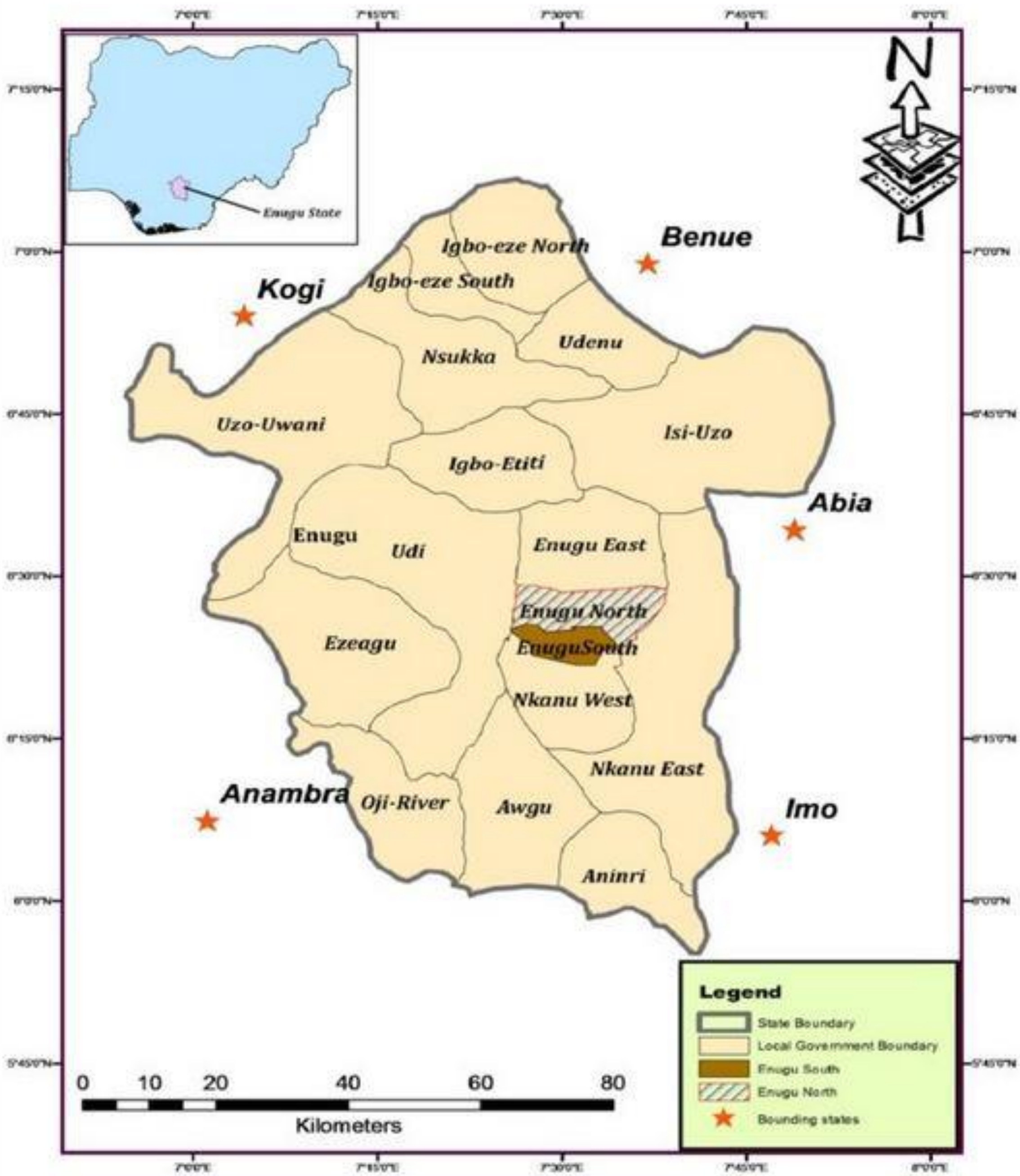


Figure 1. Map of Enugu State with Enugu North Local Govt. area hatched.

as other relevant sources. The process of acquiring data also included ground-truthing which was carried out to confirm the situation of some of the buildings and also to identify on the ground, the particular structure located in an area where it is not properly detectable in the image.

Data processing includes all the stages involved in the transformation from data to information. Such information guides decision taking since analysis can be made and inferences deduced. For the purpose of the project, the stages of data processing include:

(1) Image Geo-referencing
(2) Image Digitization
(3) Attribute Data Organization
(4) Database Creation

Image geo-referencing

This entails referencing the coordinates of features so that their coordinates on a map conforms to the actual coordinates on the ground. It is of two types; image-to-map rectification and image-to-image registration. The image-to-image registration was the geo-referencing type used in this project in order to align the Google

Figure 2. Aerial photograph showing UNEC enclosed.

Table 1. Parameters of image points used for geo-referencing.

ID	srcX	srcY	dstX	dstY	dX (pixels)	dY (pixels)	Residual (pixels)
0	418.81	-337.63	333995.15	710384.55	-0.13	-0.20	0.23
1	957.68	-412.96	334680.90	710289.03	0.81	-0.17	0.83
2	980.42	-992.75	334708.01	709553.78	-0.59	0.06	0.59
3	1513.32	-253.44	335385.59	710490.63	-0.10	0.31	0.32

Earth imagery with the geo-referenced aerial photograph of the study area. In this work, four points were used to geo-reference the image whose parameters are tabulated in Table 1.

Image digitization

This is also known as vectorization, simply the process of converting the raster form of an image into vector using points, lines and polygons. The image digitization process simply encapsulates how the QGIS software was used to transform the already geo-referenced image into its vector format from which map can be produced and also serve as the base of the database created. The map of the study area was produced immediately after digitizing the required datasets from the basemap which are boundary, buildings, and roads. This of course was accomplished using the 'composer manager' of the QGIS software.

Attribute data organization

This involved organizing the contents of the attribute data in the Microsoft Excel environment. All the collated attributes for the buildings were neatly organized in Microsoft Excel with their contents properly tagged with special codes. The codes and interpretation are shown in Table 2.

After populating these fields in Microsoft Excel, and saving it, all its contents was joined to the attribute table of the building shape file layer created in QGIS.

Database creation

A database is simply a store-house of logically related data, and a computer program that holds such amount of large data and also ensures easy access, proper management, updating, manipulation and so on, is a database management system (DBMS). The process of creating a database was achieved for this project using the PostgreSQL database management system. Besides creating a database, it is also paramount that there is a link between the attribute dataset in the PostgreSQL database management system and the spatial dataset in PostGIS (the spatial database extender of PostgreSQL). After the creation of the database, hyperlinking was done to connect each of the building footprints to their

Table 2. Codes for buildings' attributes and their interpretation.

Code	Interpretation
ID	Identification number attached to the feature
PPT/ST_NO	Location or address of the building
PURPOSE	Purpose for which the building was constructed
SHAPE	Shape of the building
CONST_DATE	Construction date of the building
CONST_DET	Construction details of the building
NUM_FLR	Number of floors in the building
FLR_AREA	Floor area of the building
BLD_TYPE	Type of building
NUM_DRS	Number of doors in the building
NUM_WIN	Number of windows in the building
NAME	Name of the building

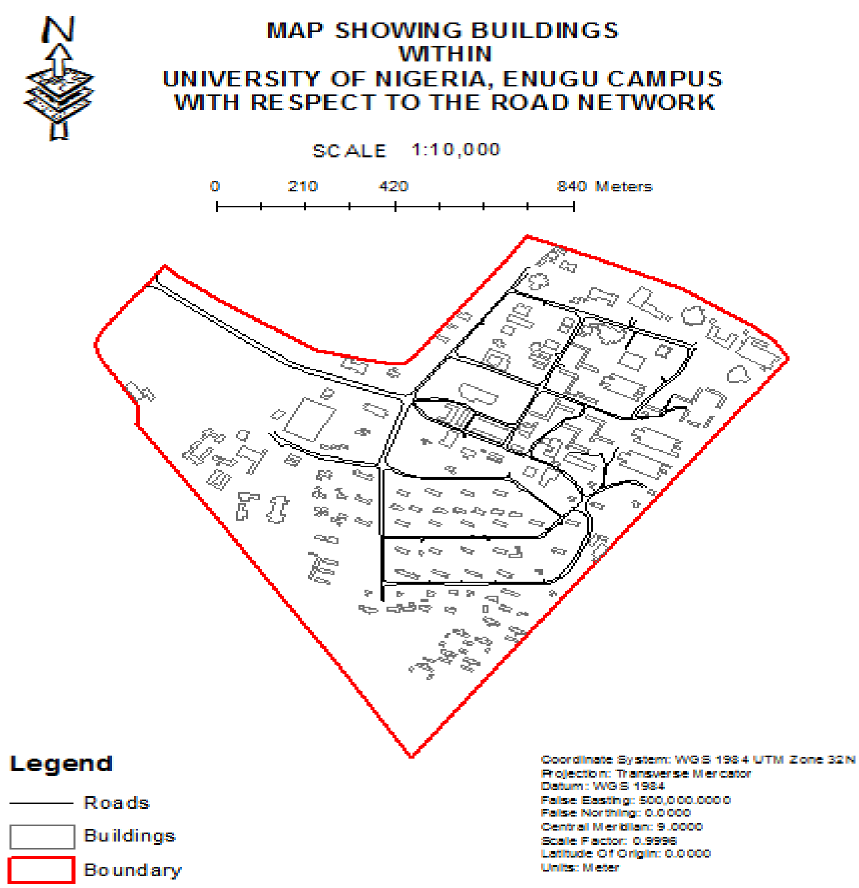


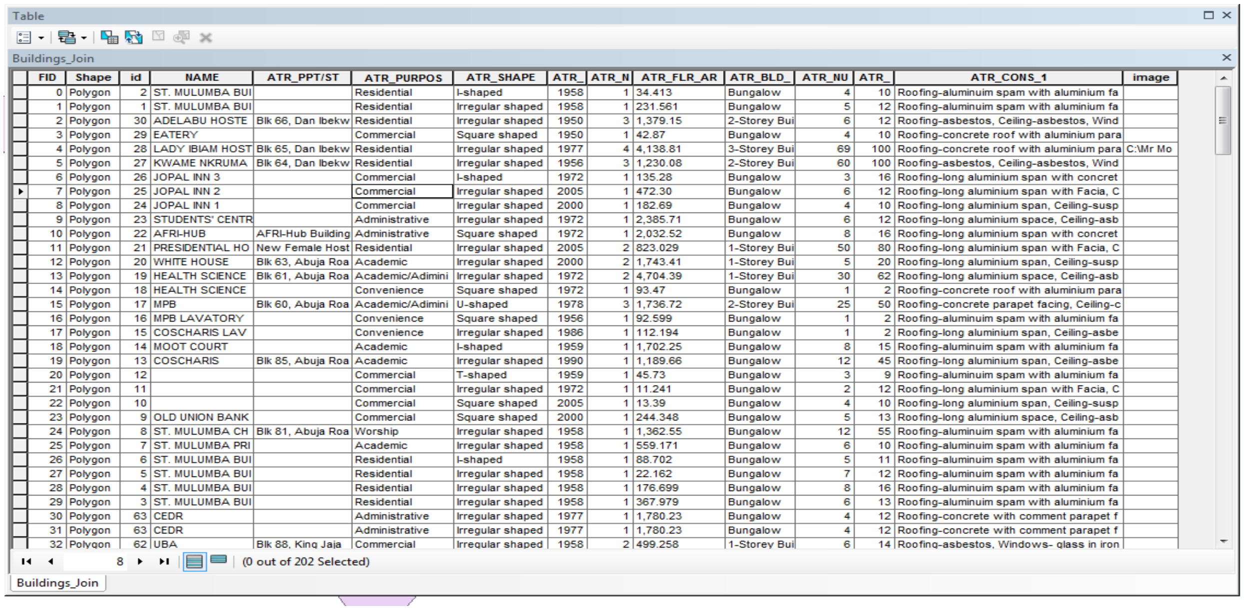
Figure 3. Map of University of Nigeria, Enugu Campus (Designed with the map composer).

corresponding images.

RESULTS

The results obtained include a map of the study area (Figure 3), a database containing attributes of all the buildings in the campus created using the PostgreSQL DBMS (Figure 4) and seamless configuration of the QGIS as a visualization and interaction tool for the database.

Details as well as attributes of any building of interest contained within the target area of the database can be



Table

Buildings_Join

FID	Shape	id	NAME	ATR_PPT/ST	ATR_PURPOS	ATR_SHAPE	ATR_	ATR_N	ATR_FLR_AR	ATR_BLD_	ATR_NU	ATR_	ATR_CONS_1	image
0	Polygon	2	ST. MULUMBA BUI		Residential	I-shaped	1958	1	34.413	Bungalow	4	10	Roofing-aluminuim spam with aluminium fa	
1	Polygon	1	ST. MULUMBA BUI		Residential	Irregular shaped	1958	1	231.561	Bungalow	5	12	Roofing-aluminuim spam with aluminium fa	
2	Polygon	30	ADELABU HOSTE	Blk 66, Dan Ibekw	Residential	Irregular shaped	1950	3	1,379.15	2-Storey Bui	6	12	Roofing-asbestos, Ceiling-asbestos, Wind	
3	Polygon	29	EATERY		Commercial	Square shaped	1950	1	42.87	Bungalow	4	10	Roofing-concrete roof with aluminium para	
4	Polygon	28	LADY IBIAM HOST	Blk 65, Dan Ibekw	Residential	Irregular shaped	1977	4	4,138.81	3-Storey Bui	69	100	Roofing-concrete roof with aluminium para	C:\Mr Mo
5	Polygon	27	KWAME NKRUMA	Blk 64, Dan Ibekw	Residential	Irregular shaped	1956	3	1,230.08	2-Storey Bui	60	100	Roofing-asbestos, Ceiling-asbestos, Wind	
6	Polygon	26	JOPAL INN 3		Commercial	I-shaped	1972	1	135.28	Bungalow	3	16	Roofing-long aluminium span with concret	
7	Polygon	25	JOPAL INN 2		Commercial	Irregular shaped	2005	1	472.30	Bungalow	6	12	Roofing-long aluminium span with Facia, C	
8	Polygon	24	JOPAL INN 1		Commercial	Irregular shaped	2000	1	182.69	Bungalow	4	10	Roofing-long aluminium span, Ceiling-susp	
9	Polygon	23	STUDENTS' CENTR		Administrative	Irregular shaped	1972	1	2,385.71	Bungalow	6	12	Roofing-long aluminium space, Ceiling-asb	
10	Polygon	22	AFRI-HUB	AFRI-Hub Building	Administrative	Square shaped	1972	1	2,032.52	Bungalow	8	16	Roofing-long aluminium span with concret	
11	Polygon	21	PRESIDENTIAL HO	New Female Host	Residential	Irregular shaped	2005	2	823.029	1-Storey Bui	50	80	Roofing-long aluminium span with Facia, C	
12	Polygon	20	WHITE HOUSE	Blk 63, Abuja Roa	Academic	Irregular shaped	2000	2	1,743.41	1-Storey Bui	5	20	Roofing-long aluminium span, Ceiling-susp	
13	Polygon	19	HEALTH SCIENCE	Blk 61, Abuja Roa	Academic/Adimini	Irregular shaped	1972	2	4,704.39	1-Storey Bui	30	62	Roofing-long aluminium space, Ceiling-asb	
14	Polygon	18	HEALTH SCIENCE		Convenience	Square shaped	1972	1	93.47	Bungalow	1	2	Roofing-concrete roof with aluminium para	
15	Polygon	17	MPB	Blk 60, Abuja Roa	Academic/Adimini	U-shaped	1978	3	1,736.72	2-Storey Bui	25	50	Roofing-concrete parapet facing, Ceiling-c	
16	Polygon	16	MPB LAVATORY		Convenience	Square shaped	1956	1	92.599	Bungalow	1	2	Roofing-aluminuim spam with aluminium fa	
17	Polygon	15	COSCHARIS LAV		Convenience	Irregular shaped	1986	1	112.194	Bungalow	1	2	Roofing-long aluminium span, Ceiling-asbe	
18	Polygon	14	MOOT COURT		Academic	I-shaped	1959	1	1,702.25	Bungalow	8	15	Roofing-aluminuim spam with aluminium fa	
19	Polygon	13	COSCHARIS	Blk 85, Abuja Roa	Academic	Irregular shaped	1990	1	1,189.66	Bungalow	12	45	Roofing-long aluminium span, Ceiling-asbe	
20	Polygon	12			Commercial	T-shaped	1959	1	45.73	Bungalow	3	9	Roofing-aluminuim spam with aluminium fa	
21	Polygon	11			Commercial	Irregular shaped	1972	1	11.241	Bungalow	2	12	Roofing-long aluminium span with Facia, C	
22	Polygon	10			Commercial	Square shaped	2005	1	13.39	Bungalow	4	10	Roofing-long aluminium span, Ceiling-susp	
23	Polygon	9	OLD UNION BANK		Commercial	Square shaped	2000	1	244.348	Bungalow	5	13	Roofing-long aluminium space, Ceiling-asb	
24	Polygon	8	ST. MULUMBA CH	Blk 81, Abuja Roa	Worship	Irregular shaped	1958	1	1,362.55	Bungalow	12	55	Roofing-aluminuim spam with aluminium fa	
25	Polygon	7	ST. MULUMBA PRI		Academic	Irregular shaped	1958	1	559.171	Bungalow	6	10	Roofing-aluminuim spam with aluminium fa	
26	Polygon	6	ST. MULUMBA BUI		Residential	I-shaped	1958	1	88.702	Bungalow	5	11	Roofing-aluminuim spam with aluminium fa	
27	Polygon	5	ST. MULUMBA BUI		Residential	Irregular shaped	1958	1	22.162	Bungalow	7	12	Roofing-aluminuim spam with aluminium fa	
28	Polygon	4	ST. MULUMBA BUI		Residential	Irregular shaped	1958	1	176.699	Bungalow	8	16	Roofing-aluminuim spam with aluminium fa	
29	Polygon	3	ST. MULUMBA BUI		Residential	Irregular shaped	1958	1	367.979	Bungalow	6	13	Roofing-aluminuim spam with aluminium fa	
30	Polygon	63	CEDR		Administrative	Irregular shaped	1977	1	1,780.23	Bungalow	4	12	Roofing-concrete with comment parapet f	
31	Polygon	63	CEDR		Administrative	Irregular shaped	1977	1	1,780.23	Bungalow	4	12	Roofing-concrete with comment parapet f	
32	Polygon	62	UBA	Blk 88, King Jaja	Commercial	Irregular shaped	1958	2	499.258	1-Storey Bui	6	14	Roofing-asbestos, Windows- glass in iron	

8 (0 out of 202 Selected)

Buildings_Join

Figure 4. Contents of the PostgreSQL database management system.

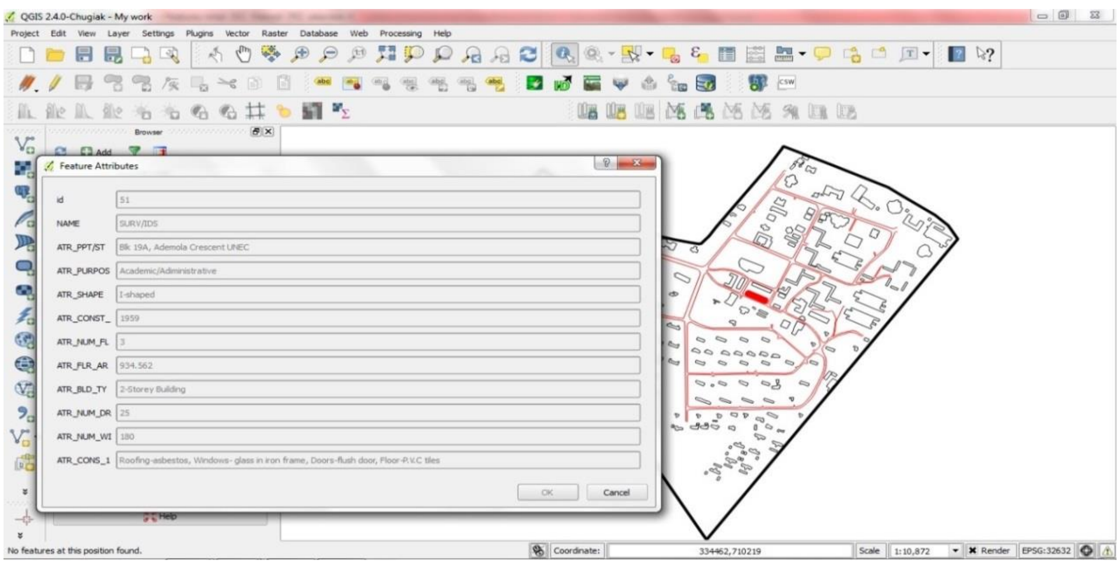


Figure 5. Display of the attributes of 'Department of Geo-informatics and Surveying' after selecting the image on the screen.

extracted through the QGIS application where the map is housed. In other words, clicking on a building in the map on the QGIS interface gives one access to the information about the building contained in the database thereby making it easier for end users who may not be familiar with the database application to be able to get the information they require by just clicking on the building of interest identified on the map.

Figure 4 is a snapshot of the information collated pertaining to the buildings using the database manager of the QGIS software.

The QGIS application was configured to serve as a visualisation tool for the database. After which it became possible to access the contents of the database from the QGIS interface. Figures 5 and 6 show the visualization and interaction capacity of the QGIS software, because with a click on any of the buildings in the map, its attributes immediately appeared on-screen, making it easy to access holistically the attributes of any desired building.

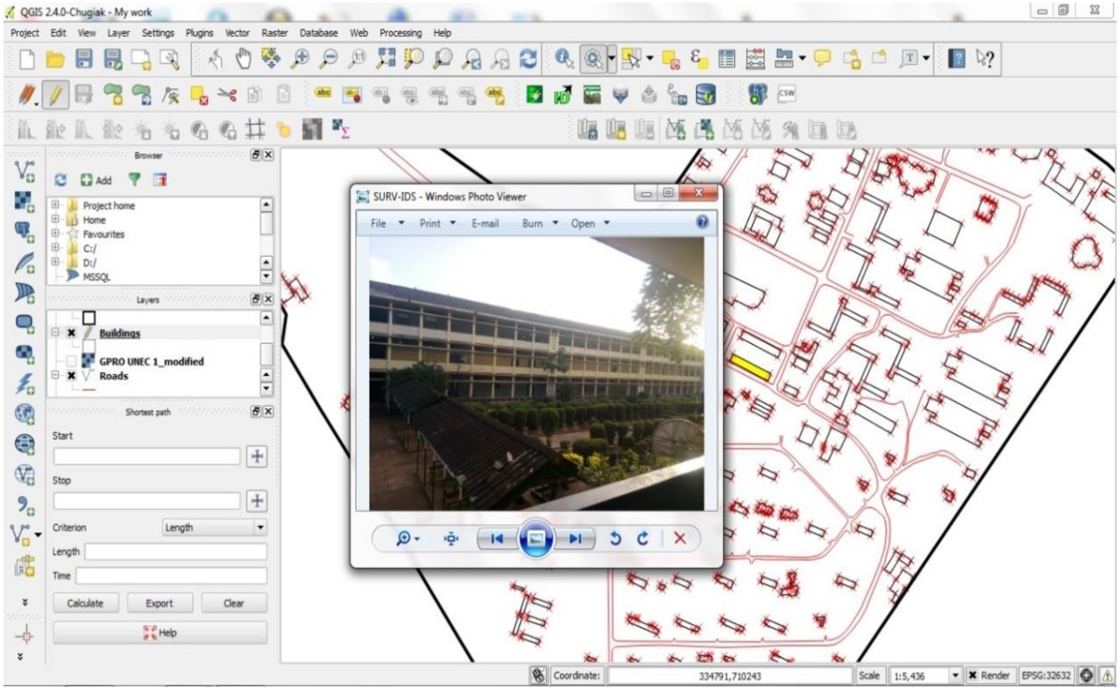


Figure 6. Display of the hyperlinked image of the Department of Geoinformatics and Surveying/Institute of Development Studies attached to its building footprint.

DISCUSSION

The development of a BIS was well achieved as all buildings within the university campus are now captured with their attributes. The information contained in the database will be very useful especially to decision makers on the distribution of resources, proper citing of new structures as well as for security purposes especially at the residential because details of all blocks can be easily extracted. QGIS on the other hand presents a lot of potentials for the GIS community. Before now, the high cost of acquiring operational license for commercial GIS applications has made it difficult; especially in developing countries like Nigeria, for GIS users to deploy their abilities in solving GIS related problems around their locality. In comparison with other GIS software such as ArcGIS, the QGIS was considered a better option, especially because of the fact that it is open-source and can be easily accessed unlike the ArcGIS which is not freely available. Other advantages of QGIS include its boatloads of plug-ins that can be used to solve every day GIS problems. The software has over 300 plug-ins which gives it an edge over other GIS applications.

QGIS is also equipped with a special tool known as the 'composer manager', a special interface majorly designed for all cartographic activities. This tool was utilized in map drafting.

The database was obtained using the 'DB manager' in the QGIS environment alongside the PostgreSQL database management system, this therefore presents new sets of tools for proper documentation and inventory. The symbiotic relationship that exists between the QGIS and PostgreSQL is the reason why the QGIS interface was successfully configured as the visualization platform of the information relating to the buildings which is resident in the PostgreSQL database management system.

Moreover, the PostgreSQL database management system, alongside the QGIS software, also avails any user the ability to query the database using SQL (structured query languages) and demand from it, any record concerning the subject under study, that is, buildings in the study area.

Conclusion

The university campus is similar to an urban area because of its spatial size, structures, activities, etc. Thus, it is important to develop a CIS in order to properly manage and monitor these infrastructures and their development.

To achieve the aim of developing a BIS for all buildings within the campus, a geo-referenced aerial image of the study area was acquired. Also, a recent Google Earth imagery of the same location was downloaded as well. The image-to-image registration performed on both images gave rise to the accurate geo-referencing of the latter image with reference to the former.

The digitization process of the image led to the realization of a map of buildings in the university with respect to the road networks situated therein. This map is a culmination of all the datasets extracted from the base map (which is the image used). The realization of this map saw the development of a database comprising non-spatial data associated with the buildings in the university, using PostgreSQL, as well as the possibility of visualizing and interacting with this database management system, through the QGIS interface.

The results achieved provide spatial and non-spatial information about the buildings, as well as opportunity to make an inquiry about them, and therefore serves as a framework for future works. It can also be used as a template to carry out further works on BIS for other campuses as it is not yet a well-researched subject in Nigeria.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors acknowledge the enabling research atmosphere provided by the GIS lab of the Department of Geoinformatics and Surveying, Faculty of Environmental Studies, University of Nigeria, Enugu Campus and the support given by the Head of the Department in terms of lab equipment and GIS personnel.

REFERENCES

Arif CA, Tahsin Y (2002). Web based campus information system: Department of Geodesy and Photogrammetry Engineering Karadeniz Technical University,Trabzon, Turkey. International Symposium on GIS, September 23-26, Istanbul-Turkey.

Aysel G, Aylin S, M.Kutay Y, Müúerref Y (2015). Developing Geographical Information Systems of Mustafa Kemal University Tayfur Ata Sökmen Campus. Academic Journal of Science 04(02):53-60.

Cete M, Palancioglu M, Geymen A, Alkan M (2010). The Turkish Cadastral Information System and Lessons Learned. Scientific Research and Essays 5(7):625-633.

Chrisman NR (2002). Exploring Geographic Information Systems. New York: Taylor & Francis, pp. 13-14.

Fajemirokun F, Adewale O, Idowu T, Oyewusi A, Maiyegun, B (2006). A GIS Approach to Crime Mapping and Management in Nigeria: A Case Study of Victoria Island Lagos. Conference proceeding on the XXIII FIG Congress with the Theme: Shaping the Change, October 8-13, Munich, Germany.

Folger P (2009). Geospatial Information and Geographic Information Systems (GIS): Current Issues and Future Challenges. Congressional Research Service Report for Congress 2009.

Konsol D (2001). Creating a new database for the physical structure of the campus area of Çukurova University using GIS: Graduate Thesis, Çukurova University, Balcali, Adana.

Meyers JR (2000). GIS in the Utilities. https://www.geos.ed.ac.uk/~gisteac/gis_book_abridged/files/ch57.pdf

Motuka MA (2008). GIS In Facilities Management: A Case Study of the U-block at the Kenya Polytechnic University College. Unpublished Project Report, Department of Geospatial and Space Technology, University of Nairobi.

Rainer RK, Turban E, Potter RE (2007). Introduction to Information Systems, New Jersey, John Wiley & Sons.

Savoie MJ (2012). Building Successful Information Systems: Five Best Practices to Ensure Organizational Effectiveness and Profitability, New York. Business Expert Press.

Tarhan Ç, Saygin Ö, Çinar A K, Yetiş Y, Başaran G (2006). A GIS-based Campus Information System: Izmir Institute of Technology. Retrieved 2018, May 25, from https://www.researchgate.net/publication/23732019

Topay M, Kaya LG, Yildrim B, Ikiz E, Demritas SO (2004). ZKU Bartin Campus Information System. ZKU Bartin Faculty of Forestry Journal 1-11:71-77.

Vol. 15(8), pp. 330-338, August 2021
DOI: 10.5897/AJEST2019.2781
Article Number: 3741D9067532
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

ACADEMIC JOURNALS
expand your knowledge

African Journal of Environmental Science and Technology

Full Length Research Paper

Assessment of open defecation in Kwahu Afram Plains South District, Ghana

Daniel Kwarteng Amponsah

Department of Environmental and Natural Resources Management, Faculty of Development Studies, Presbyterian University College, Abetefi, Ghana.

Received 16 October, 2019; Accepted 20 January, 2020

This study examined the barriers to open defecation (OD) free in Kwahu Afram Plains South District, Ghana. A combination of diverse tools was used to collect the data (in-depth interviews, Focus Group Discussions (FGDs) and observation), different means was adopted in selecting the participants. Much of the time in the early stages of the field work was spent having interactions with various groups within the community. Notable groups include the community care coalition, savings groups, mother to mother support groups and community child protection committee (CPCC), the fishmongers as they waited for fish at the beach, and the fishermen who had either returned from fishing or did not go for fishing and were relaxing under their shed. A questionnaire was administered to 169 households randomly selected from 6 communities in the Tease Area Council and 5 communities in the Samanhyia Area Council. The findings revealed that, 69% indicated their responsiveness to continue OD if subsidy is not introduced. 64% alluded that, every household should own a sanitary toilet facility however in terms of measures to ensure sanity at the toilet facility. 110 respondents representing 65% were not able to articulate a measure to the usage of sanitary toilet facility. 74% were not able to articulate a measure to ensure cleanliness at the toilet facility. The findings of the research conclude that, the inability of households to construct toilet facility highly influenced the state of open defecation in communities and this is translated into the limited toilet facilities in communities.

Key words: Finance mechanisms, open defecation free, Ghana, families, households.

INTRODUCTION

The Joint Monitoring Programme (JMP) of the World Health Organization (WHO) and UNICEF defines improved sanitation as “a sanitation system in which excreta is disposed of in such a way that there is reduced risk of faecal-oral transmission to its users and the environment”. Specific types of improved sanitation facilities recognized by the JMP include flush or pour-flush latrine, pit latrine with a slab, ventilated improved pit (VIP) latrine and the composting toilet (Karnib, 2014). To be accepted as ‘improved’, a sanitation facility is required to be used exclusively by only one household.

Access to improved latrines at home and in public places is a crucial defense to humans and the environment against faecal-oral transmission of

E-mail: kamdanny100@gmail.com.

pathogenic agents (Mara et al., 2010).

The case of low-income peri-urban and urban slums is of much greater concern due to their frequent association with vector-borne diseases, bacterial infections and contamination of drinking water amidst a rapidly growing population (Nakagawa et al., 2006).

Nevertheless, the impact of latrine provision on public health is dependent on the response of the intended users, especially their commitment to regularly use and maintain the facility. To ensure regular latrine usage, the choice of technology, the design and construction of facilities, as well as their operation and maintenance should be directly linked to the defecation practices, preferences and cultural values of the intended users (Garfi and Ferrer-Marti, 2011). It is, therefore, crucial to understand the factors that influence latrine usage and the barriers to regular use in any cultural and socio-economic context. Understanding of such factors is required to guide the development of technical and social interventions that are consistent and likely to stimulate local drivers of latrine usage (Sarkingobir and Sarkingobir, 2017).

In Ghana, only 14% of the population has access to improved sanitation as against an MDG target of 54% set for 2015 (JMP, 2014). The proportion of Ghana's population depending on shared sanitation, including public toilets (59%), is the highest in the world (JMP, 2014). According to the JMP, 19% of Ghanaians practice open defecation while 8% depend on various forms of unimproved sanitation options such as bucket latrines. In terms of technology mix, nearly half of Ghanaian households depend on dry sanitation systems such as the simple pit and ventilated improved pit latrines while 10% depend on wet or flush on-site systems (Ghana Statistical Service, 2008). Sewerage is only piloted in parts of the country and covers only about 3% of Ghanaian households (GSS, 2013). To improve the status of sanitation in the country, the government has over the last decade introduced a number of policies including the adoption of the community-led total sanitation (CLTS) approach and a strong advocacy for households in residential areas to acquire their own toilet facilities, with public sanitation facilities only recommended for transport terminals and other commercial centers (Ministry of Local Government and Rural Development, 2010a). In spite of the recent efforts to improve sanitation in Ghana, the statistics show that progress towards the Millennium Development Goals (MDGs) has been slow, with some policies simply not yielding the anticipated results. For instance, the use of hygiene education and subsidies to increase household latrine uptake under the Rural Water Supply Programme IV (2005-2009), implemented in selected districts in the Ashanti Region, failed to generate the expected response from the beneficiaries (Ampadu-Boakye et al., 2011). In each of the participating districts, 226 latrines were allocated to be constructed with 50% subsidy. However, in some districts, less than 5% of the allocated latrines were actually constructed under the programme. Among the reasons attributed to the poor response to the intervention in these districts was the failure to conduct background studies in the communities prior to the start of the project.

Thus, this study was conducted in the coastal peri-urban setting of Ghana to understand the factors influencing latrine usage and the barriers or constraints that discourage regular use of existing household and communal latrines.

MATERIALS AND METHODS

Description of the study areas

The study was conducted in two area councils of the Kwahu Afram Plains South District. The Area Councils were Samanhyia Area Council and Tease Area Council (Figure 1). The Kwahu Afram Plains South District was carved out from the Kwahu North District and forms part of the newly created districts in the country. The Afram Plains South District is located between Latitudes 6° 40^1 N and 7° 10^1 N; longitudes 0° 40^{1}E and 0° 10^l E; at the North-Western corner of Eastern Region with a total land area of approximately 3,095 km^2. The district is bounded to the north by the Kwahu Afram Plains North, to the south by Kwahu South, to the east by the Volta River and to the west by two districts in the Ashanti region precisely Sekyere East and Ashanti-Akim Districts (GSS, 2013).

Data collection and analysis

The study communities were selected due to peculiar socio-economic and demographic characteristics as a result of the differences in their physical locations, which invariably influence their defecatory preferences and practices (Table 1).

Proportion of respondents

A proportional sampling technique was used to sample participants for the study.

Proportion of respondent = Population per community/Total population (both councils) ×100

A combination of diverse tools was used to collect the data (in-depth interviews, Focus Group Discussions (FGDs) and observation), different means was adopted in selecting the participants. Much of the time in the early stages of the field work was spent having interactions with various groups within the community. Notable groups include the community care coalition, savings groups, mother to mother support groups and community child protection committee (CPCC), the fish mongers as they waited for fish at the beach, and the fishermen who had either returned from fishing or did not go for fishing and were relaxing under their shed. A total of 297 respondents were selected from the Samanhyia Area Council and Tease Area Councils of the Kwahu Afram Plains South District.

All the informants and discussants for the study were purposively selected. They were people that is believed to have rich information and from whom one could learn much about issues of central importance to the purpose of the research. Informants and participants were made up of adult males and females and the

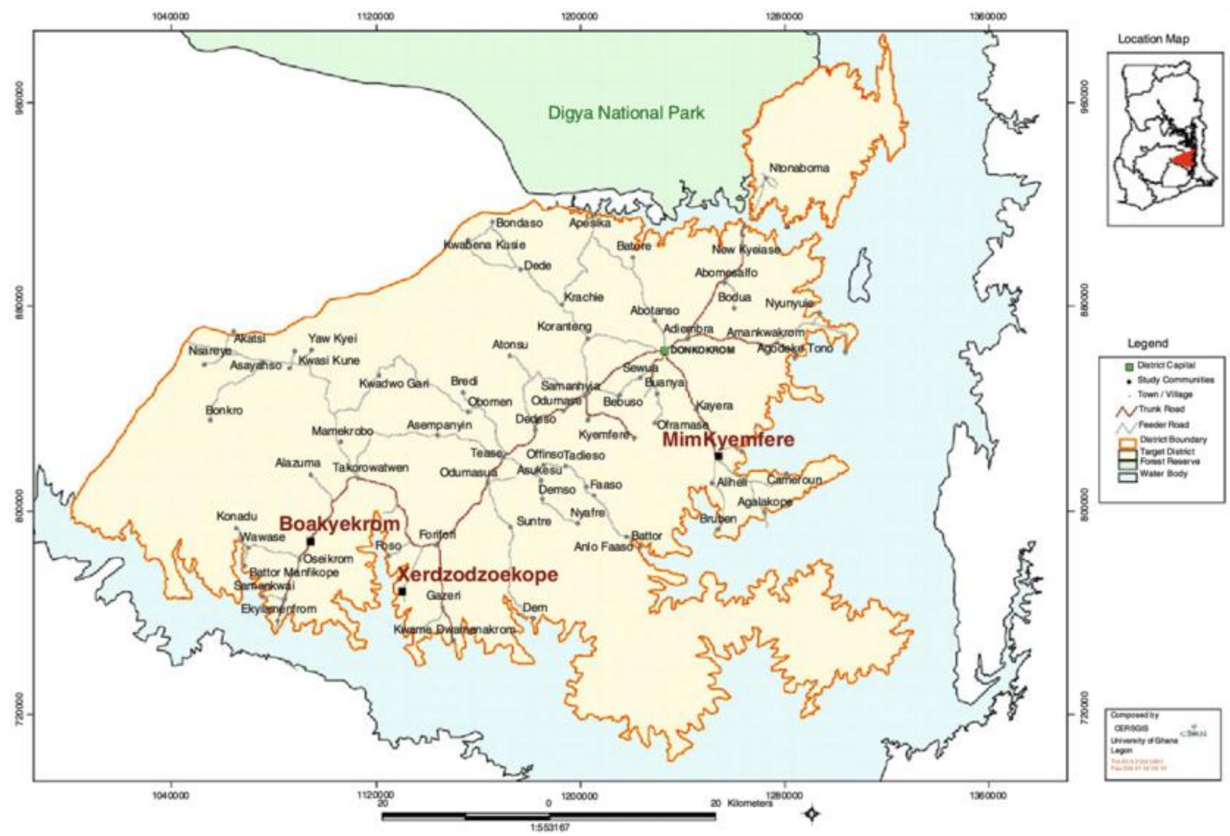


Figure 1. Map of the study area.

Table 1. Systematic representation of how sample size for the study was drawn.

Name of area council	Sample size	
	Population	Proportion of respondent
Tease Area Council		
Ameyaw	57	8
Dimso	67	9
Asukese II	121	17
Offinso	98	14
Praprabaabida	88	13
Asikam	56	8
Sub Total		
Samanhyia Area Council		
KwasiKuma	212	30
Kyemfre	103	15
Mmradan	189	27
Darteykrom	79	11
Somsei	121	17
Sub-Total	704	169

youth living in the community. A set of selection criteria was developed which aided in hand-picking the informants and participants. Informants for the in-depth interviews were drawn from the Environmental Health and Sanitation Directorate of the District Assembly, chiefs and opinion leaders, Water and Sanitation Management Committee (WATSAN). The criteria for selecting key

Table 2. Age of respondent.

Response	Frequency	Percent
15-25	4	2
26-35	20	12
36-45	36	21
46-55	64	38
56-65	44	26
66-75	1	1
Total	169	100

Source: Field Survey (2019).

Table 3. Sex distribution of respondent.

Response	Frequency	Percent
Male	89	53
Female	80	47
Total	169	100

Source: Field Survey (2019).

informants were: being an indigene or migrant who had lived in the community for at least ten years, having good knowledge of the history of the community, and should be above 18 years old.

Data processing and analysis

The data was checked for distribution and outliers. The questionnaire was coded in Statistical Package for Social Sciences (SPSS) version 17; descriptive statistics was done to derive numerical and non-numerical data presentation models including graphs, tables and frequencies among others for the quantitative data. For qualitative, data was coded according to the objectives. Grouping of the coded data was done according to themes after reading through. The recorded interviews were transcribed for the qualitative study and were used in write-up under specific themes.

RESULTS AND DISCUSSION

Demographic characteristics of respondents

The finding of the study specifies that 38% of the respondents were between the ages of 46-55 years. 26% of the respondents were between the ages of 56-65 years. 21% were between the ages of 36-45 years. 12% of the respondents were between 26-35 years while 2 and 1% of the respondents were between the ages of 15-25 years and 66-75 years. It can be observed that, the majority of the respondents were within the labour force representing 59% (Table 2).

Table 3 shows that, the sex distribution of the respondents. From the table, 53% were male while 47% were found to be female.

The findings of the study reveal that, 67% of the respondents were farmers while 23.1% were traders. 5% of the respondents were fishmongers while 4% of the respondents were fishermen. The remaining 2% were pupil teachers (Table 4).

Determination of the social, economic, and physical barriers to open defecation free

According to Table 5, majority of the respondents representing 81% indicated that, there is no taboo that regulates open defecation in the community. However, 10% of the respondents indicated otherwise.

The findings of the study revealed the following taboos that have restricted families to end open defecation.

"…The faeces of in-laws should never mix. To avoid the father-in-law and daughter-in-law's faeces mixing, there are gender-segregated open defecation sites so that the taboo is not broken…"

Another respondent indicated that *"… I do not use another family's open defecation site, lest you are bewitched. Our family lineage believes that person's faeces can be used to bewitch us. Therefore, we avoid using a defecation site other than their own. Witchcraft still plays a major role in our community and we have a mortal fear of being bewitched…"*

The findings of the study describes that, faeces could easily be picked up and used for witchcraft once they have left. So it is common for people upon visiting a neighboring house to walk all the way back to their own

Table 4. Occupational status of respondent.

Response	Frequency	Percent
Fisherman	6	4
Farmer	113	67
Fishmonger	8	5
Trader	39	23
Other	3	2
Total	169	100

Source: Field Survey (2019).

Table 5. Are there taboos, norms or values surrounding defecation and human excreta disposal in this community.

Response	Frequency	Percent
Yes	17	10
No	136	81
Don't know	16	10
Total	169	100

Source: Field Survey (2019).

Table 6. How many days do you spend in to construct latrine facility?

Response	Frequency	Percent
1-3 days	1	1
4-6 days	3	2
7-10 days	13	8
Above 10 days	29	17
Total	46	27

Source: Field Survey (2019).

home, should they feel the urge to attend to a 'call of nature'.

According to Table 6, majority of the respondents representing 17% indicated that, it took them more than 10 days to construct toilet facility. 8% indicated 7-10 days period, 2% indicated between 4-6 days period while 1% indicated 1-3 days period.

According to the Chairman of the WATSAN committee, *"…Site selection and orientation usually do not take more than a day to carry out this first phase of the construction activity. Much of the time is spent on procurement processes. I will need a huge sum of money to procure all the needed materials for the construction. I will need a concrete ring (32" × 16") at least 3, 1 ring cover, 2 bag of 50 kg cement, 10 cement bag of sand, 3 cement bag of gravels, 280 bricks, 1 set of pan with siphon, 3 ft HDPE pipe 4" and a skilled labour and mason. As a farmer, I cannot afford to procure all these materials within a day or two. I will have to buy them one at a time. This will take me more than 20 days to get set for the construction..."*

The findings of the study further describes that, excavation in a rock areas also takes more for people to own a toilet facility. A respondent indicated that *"the rocky nature of the land sometimes extend our time period. I am willing to construct the toilet facility but it takes granite before I can successfully dig the hole. This prolongs the time to complete the projects and this motivates us..."*
A respondent also indicated "… *the time and season can affect their reactiveness to get a toilet facility constructed on time. In the raining season, some of the dug-outs can cave in which will retire the success of the projects and hence more often get demotivated by the raining season*…"

According to Table 7, the findings of the study specify that, majority of the respondent do not pay for access to toilet facility in their community. 99% of the respondents indicated that, they do not pay for access to toilet facility. 6% of the respondents indicated that, they pay for access

Table 7. Do you pay for using toilet facilities?

Response	Frequency	Percent
Yes	1	1
No	168	99
Total	169	100

Source: Field Survey (2019).

Table 8. Does the cost involved in building a toilet facility hinder you from getting one at home or within the community?

Response	Frequency	Percent
Yes	117	69
No	51	30
Don't Know	1	1
Total	169	100

Source: Field Survey (2019).

Table 9. Do you have a toilet facility at home?

Response	Frequency	Percent
Yes	47	28
No	122	72
Total	169	100

Source: Field Survey (2019).

to the toilet facility. A respondent indicated that *"…I pay GHC 0.30p to access the toilet facility of a neighbor. The GHC 0.30p paid covers my two children and wife. My neigbour told me that, in an instance when the toilet becomes full, he will use the money to pay for its discharge…"*

The findings of the study specifies that, 69% indicated that, the cost involved in building a toilet facility hinders them from owning a toilet facility. 30% indicated that, the cost do not deter them to construct a toilet facility or own a toilet facility (Table 8).

In a focus group discussion at Somsei Community, a respondent indicated that, "…*I am a farmer and I earn less than GHC300.00 a month and I pay for my grandchildren school fees and feeding fees. I cannot afford to construct a toilet facility of my own. Instead of using the money for the toilet construction, I will use the money to cater for the wellbeing of my wards which is paramount to me. Education is the key and I must live to leave a legacy full of promising future".*

A retired head teacher also indicated that,*"… the money of yesterday did not have the value to cater for my wards fees and toilet facility. I have six children and the younger one is in senior high school. The education of my wards is very important to me and even though I know the health hazard of the unavailability of toilet, I cannot construct one. I am on retirement; I do not earn any money at the end of the month and hence would find it difficult to pay GHC 1000.00 for the toilet construction..."*

Chiefs and opinion leaders in a focus group discussion also indicated that, artisans charge exorbitantly. The study shows that, some of them take more than GHC 1500.00, which discourages the community for the construction of their own toilet facility. "*We have directed our members to own their own toilet; however, due to the charges of the artisans we are unable to hold community members",* the Chief of Somsei said.

However, Table 9 indicated that, 28% of the respondents had available toilet facility. 72% of the respondents do not have the toilet facility. Many people who did not have toilet facility indicated the high cost of the toilet building materials and service charge as the main factors that hinders them from acquiring one of their own. The study shows that, 72% people who did not have toilet facility use the free-range system where they explore a bush or in between houses and defecates there. One person defecates on stones while 24 defecate in rubber polythene and either towns or bushes. One person

Table 10. Distance to defecation sites.

Response	Frequency	Percent
0-59 seconds walk	1	1
1- 5 minutes' walk	10	6
6- 10 minutes' walk	3	2
Total	14	8

Source: Field Survey (2019).

Table 11. Do you think every house should construct sanitary toilet?

Response	Frequency	Percent
Yes	133	79
No	36	21
Total	169	100

Source: Field Survey (2019).

uses flush or pour-flush toilet.

According to Table 10, 6% of the respondents walk less than 5 min to the defecation site. 2% of the respondents walk between 6 and 10 min while 1% uses less than 59 s to visit the defecation site.

The findings of the study reveals that, distance covered to access toilet facility does not trigger them to own a toilet facility. 25% of the respondents were dissatisfied with the distance to defecation site however 75% were satisfied with the distance.

A respondent indicated that, "… *I have no option since I cannot own a toilet facility, I am not perturbed. As long as I can get-ride of the faeces I am okay…"*

The focus group discussion indicated that, community members enjoy defecating in bushes and love to defecate. They mentioned that, they dot pay for access to an open defecation site and faeces are not seen the next day due to the free ranch of pigs. The pigs eat the faeces and the place is always clean.

Assessment of knowledge base of people on effects of open defecation free (ODF)

The findings of the study revealed that, 79% of the respondent had adequate knowledge on the advantages of sanitary toilet facility while 21% did not have any knowledge on the importance of sanitary toilet facility (Table 11).

A farmer indicated that *"…I spent almost the whole day in the farm. I normally use the open space to defecate and hence do not see the relevance of owning a toilet facility when its usage would be less…"*

The findings of the study further established the following significances of sanitary toilet facility during the focus group discussions.

A respondent indicated "…*Sanitary toilet facility helps prevent the spread of diseases…"* The head teacher of Bebuso Primary School indicated *"…The availability of toilets is even shown to increase the school attendance of teenage girls, who may not go to school during their menstrual cycle…"*

The WATSAN committee chairperson of Bebuso Community also indicated that "… *The waste from infected individuals in the community can contaminate a community's land and water, increasing the risk of infection for other individuals…"*

The District Environmental Health Officer in the Kwahu Afram Plains South District mentioned that*"…Without proper sanitation facilities, people often have no choice but to live in and drink water from an environment contaminated with waste from infected individuals, thereby putting themselves at risk for future infection. Inadequate waste disposal drives the infection cycle of many agents that can be spread through contaminated soil, food, water, and insects such as flies…"*

The findings of the study describes that, 65% of the respondents know an appropriate measure to use of toilet facility while 35% do not know any measure to ensure sanity at the toilet facility (Table 12).

The study further established that, the 35% were mostly people who defecate in bushes. A respondent indicated that *"… I defecate in the bush and in the bush, I do not clean the place. The pigs eat the faeces during the day. So I do not know any measure ensures cleanliness if the toilet facility. The pigs are our cleaners…"*

During the focus group discussions, the study further established the following measures from the respondents.

According to a respondent *"… Through the intervention of World Vision I participated in a handwashing workshop and I got to know that, one must wash the hands thoroughly after visiting the toilet…"* A pupil from Koranteng Primary school indicated *"…using liquid soap*

Table 12. Do you know an appropriate measure to usage of sanitary toilet facility.

Response	Frequency	Percent
Yes	59	34.9
No	110	65.1
Total	169	100.0

Source: Field Survey (2019).

Table 13. Are there local regulations to discourage OD in the community?

Responses	Frequency	Percent
Yes	2	1
No	167	99
Total	169	100

Source: Field Survey (2019).

Table 14. Consequences of open defecation.

Consequences of open defecation	Frequency	%
Threat to public health	21	12.43
Threat to achievement of sustainable development goals	5	2.96
Leading to water pollution	33	19.53
Facilitates Fecal oral transmission of diseases	23	13.61
Harm our overall sanitation	20	11.83
Open defecation is a factor of diarrhea, cholera, typhoid ,hepatitis, cholera ,trachoma and others	67	39.64
Total	169	100

Source: Field Survey (2019).

is a better option than bar soap as the latter could be a source of infection…"

Another respondent also indicated that "*…Wash your hands thoroughly with soap every time you use the toilet…"*

The findings of the survey describes that, 99% of the respondents indicated that there is no local regulation that discourage open defecation (OD) in the community. 1% of the respondent indicated that, there is a local regulation that restricts open defecation (Table 13).

Findings from the focus group discussion indicated that, majority of the respondents do not have toilet facility and hence practice open defecation and most of the opinion leaders see no problem with it.

An opinion leader indicated that, *"… I am aware that open defecation is not good however we cannot restrict members not to defecate in bushes. Community members have complained on the cost of materials and other charges. We therefore became considerate and hence until 20 years to come, I do not think we can restrict members not to defecate in bushes…"*

Another opinion leader indicated that, *"… I saw the need for a local regulation but sometimes lineage influences the enforcement of the rules. I might not default but my nephew might default and as a leader of the community, I cannot allow my nephew to face the law. I will plead for forgiveness. When this happens, if other family members default I cannot say they should be sanctioned because my nephew was set free..."*

The findings of the study further specify that, respondents were guided by set of guidelines that regulates open defecation. The community has restricted members not to defecate openly but rather should join others who have some facilities. However, they have given a year momentum for each household to have a toilet facility. Amidst this, members still defecate openly, the respondents alluded.

The study further maintained that, the byelaws are not enforced since most of the respondents through focus group discussions indicated that, they were not aware of the existence of byelaws.

The findings of the survey describes that, 39.64% believe that open defecation is a factor of a factor of diarrhea, cholera, typhoid, hepatitis, cholera, trachoma and others, 11.83% believes that open defecation is harmful to the Afram Plain District overall sanitation (Table 14).

Some of the views of the participants are reflected in the following quotes "*Defecating in the open has been the cause of our illness in our communities. Nowadays it can cause some more health upsets. Open defecation brings about infections. The health consequences of open defecation are many (different diseases) because you do not know people who are infected in area that you want to defecate as well. Most at times has foul stench which is capable of affecting people especially girls. A nurse among the FGD mentioned that, in children, vaginal infections are usually caused by bacteria from the anus. These bacteria may be moved to the vagina when girls, particularly those aged 2 to 6 years, wipe from back to front or do not adequately clean the genital area after bowel movements".*

Another female participant in the FGD also alluded that "*I was very weak and did not have appetite for food. I had running stomach at dawn so they took me to the health center in this community. We were told that what brought about it is open defecation. It was then that I realized that, all these mosquitoes, when they perch on the faces, they will carry around and when they touch us or our food, it causes running stomach*

Conclusion

The research concludes that, the inability of households to construct toilet facility highly influenced the state of open defecation in communities and this is translated into the limited toilet facilities in communities.

RECOMMENDATIONS

The research suggests that principle of credit financing may be considered in assisting households to construct home toilets.

There is a need to develop appropriate finance mechanisms, through partnerships with district authorities and local financial institutions that ensure financial discipline and ability to recover the cost of investment.

Community-led initiatives that draw on the creativity and capacity of local people to take control of their change processes must be integrated into open defecation intervention programmes.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Ampadu-Boakye J, Dotse FM, Laryea NO, Karikari DY, Gyan E (2011). Improving access to basic sanitation in Ghana. Lessons from a water and sanitation project in Ghana Water and Sanitation Services Delivery in a Rapidly Changing Urban Environment. . InGhana Water Forum Journal 1:23-30.

Garfi M, Ferrer-Marti L (2011). Decision-making criteria and indicators for water and sanitation projects in developing countries. Water Science and Technology 64(1):83-101.

GSS (2013). 2010 population and housing census report: Millennium Development Goals in Ghana. GSS, Accra.

Joint Monitoring Programme (JMP) (2014). Progress on sanitation and drinking water: 2014 update. WHO and UNICEF http://www.wssinfo.org/fileadmin/user_upload/resources/JMP_report_2014_webEng.pdf, Accessed 10 July 2014.

Karnib A (2014). A methodological approach for quantitative assessment of the effective wastewater management: Lebanon as a case study. Environmental Processes 1(4):483-495.

Mara DD (2010). The design of ventilated improved pit latrines. Technology advisory group technical note no.13. The International Bank for Reconstruction and Development and the World Bank, Washington Usage and Barriers to Use of Latrines in Ghana 273. https://www.ircwash.org/sites/default/files/Mara-1984-Design.pdf

Ministry of Local Government and Rural Development (2010a). Environmental Sanitation Policy (Revised 2009) P. 35.

Nakagawa N, Oe H, Otaki M, Ishizaki K (2006) Application of microbial risk assessment on a residentially- operated bio-toilet. Journal of Water and Health 4(4):479-486

Sarkingobir Y, Sarkingobir S (2017). Open defecation, a threat to public health and sustainable Development Goals: a case study of Gwadabawa local government, Sokoto state, Nigeria. International Journal of Medical and Biosciences 1(1):28-37.

Vol. 15(8), pp. 339-348, August 2021
DOI: 10.5897/AJEST2021.3006
Article Number: C24F31967563
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

ACADEMIC JOURNALS
expand your knowledge

African Journal of Environmental Science and Technology

Full Length Research Paper

Briquette production from sugar cane bagasse and its potential as clean source of energy

Messay Emana Getu[1*], Birhanu Ayalew Abebe[1], Mulissa Jida Mideksa[1], Genet Tsegaye Araya[1], Endale Wondu Amare[2] and Gutema Bati Fedi[3]

[1]Environmental Biotechnology Directorate, Ethiopia Biotechnology Institute, Ethiopia.
[2]Sugar Technology and Engineering Research Program, Ethiopian Sugar Corporation, Research and Development Center, Ethiopia.
[3]Socio Economic Research Program, Ethiopian Sugar Corporation, Research and Development Center, Ethiopia.

Received 11 March, 2021; Accepted 26 May, 2021

Large quantities of bagasse are regularly accumulated on open spaces around sugar factory thereby endangering fragile ecosystem. The sugar cane bagasse carbonization process can be put into effect as an environmentally friendly, energy self-providing continuous flow technology. Therefore, the objective of this study was to use bagasse for the production of high caloric value briquette to safeguard the environment from pollution. Bagasse sample was collected from Wonje sugar factory and carbonized in an oxygen deficient environment at Ethiopian Rural Energy Development and Dissemination Center Laboratory, Addis Ababa. The carbonized materials were mixed with clay and molasses as a binder in different ratio to make a briquette using briquette extruder machine. Caloric value of the briquettes produced from bagasse using clay and molasses as a binder in different ratio ranged between 3,529-4,064 and 3,964-4,442 cal/g, respectively. The highest caloric value using clay as a binder was in the ratio 20:80 and the lowest caloric value using molasses as a binder was in the ration 25:75. Further analysis showed that through conversion of bagasse from Wonji sugar factory into briquette, annually the factory could generate 3.1×10^{-10} cal of energy and substitutes 13.01 m^3 of firewood or save 0.13 to 0.16 ha of tropical forests from deforestation and have the potential to sequestrate 17.90 to 22.03 tons of carbon annually. Further, the study concluded that briquettes produced from bagasse could be used as a quality source of energy and bagasse waste management option around sugar industry.

Key words: Energy, briquette, carbon sequestration, caloric value.

INTRODUCTION

Sugar development sector is one of enormous projects which enables industry take a leading role in the nation's economy. Ethiopia has huge human as well as natural resources which enable the nation to broaden this export oriented manufacturing industry sector and its productivity. The nation has suitable climate, wide and proved irrigable agricultural land (more than 500 thousand hectares) as well as abundant resource of water to use through canal

*Corresponding author. E-mail: genetehaia@gmail.com. Tel: 251911561837.

schemes. The government in its effort to ensure equitable share of the nation's resource among its peoples, has started broadening the sugar development sector.

The industrial strategic development plan of Ethiopia gives great emphasis to improve export-led products to join the international market in large-scale such as sugar factory. Sugar sector plays a unlimited role in the socio-economy of Ethiopia since it produces sugar for household and industrial consumptions, provides great job opportunity for the nationals, serves as source of energy and co-products are used for miscellaneous purposes. However, the liquid, gaseous and solid effluents produced from sugar industry have adverse impact on ecosystem and environment due to their high BOD load and toxicity. Bagasse is a main byproduct of sugar industry which finds a useful utilization in the same industry as an energy source. Sugarcane consists of 25 to 30% bagasse whereas sugar recovered by the industry is about 10% (Maung et al., 2015). Bagasse has high calorific value and hence it is usually used as a fuel in boilers in the sugar mills to generate steam and electricity. Each ton of sugarcane generates approximately 26% of bagasse (at a moisture content of 50%) and 0.62% of residual ash (Maung et al., 2015). However, currently, not all bagasse produced is used in the factories for the generation of heat and power. It is difficult to handle, transport and where storage facilities are lacking, and hence the surplus is dumped in compounds around the factory posing serious environmental problems, including fire hazards.

Huge amount of bagasse are produced annually by the sugar factories in Ethiopia constituting about 4.6% of the total bagasse production (Thinda et al., 2012). Disposal of bagasse has become a serious problem and large quantities of bagasse are regularly accumulated on open spaces around sugar factory thereby endangering fragile ecosystem. To reduce pollution hazards, industry should implement environment management system to advance economic and environmental performance of sugar processing unit.

In the search for new alternative sources of ecologically friendly energy, the utilization of Bagasse for the production of briquettes has become a good alternative. A briquette is biochar in a particular shape, made by using pressing techniques and adhesives (Fikri and Sartika, 2018). Bagasse carbonization process is environmentally friendly, energy self-providing continuous flow technology. Thus, the objective of the research was to use bagasse for the production of energy (high caloric value briquette) and ultimately safeguard the environment from pollution.

MATERIALS AND METHODS

Wonji-Shoa Sugar Factory is found in Oromiya Regional State at 108 km South of Addis Ababa near Adama city in Woniji town which was established by a Dutch holding HVA Company, 1954 (Figure 1).

In this study, apparatus such as carbonization machine, bagasse, plastic bags, oven, analytical balance, bomb calorimeter, briquetting extruder machine, mixer, cook stoves, molasses, and clay were used to produce briquette.

Sample collection and preparation

Bagasse sample was collected from Wonje Sugar Factory by using different plastic bags and transported to Ethiopia Biotechnology Institute laboratory before characterization of the sample.

Then, the collected samples of bagasse were chopped into suitable size, and then dried in oven dryer at a temperature of 500°C for 24 h. All physical and chemical analyses of the sample were done at Ethiopian Rural Energy Development and Dissemination Center Laboratory. Figure 2.

Procedure of briquette production

The bagasse sample was allowed to dry in oven for 24 h before carbonization to remove the moisture and facilitate the carbonization process. The bagasse sample was carbonized separately in an oxygen scarce environment using metal barrel-kiln carbonization machine. The process of carbonization was carried out in oxygen limited condition in barrel kiln with long chimney; which was used to control the proper air for carbonization process. Then, the carbonized material was removed immediately from the metal barrel-kiln carbonization machine and cooled using water. The cooled charcoal was dried in a naturally ventilated room at temperature of 25 to 30°C for two days. After being cooled and dried, the carbonized bagasse was ground using a milling machine (hammer mill) and sieved with a mesh size of 3 mm to obtain particles in the size range from 1 to 3 mm Figure 3.

The prepared carbonized materials/charcoal powder was mixed with a binder to produce a briquette. Clay and molasses were used as a binder in different ratio for making briquette during the experiment. Based on the experiment design the binder was manually mixed in different concentration with the prepared carbonized materials/charcoal. Then the mixture was converted into briquettes by using a briquette extruder machine. Finally, the briquettes were placed on a suitable material for drying under the sun.

Proximate analysis of produced briquettes

All proximate analysis of the produced briquette was carried out in the Ethiopian Rural Energy Development and Dissemination Center Laboratory, Ethiopia, Addis Ababa.

Moisture content

The percentage of moisture content of the raw biomass (PMC) was determined using standard method of American Society for Testing Materials (ASTM D 4442-07) on the basis of dry biomass which was found by weighing samples of obtained briquette (W1) and oven drying it at 105°C and intermediate weight of sample was recorded in every 60 min until the constant weight was obtained (W2). Then, the difference in weight (W1 - W2) was calculated to determine the sample's percentage moisture content using the following equation:

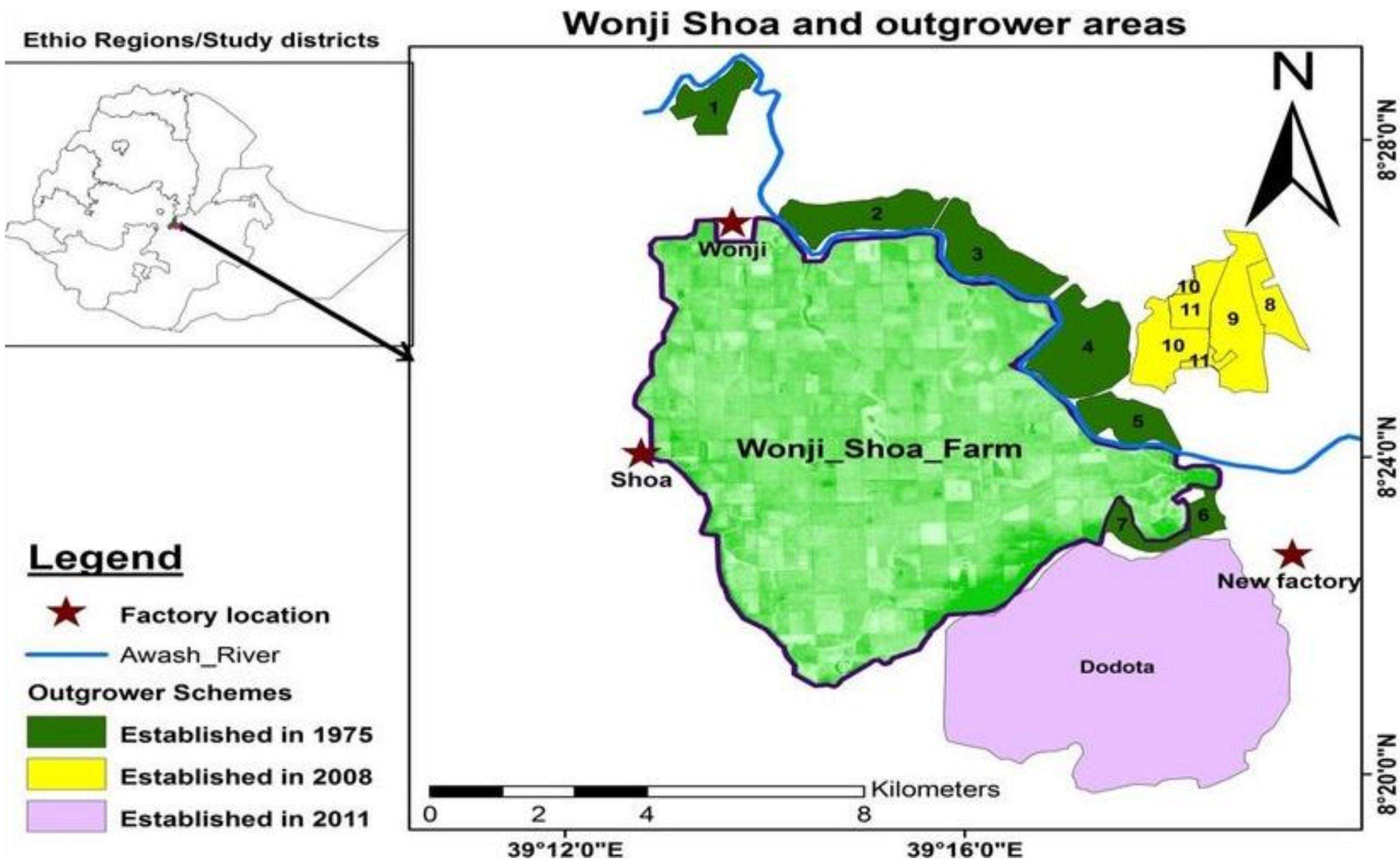


Figure 1. Map of Wonje sugar factory area.

$$PMC = (W1 - W2/ W1) \times 100 \quad (1)$$

where W1 = Initial weight of sample before drying, W2 = Final weight of sample after drying and PMC = percentage moisture content.

Volatile matter

The percentage of volatile matter (PVM) content was determined using the standard method CEN/TS 15148. Two grams of sample was pulverized and oven dried at 105°C until its weight was constant. Then, the sample was heated at 550°C for 10 min and weighed after cooling in desiccators. The PVM was calculated using the following equation:

$$PVM = (W1 - W2/ W1) \times 100 \quad (2)$$

where PVM = Percentage of Volatile Matter, W1 = Initial weight of sample, and W2 = Final weight of the sample after cooling.

Ash content

The percentage of ash content (PAC) was determined using CEN/TS14775 standard method. The percentage of ash content (PAC) was also determined by heating 2 g of the pulverized sample in the furnace at a temperature of 550°C for 4 h and weighed after cooling in a desiccator to obtain the weight of ash. The PAC was determined using the following equation:

$$PAC = (W2/ W1) \times 100 \quad (3)$$

where W1 = Initial weight of dry sample, W2 = Final weight of ash obtained after cooling sample and PAC = percentage of ash content.

Fixed carbon

The percentage of fixed carbon (PFC) was calculated by subtracting the sum of percentage volatile matter (PVM) and percentage ash content (PAC) and percentage moisture content from 100% as shown in the following equation:

$$\text{Fixed Carbon} = 100\% - (PAC + PMC + PVM) \quad (4)$$

Gross calorific value

To determine the gross calorific value of produced briquette, Bomb Calorimeter at Ethiopian Rural Energy Development and Dissemination Center Laboratory was used. The briquette specimens were analyzed by an adiabatic oxygen bomb Calorimeter Parr 6200 calorimeter of Parr M39889 and Parr M39805 oxygen bomb, which were used as per instruction manual according to ASTM D-5865-95.

Figure 2. Bagasse sample preparation.

Figure 3. Metal barrel-kiln carbonization machine.

Table 1. Caloric value of the raw samples (boiler bottom ash, boiler fly ash and raw bagasse).

Raw material	Trial one (cal/g)	Trial two (cal/g)	Trial three (cal/g)
Boiler bottom ash	± 676.5	± 651.64	± 663.6
Boiler fly ash	± 800	± 750	± 775.8
Raw bagasse	± 3561.2	± 3813.83	± 3746.59

Emission test, burning time and combustion efficiency

The emission of the produced briquette was analyzed using dust detector (TISCH Air Environment) equipment) and CO analyzers (Gas Alert Micro 5).

Data collection and analysis

Data were collected before carbonization process to determine the caloric value of the sample and on carbonization process and the laboratory analysis of briquettes. The results were recorded, processed and analyzed using Microsoft excels. Descriptive statistics and chart graph were used to compare means and standard deviation (SD) of the result of analysis. All the analysis assays were done in triplicate (n=3).

RESULTS AND DISCUSSION

Physical and chemical analysis

Caloric value of raw material

The study analyzes the caloric value of boiler bottom ash, boiler fly ash and raw bagasse to be used for the production of briquettes; hence characterization raw material of briquette for their proximate and physical properties is very important (Oladeji, 2010). The result of the caloric value of the raw samples (Boiler Bottom Ash, Boiler fly ash and raw bagasse) is shown in Table 1.

The calorific value defines the total heat energy which occurs in a material. From the table, raw bagasse has the highest calorific value of 3,813.83 cal/g, which may be due to the high carbon content of bagasse. Boiler bottom ash and boiler fly ash had the lower caloric value of 651 and 750 cal/g, respectively and which is very less with the calorific values of cotton stalk 1,670.9 cal/g, bamboo leaves 1,572.5 cal/g and prosopis 1,773.9.47 cal/g (Bharat, 2012). This may be due to the fact that it has low carbon content because it was burned to start the boiler for the electrification purpose. Due to high content of caloric value, raw bagasse was selected for the production of briquette.

Conversion efficiency and caloric value of carbonized bagasse

The conversion efficiency of the bagasse into carbonized material is 38.36% (from 100 kg of raw bagasse net average carbonized bagasse amounted to 38.36 kg) which was relatively good when compared with Weldemedhin et al. (2014), 31.02±0.84% for that of coffee pulp and 32.61±1.60% for coffee husk. Annually, Wonje Sugar Factory generates 15,000 tons (15, 000,000 kg) of excess bagasse (Personal communication with the Wonji Sugar Factory officials and calculated result from compiled annual report of the factory). Based on this fact, if the factory carbonized all the excess bagasse, annually the factory produced 5,754 tons (5,754,000 kg) of carbonized bagasse.

Calorific value is the most significant combustion property for determining the suitability of briquette as fuel. Calorific value gives an indication on the quantity required to generate a specific amount of energy. The average caloric value of the carbonized bagasse was 5,535.5 cal/g, which is high value to produce energy or briquette. As a result, if 5,754 tons (5,754,000 kg) of carbonized bagasse without any binder, the factory could possibly produce 31,851,276,000 calorific value of total energy annually. Therefore, Wonje Sugar Factory could generate 3.1×10^{-10} cal of energy annually from excess carbonized bagasse.

One kilogram of fuel wood gives 13.8 MJ of energy, which is equal to 3,296.82 cal/g of energy and 1 m^3 of fuel wood equals to 750 kg (FAO, 2020). Therefore, through production of briquettes, the factory could possibly substitute energy obtained from 13.01 m^3 of firewood. Tropical high forest could give 80 to 100 m^3 of firewood per hectare (FAO, 2020). Based on this conversion, Wonje Sugar Factory could save 0.13 to 0.16 ha of tropical forest from deforestation annually. Correspondingly, the aboveground carbon sequestration of tropical rain forest is 137.73 tons of carbon per hectare (Terakunpisut et al., 2007). Accordingly, the factory could save forests which have the potential to sequestrate 17.90 to 22.03 tons of carbon annually.

Production of briquette

The quality of briquettes is dependent on the raw materials and the briquetting process. The desired qualities for briquettes as fuel include good combustion, stability and durability in storage and in handling (including transportation), and safety to the environment

Figure 4. Produced briquettes.

when combusted (ElHaggar, 2007). In this study, the carbonized bagasse briquettes were produced using clay and molasses as a binding to compare the caloric value of each briquette in different ratio Figure 4.

All briquettes made from this study except a mixture of carbonized bagasse with 30% of clay as a binder, all have a greater calorific value of briquettes produced from elephant grass which was 3817.6 cal/g (Onuegbu et al., 2012). The Caloric Value of Carbonize Bagasse using clay as a binder with different ration is as shown in Figure 5.

The highest caloric value was in the ratio 20: 80 (20% of the sample was clay and the rest 80% was carbonized bagasse). The lowest value was in the ration 30:70 which is 3,529 cal/g. The caloric value of briquettes produced in the ratio 22:78 and 25:75 is 3920 and 3865 cal/g, respectively. The result shows that when the amount of clay increases the caloric value will decrease; this is due to the nature of binding material clay.

The average of the calorific mean values of the briquettes produced from carbonized bagasse in the ratio of 20: 80 (20% of the sample was clay and the rest 80% was carbonized bagasse) is 4.064 cal/g. If, 5,754 tons (5,754,000 kg) of carbonized bagasse was mixed with the specified proportion of the binder Wonji Sugar Factory could possibly produce 6,904.8 tons (6,904,800 kg) of briquettes annually, which would have a calorific value of 28,061,107,200 as total energy. Therefore, Wonje Sugar Factory could generate 2.8×10^{-10} cal of energy annually from excess carbonized bagasse in the ratio of 20:80 (20 percent of the sample was clay and the rest 80% was carbonized bagasse).

One kilogram of fuel wood gives 13.8 MJ of energy, which is equal to 3,296.82 cal/g of energy and 1 m^3 of fuel wood equals to 750 kg (FAO, 2020). Therefore, through production of briquettes, the factory could possibly substitute energy obtained from 11.34 m^3 of firewood from excess carbonized bagasse in the ratio of 20: 80 (20% of the sample was clay and the rest 80% was carbonized bagasse). Tropical high forest could give

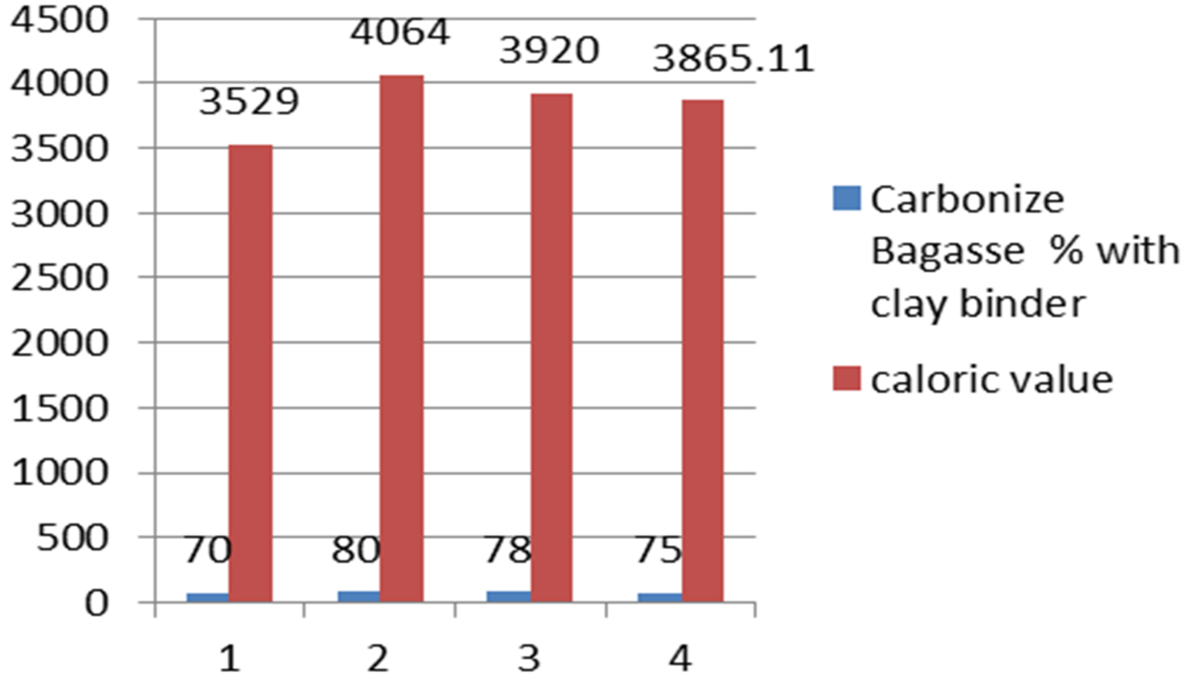


Figure 5. Caloric value of carbonize bagasse briquette using clay as a binder.

80 to 100 m^3 of firewood per hectare (FAO, 2020). Based on this conversion, Wonje Sugar Factory could save 0.12 to 0.14 ha of tropical forest from deforestation annually from excess carbonized bagasse in the ratio of 20:80 (20% of the sample was clay and the rest 80% was carbonized bagasse) . Correspondingly, the aboveground carbon sequestration of tropical rain forest is 137.73 tons of carbon per hectare (Terakunpisut et al., 2007). Accordingly, the factory could save forests which have the potential to sequestrate 16.52 to 19.28 tons of carbon annually. The Caloric Value of Carbonize Bagasse using molasses as a Binder with different ration is as shown in Figure 6.

The Caloric Value of Carbonize Bagasse using molasses as a binder with different ration analysis in graph 2 shows that when the amount of molasses as binder increases from 10 to 25% the calorific value decreases from 4442 to 3964 Cal/g.

Maximum caloric value was recorded in the ratio 10: 90 (10% of the sample was mollasse and the rest 90% was carbonized bagasse). The lowest value was in the ration 25:75 which is 3,964 cal/g. The caloric value of briquettes produced in the ratio 14: 86 and 18:82 was 4,080 and 4,004 cal/g, respectively. The result shows that when the amount of molasses increases the caloric value decreases.

The average of the calorific mean values of the briquettes produced from carbonized bagasse in the ratio of 10:90 (10% of the sample was mollasse and the rest 90% was carbonized bagasse) is 4.442 cal/g. If, 5,754 tons (5,754,000 kg) of carbonized bagasse was mixed with the specified proportion of the binder, Wonji Sugar Factory could possibly produce 6,329.4 tons (6,329,400 kg) of briquettes annually, which would have a calorific value of 28,115,194,800 as total energy. Therefore, Wonje Sugar Factory could generate 2.8 × 10^{-10} Cal of energy annually from excess carbonized bagasse in the ratio of 10: 90 (10% of the sample was mollasse and the rest 90% was carbonized bagasse).

One kilogram of fuel wood gives 13.8 MJ of energy, which is equal to 3,296.82 cal/g of energy and 1 m^3 of fuel wood equals to 750 kg (FAO, 2020). Therefore, through production of briquettes, the factory could possibly substitute energy obtained from 11.37 m^3 of firewood from excess carbonized bagasse in the ratio of 10:90 (10% of the sample was mollasse and the rest 90% was carbonized bagasse). Tropical high forest could give 80 to 100 m^3 of firewood per hectare (FAO, 2020). Based on this conversion, Wonje Sugar Factory could save 0.11 to 0.15 ha of tropical forest from deforestation annually from excess carbonized bagasse in the ratio of 10: 0 (10% of the sample was mollasse and the rest 90% was carbonized bagasse). Correspondingly, the aboveground carbon sequestration of tropical rain forest is 137.73 tons of carbon per hectare (Terakunpisut et al., 2007). Accordingly, the factory could save forests which have the potential to sequestrate 15.6 to 20.65 tons of carbon annually.

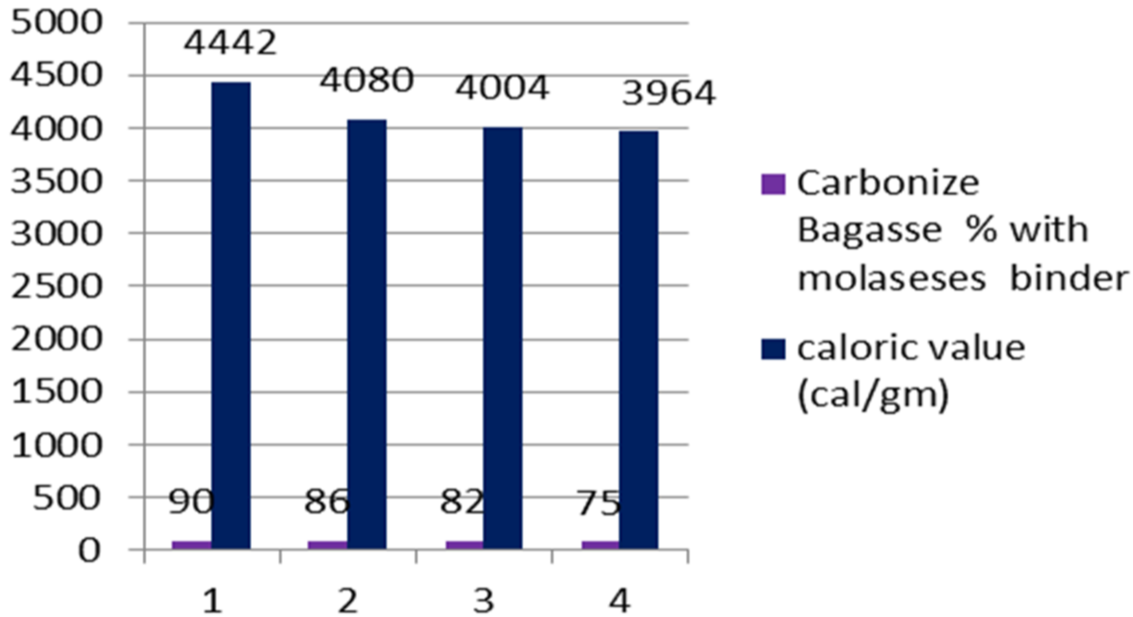


Figure 6. Caloric value of carbonize bagasse briquette using molasses as a binder.

Table 2. Proximate value of produced briquette using clay as a binder at 20:80 ratio and molasses as a binder at 10:90 ratio.

Sample type	Moisture content (%)	Volatile matter (%)	Ash content (%)	Fixed carbon (%)	Gross heat (caloric value, cal/g)
Bagasse briquette (clay as a binder 20:80)	6	27	4	40	4064
Bagasse briquette (molasses as a binder 10:90)	5	25	3	42	4080

Proximate value of the optimal briquette produced

Table 2 shows the proximate analysis of the produced briquette using clay as a binder at 20:80 ratio and molasses as a binder at 10:90 ratio.

The moisture content of bagasse briquette clay as a binder in the ratio 20:80 and bagasse briquette molasses as a binder in the ratio 10:90 is 6 and 5%, respectively, which were less than the rice husk and corncob briquette 12.67 and 13.47%, respectively (Oladeji, 2010). High moisture levels cause lower thermal efficiency and burning rate so that it is preferred that the bio-briquette has a lower moisture level (Onukak et al., 2017).

The high volatile matter would make the fuel smoky with a lot of pollutants during combustion. The higher volatile matter can be reduced significantly by carbonization (Ibeto, 2016). The volatile matter of bagasse briquette (Clay as a binder 20:80) and bagasse briquette (molasses as a binder 10:90) obtained from this study is 27 and 25%, respectively and less than the briquettes produced from rice husk which was 67.98 (Oladeji, 2010).

Ash is the non-combustible inorganic residue remains after complete combustion. The main component present in ash is a non-combustible mineral known as silica, which is left behind after the combustion process has ended (Glushankova et al., 2018). Presence of ash decreases the heating value (Onukak et al., 2017) so that the quality briquettes have low ash contents (Carnaje et al., 2018). The tolerance level for the ash content in a fuel is below 4% (Oyelaran et al., 2017). The ash content of bagasse briquette (Clay as a binder 20:80) and bagasse briquette (molasses as a binder 10:90) obtained from this study is 4 and 3%, respectively.

Briquette produced from bagasse clay as a binder in the ratio 20:80 and molasses as a binder in the ratio 10:90 were greater than the fixed carbon content of the charcoal briquette produced from sawdust briquette which was a fixed carbon content of 20.7% (Akowuah et al., 2012). Fixed carbon is the major quality measuring parameter that determines the energy behaviors in the production of densified biomass briquettes. The fixed carbon of bagasse briquette clay as a binder in the ratio 20:80 and bagasse briquette molasses as a binder 10:90

Table 3. Combustion test and smoldering characteristics.

Type of briquette	Measured smoldering characteristics			
	Weight of briquette (g)	Time taken to light the charcoal (min)	Burning rate (g/min)	Duration end of burning (min)
CBC (70:30)	150	6	0.32	175
CBM (90:10)	170	4	0.61	168

Ratio obtained from this study is 40 and 42%, respectively.

Calorific value or heating value regulates the energy content of a fuel. It is also the property of biomass fuel that can be influenced by its moisture content and chemical composition. In addition to this, it is the most important fuel property (Aina et al., 2009). The gross heat (caloric value) of briquette produced from bagasse clay as a binder in 20:80 ratio is less than the briquette produced from molasses as a binder 10:90 ratio this might be because of the binding material property. A high calorific value will make combustion more efficient thereby reducing the amount of bio-briquettes used (Shekhar, 2011).

Combustion test

The combustion test of charcoal briquettes with different binder mix ratio was comparatively tested. It was measured against commercial. The test was conducted using the medium size. During the test the following parameters was evaluated: ease of lightning, smoldering characteristics of briquette, smokiness and odor, spark generation. Table 3 shows the combustion test and smoldering characteristics of briquette produced from bagasse clay as a binder in the ratio 20:80 and molasses as a binder in the ratio 10:90.

The result for combustion test, flame and heat efficiency test of the produced briquette from bagasse clay as a binder 20:80 ratio and briquette produced from molasses as a binder 10:90 ratio confirmed that there was no smoke except at a startup. No spark formation, no soot production, no smell or odor.

Once the briquette fired it and is not possible to quit the fire for any moment since its used long period of time for cooking about 3 to 4 h and these proper cooking times must be known to manage the proper energy consumption. Durability is one of the advantage of briquette from other fuel charcoal; furthermore predicting the practical cooking time is the important aspect in energy efficient way utilization and for a better way utilization and efficient application or usage of the produced. The duration of the produced briquette from bagasse clay as a binder 20:80 ratio and briquette produced from molasses as a binder 10:90 ratio is 115 and 112 min, respectively, it can be used for cooking, which took too long a time for cooking, especially in Ethiopian traditional food like shero and others.

Conclusion

The findings showed that bagasse was a good source to produce briquette and have high potential as a source of environmentally friendly energy, which reduces pollution around sugar factory and can be used as a good environment management system (EMS) to the sugar industry. Utilization of bagasse for the production of briquette to produce clean energy can reduce indoor air pollution and respirator infectious disease that occurred due to the release of smoke during cooking. Using bagasse for the production of briquette can also save forests from deforestation and can be used as a climate change mitigation option. Moreover, producing briquette from bagasse can generate additional income and create job opportunity for the local community and micro enterprise.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Aina OM, Adetogun AC, Iyiola KA (2009). Heat energy from value-added sawdust briquettes of Albiziazygia. Ethiopian Journal of Environmental Studies and Management 2(1):42-49.

Akowuah OA, Francis K, Stephen JM (2012). Physico-chemical characteristics and market potential of sawdust charcoal briquette. International Journal of Energy and Environmental Engineering 3:20.

Bharat GBP (2012). Biomass Characterization and its Use as Solid Fuel for Combustion. India. Iranica Journal of Energy and Environment pp. 123-128.

Carnaje NP, Talagon RB, Peralta JP, Shah K, Ferreiro JP (2018). Development and characterisation of charcoal briquettes from water hyacinth (*Eichhornia crassipes*) molasses blend 1: 1-14.

Haggar El (2007). Sustainability of Agricultural and Rural Waste Management. In Sustainable Industrial Design and Waste Management; Elsevier: Amsterdam, The Netherlands. pp. 223–260.

Food and Agriculture Organization (FAO) (2020). Forest product conversion factors. FAO, ITTO and ECC. Rome, 2020. http://www.fao.org/3/ca7952en/CA7952EN.pdf

Fikri E, Sartika C (2018). Study on the Use and Composition of Bio-Charcoal Briquettes Made of Organic Waste. Journal of Ecological Engineering 19(2):81-88.

Glushankova I, Ketov A, Krasnovskikh M, Rudakova L, Vaisman I (2018). Rice Hulls as a Renewable Complex Material Resource 7(2): 1-11.

Ibeto CN, Anisha MC, Anyanwu CN (2016): Evaluation of the Fuel Properties and Pollution Potentials of Lignite Coal and Pellets of its Blends with Different Biowastes. American Chemical Science Journal 14(1):1-12.

Maung YM, Win TT, Oo AT (2015). Preparation and characterization of bagasse ash. International Journal of Technical Research and Applications 3(1):84-87.

Oladeji J (2010). Fuel Characterization of Briquettes Produced from Corncob and Rice Husk Resides. The Pacific Journal of Science and Technology 11(1):101-106.

Onuegbu TU, Ogbu IM, Ejikeme C (2012). Comparative analyses of densities and calorific values of wood and briquettes samples prepared at moderate pressure and ambient temperature. International Journal of Plant, Animal and Environmental Sciences 2(1):40-45.

Onukak IE, Mohammed Dabo IA, Ameh AO, Okoduwa SI, Fasanya O (2017). Production and characterization of biomass briquettes from tannery solid waste. Recycling 2(4):1-19.

Oyelaran OA, Balogun O, Ambali AO, Abidoye JK (2017). Characterization of briquette produced from tannery solid waste. Journal of Materials and Engineering Structures 4(2):79-86.

Shekhar N (2011). Popularization of biomass briquettes-A means for sustainable rural development. Asian Journal of Management Research 2(1):457-473.

Terakunpisut J, Gajaseni N, Ruankawe N (2007). Carbon sequestration potential in aboveground biomass of Thong Pha Phum national forest, Thailand. Applied ecology and environmental research 5(2):93-102.

Thinda HS, Yadvinder-Singh A, Bijay-Singh B, Varinderpal-Singh B, Sharmaa S, Vashisthab M, Singha G (2012). Land application of rice husk ash, bagasse ash and coal fly ash: Effects on crop productivity and nutrient uptake in rice–wheat system on an alkaline loamy sand. Field Crops Research 135:137-144.

Weldemedhin M, Alemayehu H, Esayas A, Argaw A (2014). The Potential of Coffee Husk and Pulp as an Alternative Source of Environmentally Friendly Energy. East African Journal of Sciences 8(1):29-36.

Related Journals: