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Fondzenyuy Vitalis Fonfo
Department of Earth Sciences, University of Dschang, Faculty of Science, P.O Box 67 Dschang, Cameroon

Fondzenyuy Lionel Nyanchi
University of Bamenda, Cameroon

Water quality enhancement in Kumbo Municipality-North West region of Cameroon

Fondzenyuy Vitalis Fonfo and Fondzenyuy Lionel Nyanchi

Abstract
After research in Kumbo municipality in the North West Region of Cameroon on water quality enhancement, we were enriched with findings. Water samples were obtained from alternative sources including; Boreholes (BH), Open wells (OW), Streams (ST), Rivers (RW) and a water catchment (YEH). Field *in-situ* parameters were obtained and physico-chemical and laboratory analysis were done. Agricultural activities were identified within the vicinity of some water sources. A petrographic study of the rock samples was also done. Basalts and trachyte were the main rocks often accompanied by other volcanic rocks; ignimbrites, phonolites, rhyolites, isolated scoria and granites as the bedrock. The results obtained and discussion revealed Ca^{2+} as the dominant cation in the water samples with a decreasing order $Ca^{2+} > Mg^{2+} > Na^+$ and K^+. HCO_3^- was the dominant anion followed by SO_4^{2-}, NO_3^-, and Cl^- having very negligible concentrations in the water sources. The main water type was calcium bicarbonated. The parameters like; pH, hardness, Permeability Index, Percent sodium, Total Dissolved Solids, Residual Sodium Carbonate and Sodium Absorption Ratio, all fell within suitable ranges recommended for their particular uses on comparison with stipulated standard norms such as WHO, Swiss, Bureau of Indian Standards (BIS), and the European Union (EU). The weathering of silicate minerals largely controlled the concentration of major ions in the water sources. The quality of these water sources are influenced by the geologic and anthropogenic activities which had incidences on drinking, domestic and agricultural uses. Consequently, adequate management strategies must be adopted to sustainably protect this indispensable resource.

Keywords: Municipality, Innovative, physico-chemical, suitability, norms

1. Introduction
Effectively Kumbo municipality like other councils in Cameroon is expected to enjoy an administrative and financial autonomy in the management of local interests. To attain its missions, the municipality elaborates action plans in a budget. The main actors to realize the action plans are mainly the municipal administrative and technical corps. It is with these bodies that we initiated a reliable, innovative and cost effective means for physico-chemical analysis. This was with the application of a Hanna Instrument; HI 83200 Multiparameter photometer that enabled analysis hitherto done in laboratories via titrimetric traditional methods.

Water schemes are given an important preoccupation in Kumbo municipality, with qualitatively and quantitatively development of these water schemes as centerpiece. This remains of primordial concern in communities worldwide. An evaluation of water sources to determine their chemical compositions, the water types and their suitability for diverse purposes such as drinking, domestic and agriculture remain preoccupying. Water mineralization is due to the presence of ions derived from anthropogenic and natural sources such as water rock interactions involving dissolution of rock minerals. Application of chemical fertilizers remains one of the main anthropogenic sources of introducing some ions into water sources, but for this to be a dominant source; there must be a large scale industrial application of fertilizer absent in Kumbo municipality. Based on this assertion the main objective of this work was to use the fact that most water mineralization is as a consequence of dissolution of rock minerals.

Rock samples from the municipality were collected and thin rock sections prepared according to the Dave's method. Thin sections, microscopic observations were done to identify the minerals present in the rocks. The chemical compositions of the identified minerals were well known with their relevant chemical formulae. With these compositions relevant chemical equations were written that chemically expressed the mineral dissolutions

Corresponding Author:
Fondzenyuy Vitalis Fonfo
University of Dschang, Faculty of Science, department of Earth Sciences, P.O Box 67 Dschang, Cameroon

to release into the water bodies the different ions. The ions present were revealed via a physicochemical analysis of the studied representative water samples (Dechao *et al*., 2020; Muhammed *et al.,* 2020; Fondzenyuy and Kengni, 2021) [2, 10, 3]. This analysis in most communities has become increasingly important and has same implications in the Kumbo municipality (WHO, 2017, 2018, 2019) [20, 21, 22].

The objective of this study was to establish the mineralogy of the municipality rock samples and determine the ions present in the studied water samples. Specifically, thin rock sections revealed the minerals present while the physico-chemical results gave the ions in the water samples. The variables; Temperature (^{o}C), and pH, EC, were obtained *insitu*, while Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, NO_3^-, Cl^-, SO_4^{2-}, SiO_2 were obtained in the using the Hanna Instrument HI83200 Multiparameter Photometer.

1.1. Location of the study site

Kumbo municipality has boundaries, with Nkum to the North, Jakiri to the South, Oku to the West, and Mbven division to the East. The location of Bui division and the Geology of the study site are presented in Fig.1, while the

sampling points in Kumbo municipality are illustrated in Fig.2. having BH (Boreholes), OW (Open wells), ST (Streams), RW (Rivers) and a catchment.

1.2. Geology (Lithology)

The Bamenda highland in which Bui division and Kumbo municipality are part has a granitic basement covered by basalts and trachytes from tertiary volcanicity in the Cameroon Volcanic Line (Ngako *et al*., 2008) [11]. The division is part of the Bamenda highlands, a northward extension of the Bambouto Mountain part of the continental Cameroon Volcanic Line (C.V.L).

The dominant geologic formations of Bui are basalts and trachytes similar to those of the Bamenda Mountain as reported by (Kamgang, 2003) [7]. In these works, the Bambouto Mountain is reported to be of volcanic origin similar to its northern extension the Bamenda highlands in which Kumbo municipality the study area is found. These results are in agreement with the field observations indicating that trachytes and basalts are the dominant rock types. To these rocks are often associated phonolites, rhyolites, ignimbrites with isolated scoria.
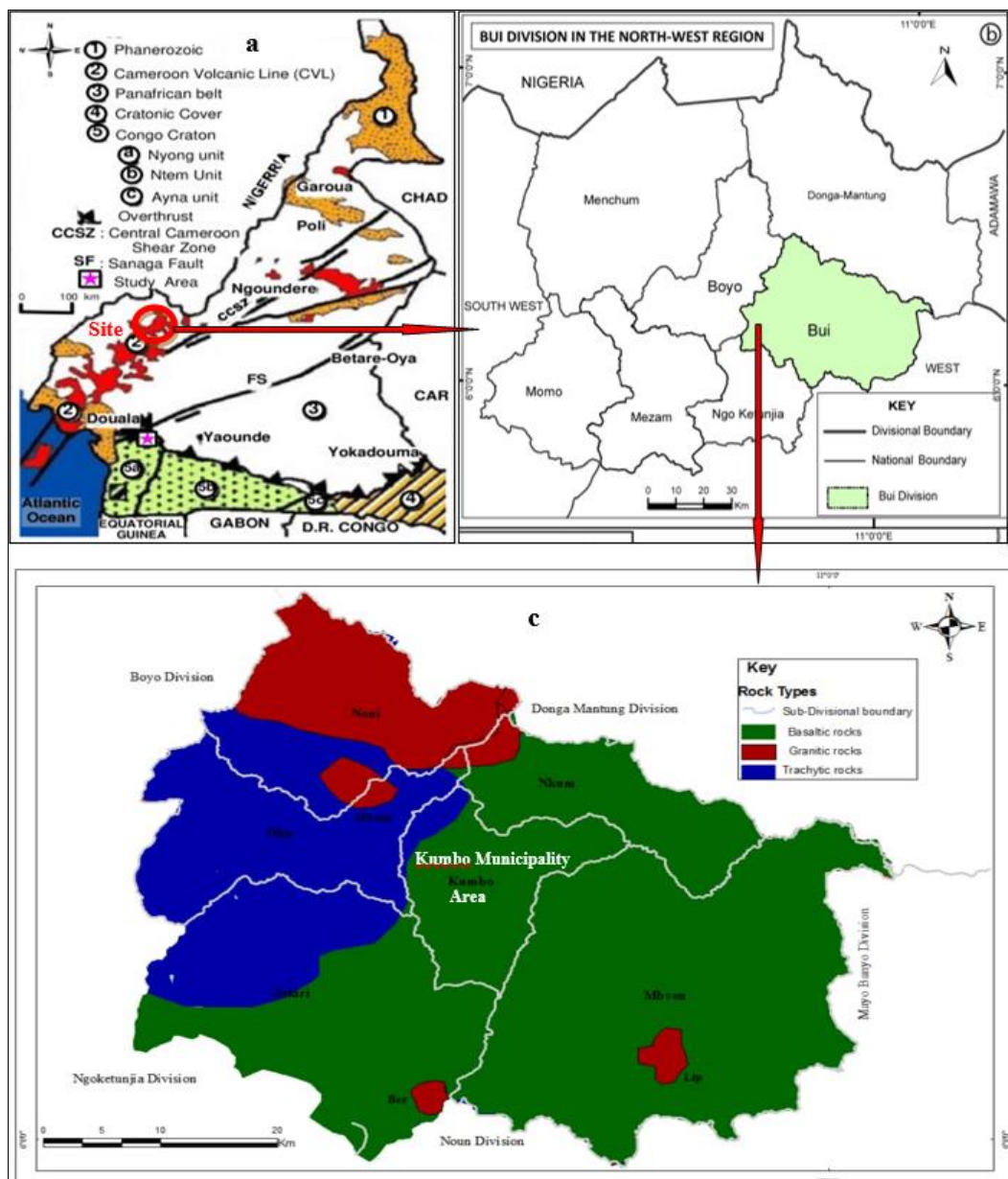

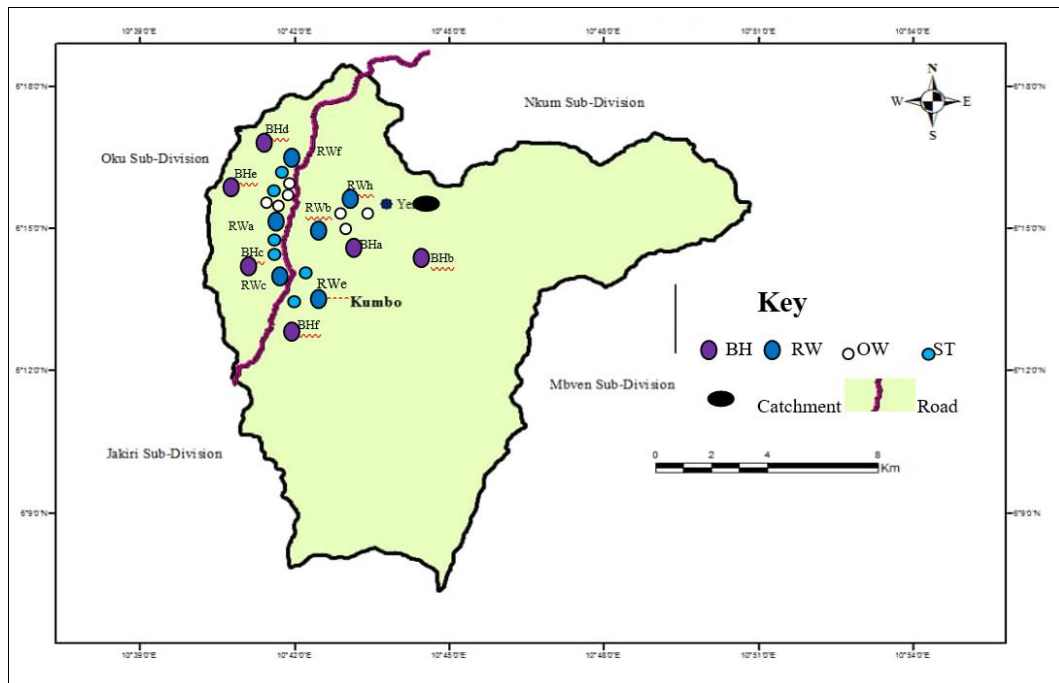**Fig 1:** (a) Site in Cameroon (b) Bui division (c) The geologic map of Bui division

Fig 2: Sampling points in Kumbo municipality

2. Materials and Method

2.1. Theoretical application of the HI 83200Multiparameter

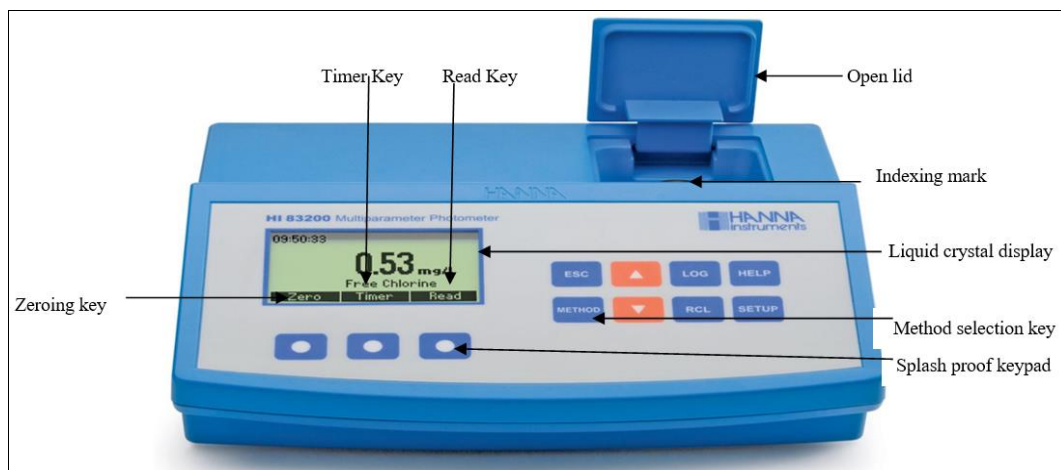Fig.3. has the Hanna Instrument; HI 83200 Multiparameter photometer used for ion analysis

Fig 3: HI 83200 Multi-parameter Bench Photometer

2.1.1. Application theory

Principles of operation of the instrument

This is based on the absorption of light, a phenomenon of interaction between radiation and matter. When a light beam crosses a substance, some of the radiation may be absorbed. The fraction absorbed depends both on the substance and its physical-chemical characteristics according to the Lambert-Beer Law;

$$-\log I / I_O = E_x\, C\, d \quad A = E_x\, C\, d$$

Where; $-\log I / I_O$ = Absorbance (A) or $\log I_O/I$ = Absorbance, I_O = Intensity of incident light beam, I = Intensity of light beam after absorption, C = Molar concentration of substance

d = Optical path through the substance (in the cuvette) E_x = Molar extinction coefficient of wave length x

The concentration; C, could be calculated from the absorbance of the substance as the other factors are known. Absorbance is a measure of the quantity of light absorbed by the sample.

The chemical analyses were based on the possibility to develop an absorbing compound from a specific chemical reaction between the reagent and the sample. The optical system of HI 83200 is made with special miniature tungsten lamps with narrow-band interference filters to guarantee both high performance and reliable results. Five measuring channels allowed a wide range of tests. The optical lay out is illustrated in Fig 4.
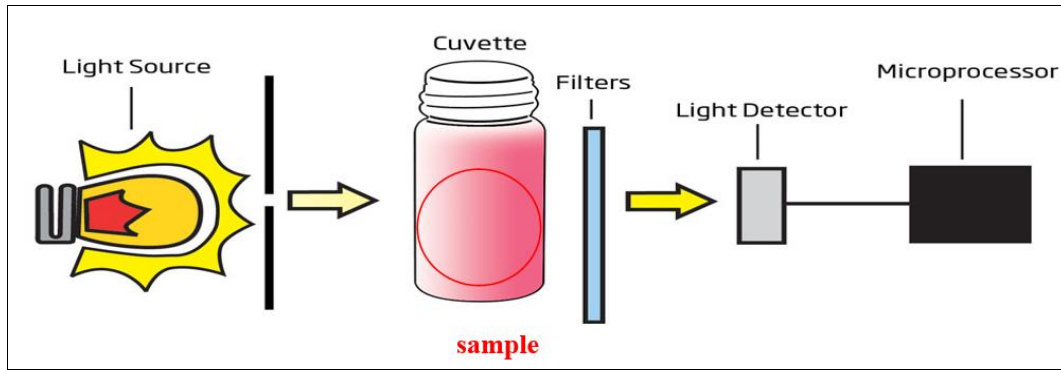
Fig 4: Instrument block diagram (Optical layout)

1. A special tungsten lamp emitted a radiation
2. The emitted radiation (light) was first conditioned (focused) and beamed through the sample contained in the cuvette
3. The optical path (length; l or distance; d) was fixed by the diameter of the cuvette
4. The transmitted light was spectrally filtered in a narrow spectral band (filters) to obtain the intensity of the incident light beam Io.
5. The photoelectric cell (light detector) collected radiation I that was not absorbed by the sample and converted it into an electric current with a potential in mVrange. The microprocessor used the potential to convert the incoming value into a desired measuring unit in mg/l that was displayed on the LCD. This value could be converted into mole/l or meq/l in function of its desired use in discussion requiring these units.

The measurement process was carried out in two phases; first the meter was zeroed and the actual measurement performed.

1. The method was first selected by pressing the METHOD key. The required volume of the sample was measured into the cuvette and inserted into the apparatus and the ZEORING key was pressed with a countdown occurring to display 0.0mg/l on the LCD.

2. The cuvette was removed and to it was added the required amount of reagent and type as précised by the method. Finally the cuvette and its mixture were inserted back into the instrument and the READ key was pressed. There was a countdown until the final reading in mg/l was displayed on the LCD.

2.1.2 Practical appilcation of the HI83200 Multi-parameter Photometer

Measuring of samples was done with a 1ml syringe to obtain the needed volume. A dropper was used for liquid reagents. The dropper was tapped several times and the outside wiped with a cloth and always kept in a vertical position while dosing the reagent. The powder reagent packet was cut open with a scissors to pour out the content.

The samples properly mixed, as specified for each method and inverted a couple of times. First the cuvette is held in a vertical position and turned upside –down and allowed for the solution to flow to the cap end, then returned to the upright position and wait for all of the solution to flow to the cuvette bottom. This is one inversion. The correct speed for this mixing technique is 10 to 15 complete inversions in 30 seconds. This is indicated in the following 'invert to mix' icons in Fig 5.
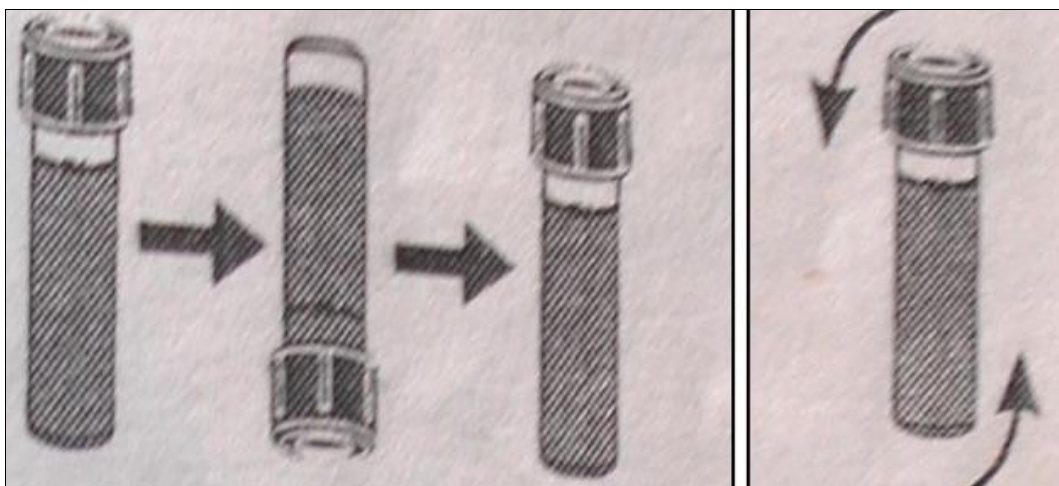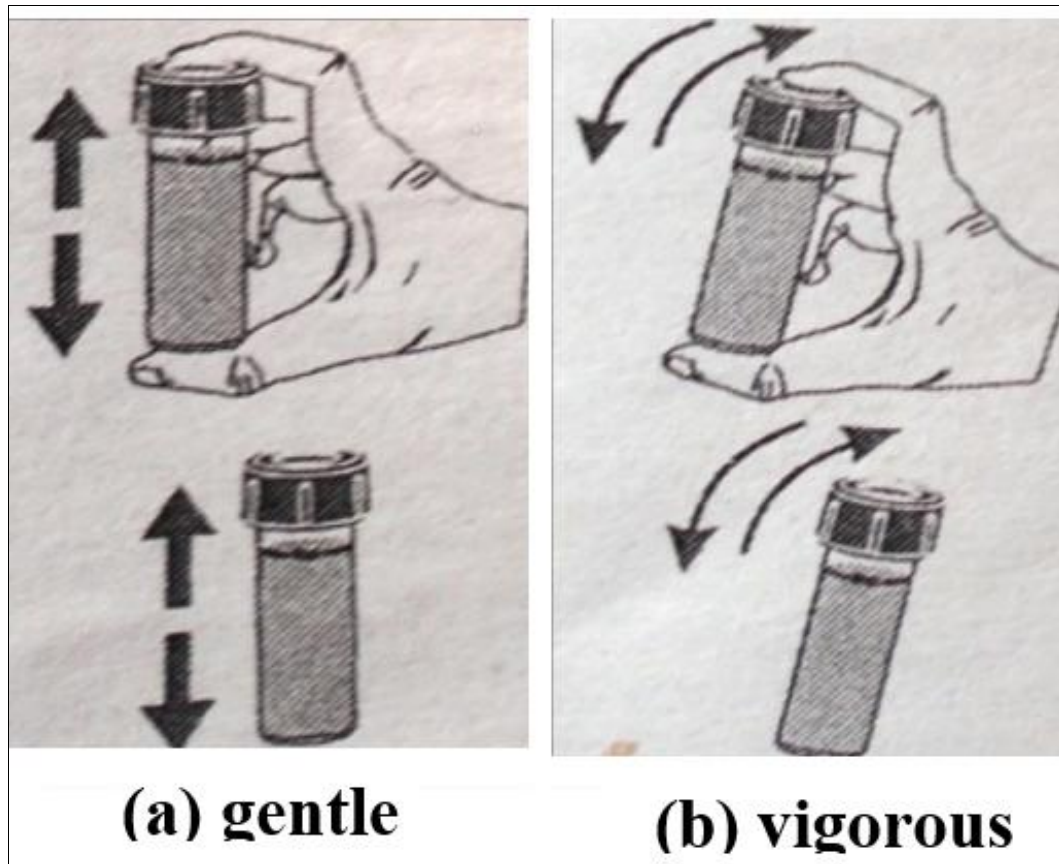

Fig 5: Invert to mix method

Shaking the cuvette by moving up and down could also be done as indicated by the particular method. The movement was either gentle or vigorous. This mixing method is indicated with 'shake gently' or 'shake vigorously' in the following icons in Fig 6.

Fig 6: Gentle and vigorous shaking

Attention was paid to push the cuvette completely down in the holder of the photometer and to align the white point on the cap to the indexing mark on the meter, Fig.7.
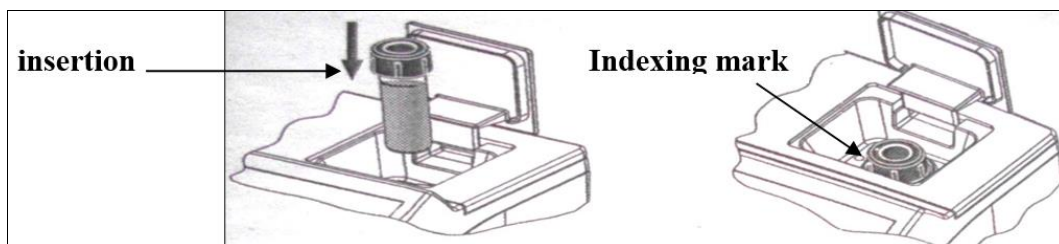
Fig 7: Insertion of cuvette in to the photometer

To avoid the reagent bottle from leaking and to obtain more accurate measurements, the cuvette was first closed with a plastic stopper, then a black cap. Each time the cuvette was used, the cap was tightened to the same degree. Whenever the cuvette was placed into the measurement cell, it must be dry outside, and free of fingerprints, oil or dirt. It was wiped thoroughly with lint -free cloth prior to insertion. The capping and wiping of the cuvette is illustrated in Fig.8.
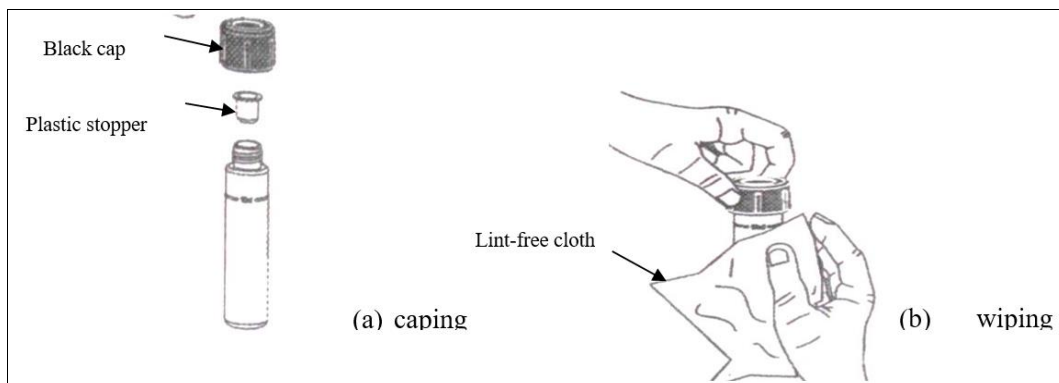
Fig 8: Caping and wiping the cuvette

Comparing the detection limits and accuracy from the photometer with other methods particularly the titrimetric method that embodies both colorimetry and gravimetric methods express the photometer to have more defendable and reliable data. During a titration, many instruments are used each with its own error inherent at manufacture, such as the burette, pipette and volumetric flasks. These sources of calculated error margins will cumulate and finally result into a high deviation from the true value. Standard solutions highly needed in titrations are prepared with incumbent though minimal sources of error, such as the standard solution used $NaOH(aq)$ in most situations absorbs carbon dioxide from the atmosphere because of its deliquescence properties. The absorbed gas greatly alters concentration which will be used falsely to standardize other solutions. This impediment is not encountered with the photometer. End point determination in a titration are not strictly precise because most colour perceptions are subjective thus resulting to wrong values that falsify the essence of the analysis. With these error margins in titrations their percentage accuracy will be less than with the photometer. Consequently the use of the photometer is/was more reliable and innovative than the traditional titrimetric method used in most laboratories. Table I, shows the limits and accuracy for readings of ions on application of the 83200 Multiparameter photometer.

Table I: Detection limits / accuracy of measurements

S. No	Ion (parameter)	Detection range (limits)	Accuracy (% of reading at 25 °C)
1	Al^{3+}	0.00 to 1.00mg/l	0.02mg/l +/- 4% of reading
2	HCO_3^-	0.00 to 500mg/l	5mg/l +/- 10% of reading
3	NH_3	0.00 to 10.00mg/l	0.05mg/l +/- 5% of reading
4	NH_4^+	0.00 to 10.00mg/l	0.05mg/l +/- 5% of reading
5	K^+	0.00 to 20.0 mg/l	3.0mg/l +/- 7% of reading
6	P^H	6.5 to 8.5	0.1 pH at 25 °C
7	Mg^{2+}	0.00 to 150mg/l	5mg/l +/- 3% of reading
8	Ca^{2+}	0.00 to 400mg/l	10mg/l +/- 5% of reading
9	Cl^-	0.00 to 2.50mg/l	0.03mg/l +/- 3% of reading
10	NO_3^-	0.00 to 30.0mg/l	0.5mg/l +/- 10% of reading
11	SiO_2	0.00 to 2.00mg/l	0.03g/l +/- 3% of reading
12	SO_4^{2-}	0.00 to 100mg/l	5mg/l +/- 3% of reading
13	Fe^{3+}	0.00 to 5.00mg/l	0.04mg/l +/- 2% of reading
14	Mn^{2+}	0.00 to 20.0mg/l	0.2 mg/l +/- 3% of reading
15	Ni^{2+}	0.00 to 7.00g/l	0.07mg/l +/- 4% of reading
16	Cu^{2+}	0.00 to 5,00mg/l	0.02 mg/l +/- 4% of reading
17	Zn^{2+}	0.00 to 3.00mg/l	0.03 mg/l +/- 3% of reading

2.2. Thin rock section slide preparations

Petrographic analysis of the rock samples using Dave's method. Seven thin rock section slides from basalts, trachytes, rhyolites, phonolite, ignimbrite, granites and scoria from Bui were obtained. This was done in application of Dave's method on making thin sections (Hirsch, 2012) [6]. Thin sections of 0.03 mm (30 µm) thickness were prepared and attached on a glass slide with an epoxy and covered by another glass slide. The following steps were involved in the thin section slides preparations:

Step 1

Had as objective, to prepare a thin section with a constant thickness. The face of a glass slide was placed parallel to the face of the grinding wheel. The glass slide was ground to flatten it and roughen the surface for the epoxy to bind well. This was called a frosted glass slide that was placed in a slide holder. The grinding wheel was cleaned with a sponge and water. Water was poured on the wheel and dried with a paper towel.

Step 2

The rock sample was marked, to decide where to cut the rock. Generally, the thin section was cut in a plane perpendicular to a planar fabric on the rock.

Step 3

Cutting a slab, using a slab saw. The slab was cut from the rock along the line marked in step 2. Two cuts were made in parallel directions to obtain a slab, which was cleaned and allowed to dry.

Step 4

Part of the slab to be cut was decided and cutting the chip, reduced the size of the slab to slightly smaller than a thin section using a trim saw. Using a glass slide the correct size of the chip was determined using a diamond blade. The side of the chip from where the thin section will be made was polished to remove marks from the saw blade.

Step 5

Glue the slide to the chip. The frosted side of the slide was attached to the side of the chip that was just grounded down. The binding was by an epoxy ensuring a constant thickness across the section.
- The chip was heated up by placing it on one of hot plates with the polished side up for it not to get any dirt. This allowed the epoxy to flow easily and cure faster. Once the epoxy was well mixed, few drops were spread across the top (polished side) of the warmed chip. The epoxy was spread and waited until it soaked in 5 minutes, then more epoxy was spread. This was repeated until no more epoxy soaked into the chip.
- Sit to cure and check periodically for the first 5 to 10 minutes to be sure the slide has not slid off the chip. The epoxy cured in about 20 to 30 minutes (donot take the next step before that)

Step 6

Cutting off the chip from the slide was done as the rock chip was epoxied to the glass slide;
- This cutting off was done very slowly for it can break the slide.

- Once the chip was cut off the slide, the slide was rinsed to remove any particles.

Step 7
Grind the slide to correct thickness by grinding away rock remains but not all of it. This was the step in which most thin sections go bad. The key was to go slowly, especially near the end.
- The grinding wheel must be used carefully back and forth to evenly clean off the chip from the slide.
- Remove the slide and see if you can identify any minerals in the section. This was done and the process continued slowly until these minerals achieve the correct maximum interference colour, for example quartz is pale yellow. We proceeded slowly especially when close to the correct thickness, for it was quite easy to go from slightly too thick to slightly too thin or ground completely away. In this study, a chemical analysis on the minerals was expected as such the section needed to be polished

- Caution was taken not to grind too fast for this could lead to cracking the minerals, the edges of the slide becoming thin and thick at the center. This was because these analysis tools require a flat, smooth surface at the micrometer scale.

Step 8
Place the slide-frosted side of a second glass section on the epoxy, and this serves as a cover slide. It is best to put one side down then let the other side fall to avoid trapping bubbles.
- Move the slide around with your finger or a pencil eraser. This squeezed out extra epoxy to achieve a constant thickness. The cover slide protects the section from damage

Step 9
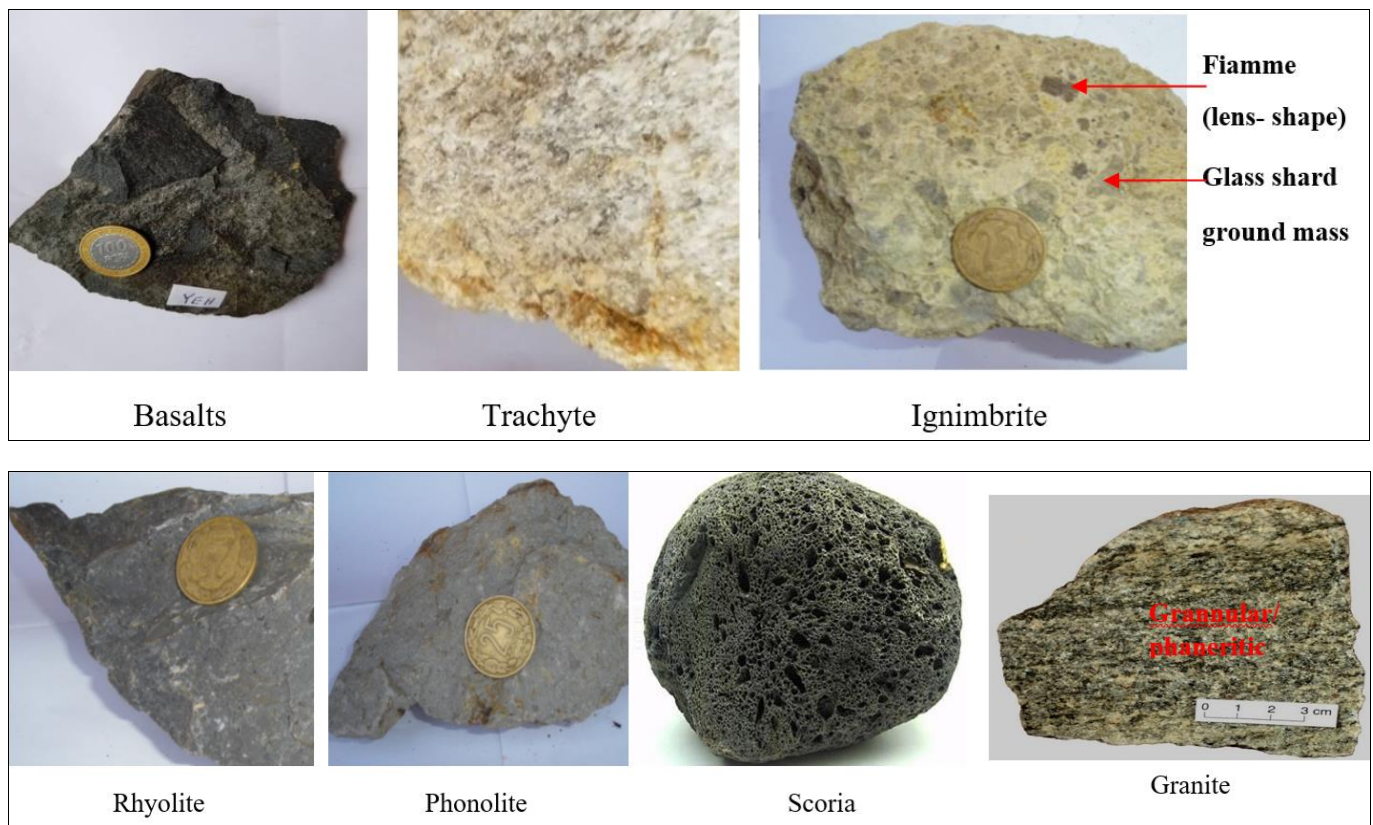Required a cleaning up of the place where the thin slide preparation was carried out.

Fig 9: Kumbo rock samples

The minerals present in the rock samples are presented in Table II.

Table 2: Summary of the minerals volcanic rocks

Rock	Minerals
Basalt	Plagioclase Olivine, pyroxene
Trachyte	Plagioclase Alkaline feldspar, pyroxene, amphibole, biotite
Rhyolite	Plagioclase Alkalinefeldspar, quartz, amphibole, biotite
Phonolite	Pyroxene
Ignimbrite Scoria	Plagioclase Quartz, biotite, alkaline, feldspar, pyroxene, rocky inclusions Plagioclase, pyroxene, olivine

The mineralogy of the rock samples of the study sites from the theoretical perception and their chemical compositions are presented in Table III. Apart from the basalts and trachytes that are widespread in Bui Division and Kumbo municipality, rhyolites, phonolites, ignimbrites and scoria also accompany these volcanic rocks. These mineralogic presentations were based on the understanding of the mineral constituents of the specific rock types and their

known chemical compositions (Whitten and Brooks, 1978) [17]. These were confirmed in the petrographic studies done in this work.

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Basalts
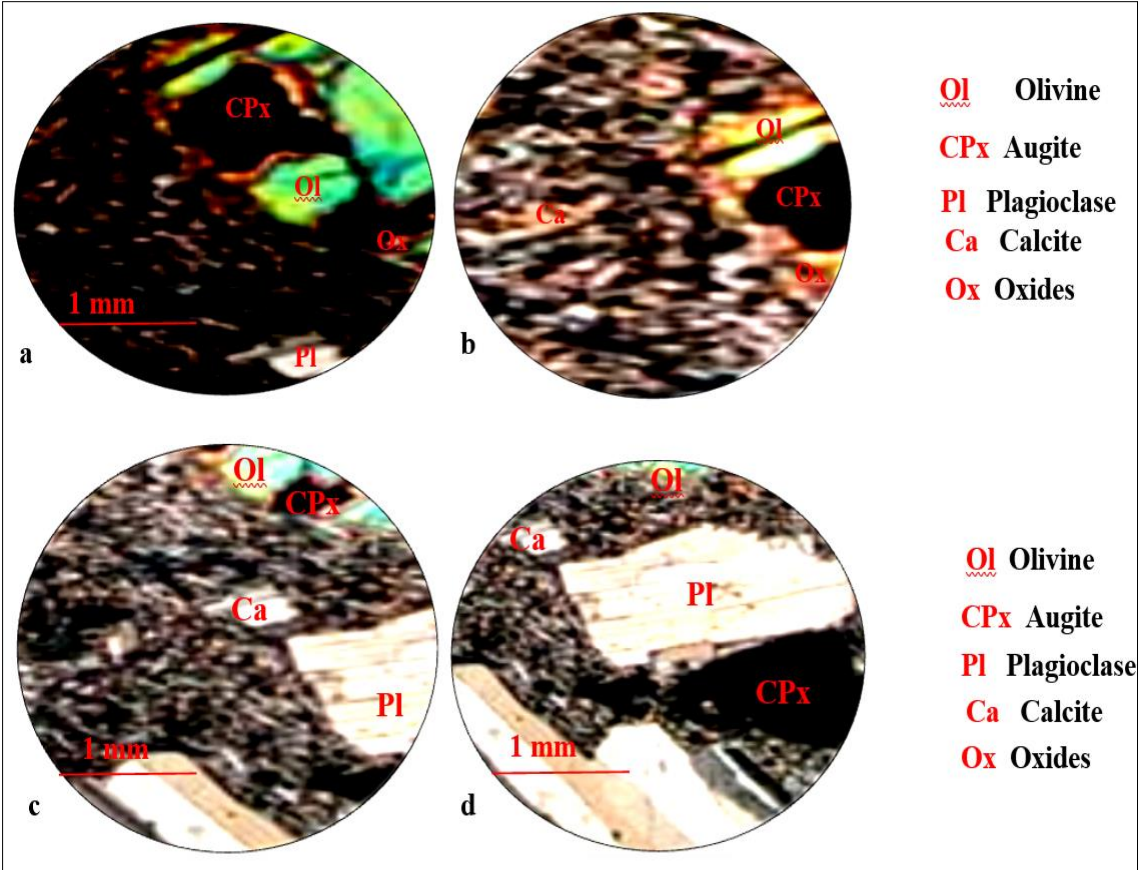
(a and b) Aphyric Basalt thin section (c and d) Porphyric Basalt thin section
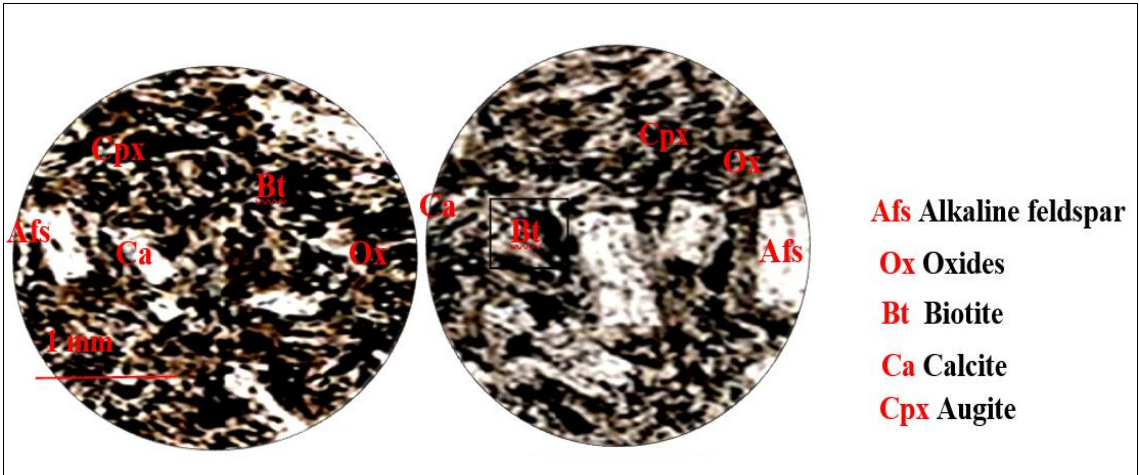
Fig 10: Basalt thin sections

Trachyte

Fig 11: Trachyte thin sections
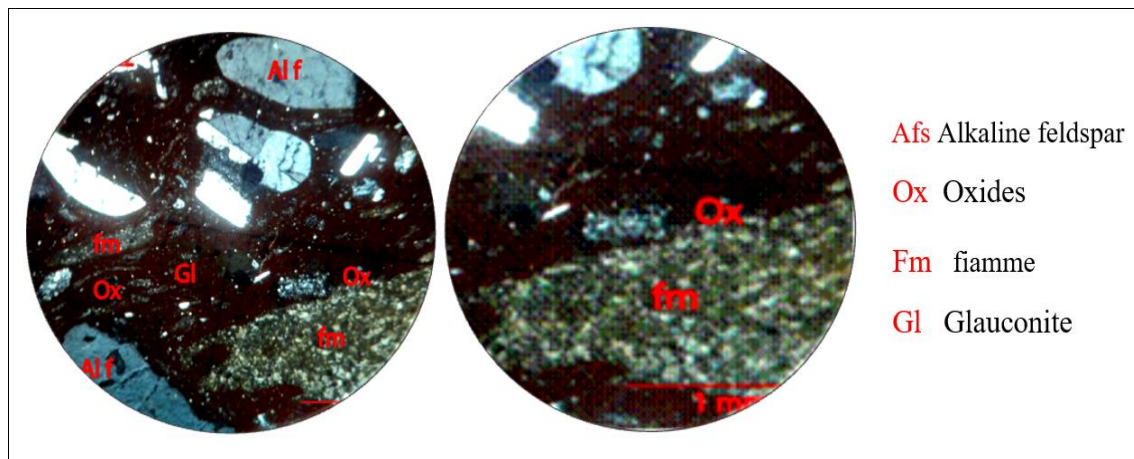
Ignimbrite

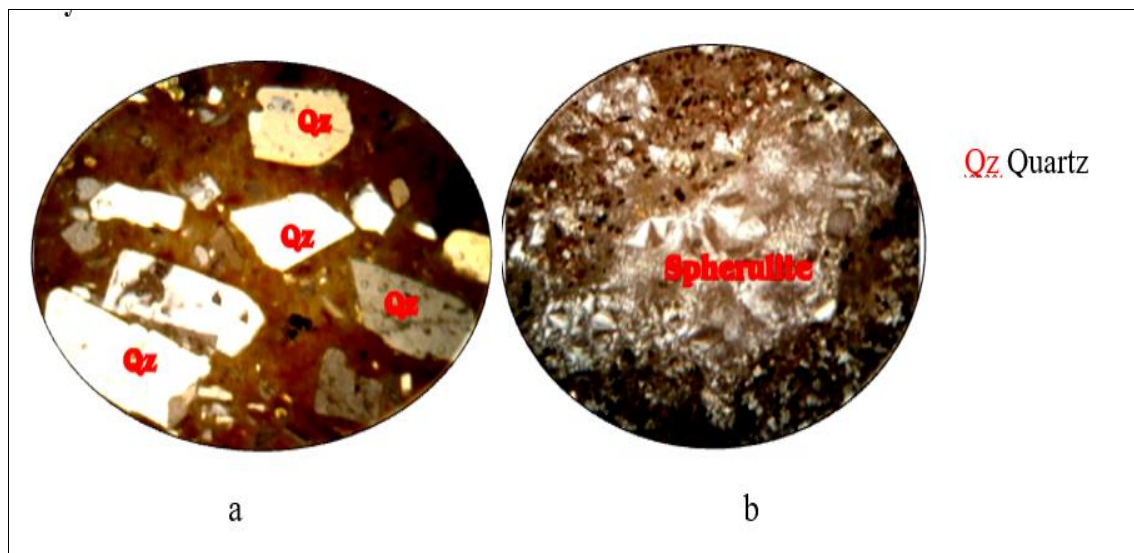**Fig 12:** Thin section of ignimbrite

Rhyolite

Fig 13 (i): Rhyolite thin sections (a) Automorphic crystals of quartz, (b) Devitrification,
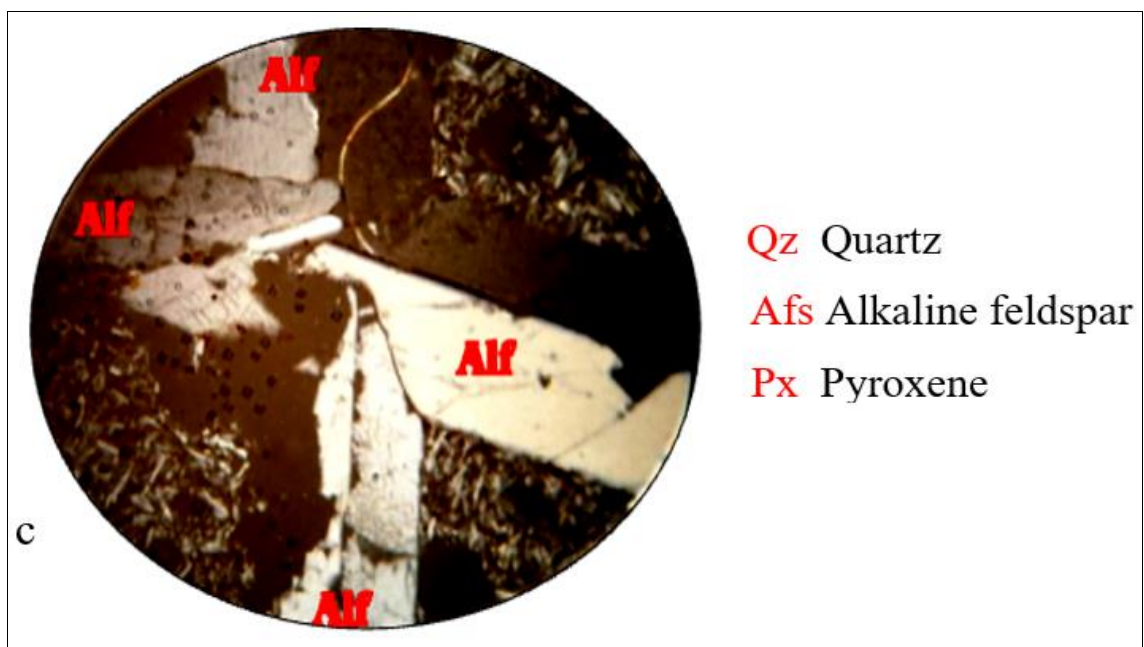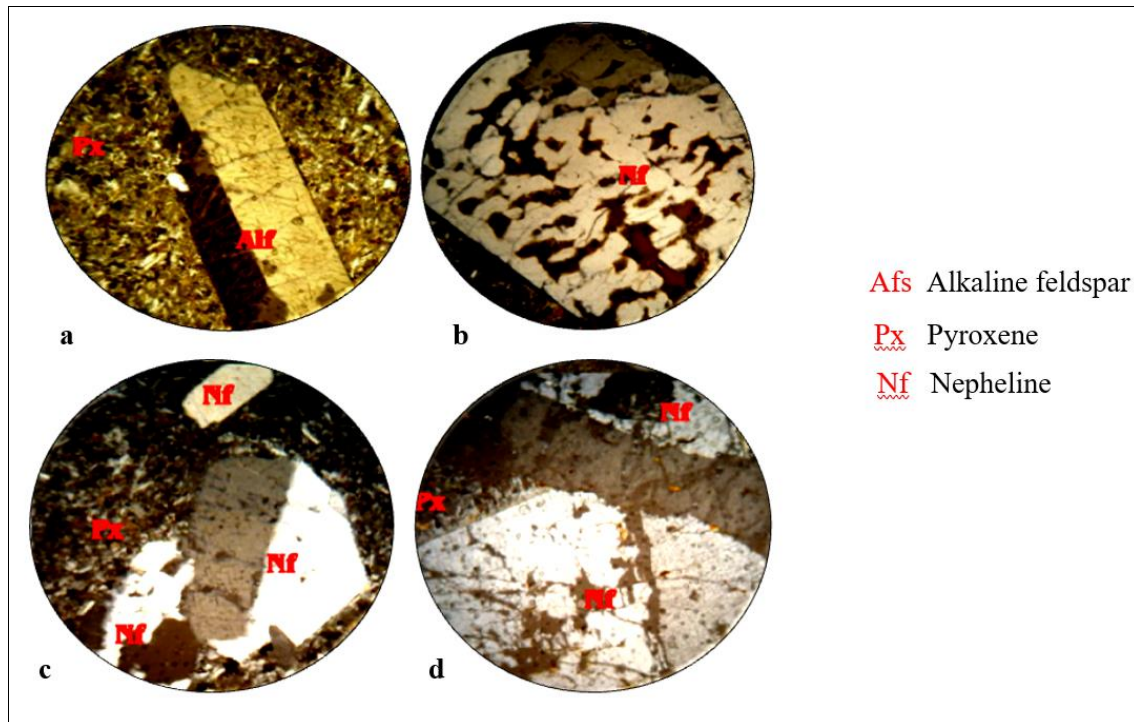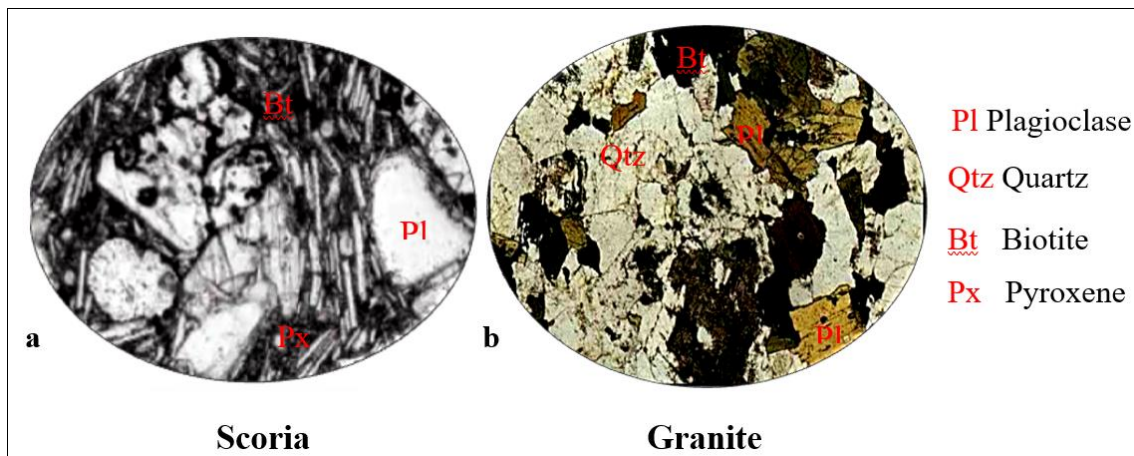

Fig 13 (ii): Rhyolite thin sections (c) Sanidine showing twining.

Phonolite

(a) Sanidine phenocrysts, (b) Nepheline skeleton, (c and d) Nepheline crystals.

Fig 14: Phonolite thin section

Fig 15: Scoria (a) and Granites (b) sample thin sections

3.1.3. Physico-chemical parameters

Presented in Tables IV and V are the parameters from YEH water catchment, boreholes; BH, open wells; OW , rivers; RW and streams; ST in Kumbo municipality.

Table 4: Physico-chemical results in from water catchment (YEH) in Kumbo in 4 expeditions (1st to 4th)

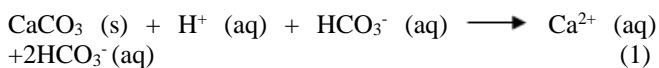| YEH																	
YEH		YEH₁	1895	21.0	7.1	0.30	192.0	0.14	0.13	9.21	40.20	0.02	33.60	31.82	14.0	10.0	0.00
		YEH₂	1895	20.5	7.0	0.22	140.8	0.13	1.00	9.00	39.90	0.01	33.54	31.03	13.9	10.8	0.00
1st		YEH₃	1895	20.6	6.7	0.20	128.0	0.11	0.08	8.52	37.82	0.01	31.50	31.00	13.2	10.1	0.00
		YEH₄	1895	22.9	6.8	0.28	179.2	0.12	0.09	8.80	38.54	0.01	32.30	31.40	13.6	10.0	0.00
2nd		YEH₁	1895	20.4	6.7	0.21	134.4	0.10	0.07	8.50	37.80	0.01	31.40	31.00	13.7	10.7	0.00
		YEH₂	1895	22.7	6.7	0.20	128.0	0.10	0.07	8.51	37.81	0.01	31.42	31.00	13.5	11.0	0.00
YEH		YEH₁	1895	21.0	7.1	0.30	192.0	0.14	0.13	9.21	40.20	0.02	33.60	31.82	14.0	10.0	0.00
		YEH₂	1895	20.5	7.0	0.22	140.8	0.13	1.00	9.00	39.90	0.01	33.54	31.03	13.9	10.8	0.00
3rd		YEH₃	1895	20.6	6.7	0.20	128.0	0.11	0.08	8.52	37.82	0.01	31.50	31.00	13.2	10.1	0.00
		YEH₄	1895	22.9	6.8	0.28	179.2	0.12	0.09	8.80	38.54	0.01	32.30	31.40	13.6	10.0	0.00
4th		YEH₁	1895	20.4	6.7	0.21	134.4	0.10	0.07	8.50	37.80	0.01	31.40	31.00	13.7	10.7	0.00
		YEH₂	1895	22.7	6.7	0.20	128.0	0.10	0.07	8.51	37.81	0.01	31.42	31.00	13.5	11.0	0.00

Table 5: Physico-chemical parameters of groundwater and surface water in Kumbo municipality

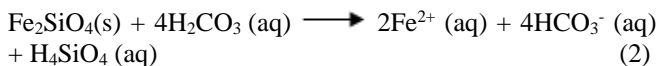| ID	Alt M	Site (Name)	Depth m	T °C	pH	EC μs/cm	Na+	K+	Ca2+	Mg2+	HCO3- mg/l	NO3-	Cl-	SO42-	SiO2
OW5a	1613	Komban street	1.0	21.0	5.9	0.21	0.10	0.09	34.20	8.50	31.42	11.0	0.02	12.9	32.00
OW5b	1654	Tobin Mosque	46	19.9	6.5	0.19	0.13	0.06	33.96	8.62	32.00	10.9	0.01	13.0	31.00
OW5c	1721	CS Tobin	48	20.9	6.8	0.23	0.11	0.08	33.92	8.91	33.21	10.6	0.01	13.3	32.90
OW5d	1734	Catholic Univ	50	20.0	6.7	0.18	0.11	0.06	34.00	7.90	33.00	11.2	0.01	13.1	31.36
OW5e	1845	SAC	36	19.8	6.5	0.24	0.10	0.07	32.91	8.02	31.19	11.3	0.02	13.8	33.70
OW5f	1916	Bamkikaiy	4	20.2	6.0	0.22	0.14	0.10	32.98	8.52	31.00	11.2	0.00	13.6	32.10
OW5g	1946	LAP Centre k'bo	15	21.2	5.9	0.20	0.12	0.09	34.00	8.53	31.20	10.8	0.01	13.9	32.00
OW5h	1922	Pig farm Bamkikaiy	19	21.1	6.8	0.17	0.13	0.09	34.03	8.51	31.00	10.3	0.01	14.0	33.00
ST5a	1695	Meluf upper	----	20.0	6.7	0.19	0.11	0.08	34.11	8.50	32.00	11.0	0.01	14.4	32.10
ST5b	1671	Meluf lower	----	21.0	6.8	0.18	0.10	0.09	33.97	7.92	33.21	10.9	0.01	13.2	31.90
ST5c	1665	Roh Bui upper	----	19.7	6.7	0.20	0.12	0.08	33.06	8.25	30.21	11.4	0.02	13.5	31.87
ST5d	1646	Roh Bui lower	----	19.9	6.5	0.22	0.14	0.06	33.08	8.50	32.11	11.2	0.01	12.9	32.00
ST5e	1874	Roh Kimbo up	----	20.0	6.6	0.16	0.11	0.07	32.91	8.51	33.40	10.8	0.01	13.1	32.01
ST5f	1633	Roh Kimbo low	----	21.1	6.9	0.18	0.10	0.08	31.90	8.53	33.20	10.5	0.01	13.0	32.03
RW5a	1687	Meluf	----	19.9	6.5	0.21	0.13	0.08	34.11	8.10	31.00	10.1	0.00	13.0	32.82
RW5b	1620	Roh Bui	----	19.8	6.7	0.20	0.10	0.09	34.00	8.23	33.40	10.0	0.02	13.7	31.00
RW5c	1615	Meluf/ Bui	----	20.0	6.6	0.22	0.13	0.08	34.30	8.25	32.00	10.2	0.02	12.9	31.57
RW5d	1610	Roh Kimbo	----	21.0	6.8	0.19	0.14	0.07	33.90	8.51	31.19	11.5	0.02	13.4	32.50
RW5e	1604	Bui/Roh Kimbo	----	21.0	6.7	0.17	0.11	0.09	32.98	8.50	31.20	11.2	0.01	13.9	31.92
RW5f	1900	Romajaiy	----	21.2	6.6	0.23	0.10	0.10	33.21	8.52	32.00	10.9	0.01	14.0	30.90
RW5g	1876	Nji-iy	----	20.0	6.5	0.20	0.13	0.07	34.00	8.51	32.18	10.0	0.02	12.9	31.80
RW5h	1860	Kinsaan	----	19.9	6.8	0.21	0.14	0.08	34.12	8.00	31.16	10.5	0.02	13.3	31.70
BH5a	1906	GS Bamkikaiy	31	21.2	6.8	0.24	0.12	0.06	33.91	8.60	31.40	10.9	0.00	13.1	33.40
BH5b	2020	CBC Kishiy	35	22.3	6.6	0.22	0.11	0.08	33.70	7.98	30.92	11.2	0.02	13.9	32.98
BH5c	1763	GS Kiyan	50	22.0	6.7	0.20	0.10	0.05	32.91	8.51	31.20	11.0	0.01	12.9	31.82
BH5d	2037	GS Tadu	55	21.9	6.5	0.24	0.14	0.07	33.00	8.20	29.90	11.4	0.02	13.0	32.60
BH5e	1968	GS Kai	45	22.2	6.7	0.20	0.11	0.06	33.10	8.25	30.00	10.6	0.02	14.0	31.90

4. Discussion of Results

4.1. Dissolution of rock minerals

The dissolution of the minerals were presented in form of chemical equations. The ions in water were responsible for the various analysis to depict suitability for different purposes as well as classify water from the sources. Many authors have published works that support the dissolution of rock minerals as the basis of controlling water quality (Kengni *et al*., 2011; Temgoua 2011; Tay, 2012; Mengnjo *et al*., 2013) [8, 17, 16, 9]. Based on the mineralogy of the rock samples viewed in thin sections the following equations were written;
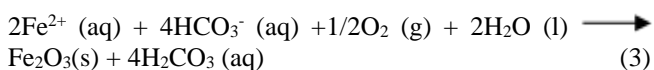
$$CaCO_3\ (s) + H^+\ (aq) + HCO_3^-\ (aq) \longrightarrow Ca^{2+}\ (aq) + 2HCO_3^-\ (aq) \tag{1}$$

Calcite

$$Fe_2SiO_4(s) + 4H_2CO_3\ (aq) \longrightarrow 2Fe^{2+}\ (aq) + 4HCO_3^-\ (aq) + H_4SiO_4\ (aq) \tag{2}$$

Olivine

In the presence of oxygen, the dissolved iron is quickly converted to haematite with a perception of iron oxides in the slides.

$$2Fe^{2+}\ (aq) + 4HCO_3^-\ (aq) + 1/2O_2\ (g) + 2H_2O\ (l) \longrightarrow Fe_2O_3(s) + 4H_2CO_3\ (aq) \tag{3}$$

Pyroxenes, amphiboles and olivines are most susceptible to oxidation because of their high iron content. Iron contained in the minerals combines with oxygen and water to form hydrated iron oxides.
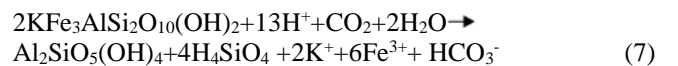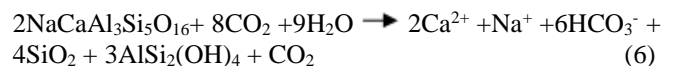
$$4Fe^{2+}\ (aq) + 3O_2\ (g) + 6H_2O\ (l) \longrightarrow 2(Fe_2O_3.\ 3H_2O)\ (s) \tag{4}$$
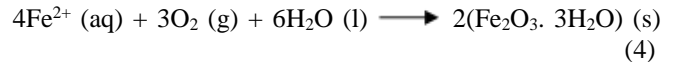
Anorthite and albite end members of the plagioclase minerals present in the rock minerals.

$$3CaAl_3Si_5O_{16} + 8CO_2 + 9H_2O \longrightarrow 3Ca^{2+} + 6HCO_3^- + 4SiO_2 + 3AlSi_2(OH)_4 + 2CO_2 \tag{5}$$
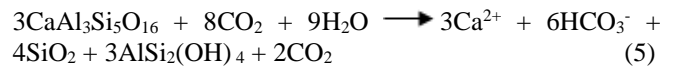
Anorthite

(Anorthite - Albite). Reactions that characterize hydrochemical evolution of groundwater in plagioclase dominated rocks.

$$2NaCaAl_3Si_5O_{16} + 8CO_2 + 9H_2O \longrightarrow 2Ca^{2+} + Na^+ + 6HCO_3^- + 4SiO_2 + 3AlSi_2(OH)_4 + CO_2 \tag{6}$$

$$2KFe_3AlSi_2O_{10}(OH)_2 + 13H^+ + CO_2 + 2H_2O \longrightarrow Al_2SiO_5(OH)_4 + 4H_4SiO_4 + 2K^+ + 6Fe^{3+} + HCO_3^- \tag{7}$$

Biotite

The variations observed in the water samples from the different water bodies were greatly due to the rocktypes of the environments and to a limited extent human activity within the vicinity of the water bodies.

4.2. Water Classification

The concentrations of major ion analysis from all sampling sites revealed the Ca^{2+}, Mg^{2+} and HCO_3^- as the dominant species. The lower concentration of K^+ in the water samples was due to its low geochemical mobility (Hem, 1989; Srinivasamoorthy *et al*., 2008) [5, 15]. The major ions relevant to the Piper diagram presented in Table VI, were used to

determine the hydrochemical facies (water type) of the water catchments , OW, BH, ST and RW in this work.

Table 6: Percentages of cations and anions for classification (Piper, 1994) [22]

Sites	Na$^+$+ K$^+$	Ca^{2+}	Mg^{2+}	HCO$_3^-$	SO$_4^{2-}$	Cl$^-$
YEH	1.00	80.60	18.30	70.20	29.90	0.07
OW	0.50	79.40	20.20	72.90	27.10	0.01
BH	0.40	79.50	20.10	70.30	29.70	0.02
ST	0.50	79.20	20.30	70.40	29.80	0.02
RW	0.40	79.30	20.20	70.30	29.50	0.02

The water classification enabled the water types of Kumbo municipality to be obtained. The Piper diagram; Fig.16 determines the water type, wherein most samples plotted in the alkaline earth metals and bicarbonate domains. This indicated the dominance of alkaline earth metals in the aquifer systems. From the percentages calculated and presented in Table VI, a general chemical nature of the water was observed by plotting major cation and anion concentrations on a Piper tri-linear diagram, (Piper, 1944) [12]. The water catchments and OW, BH, ST and RW were dominantly the calcium bicarbonate water types; Ca (HCO$_3$)$_2$.
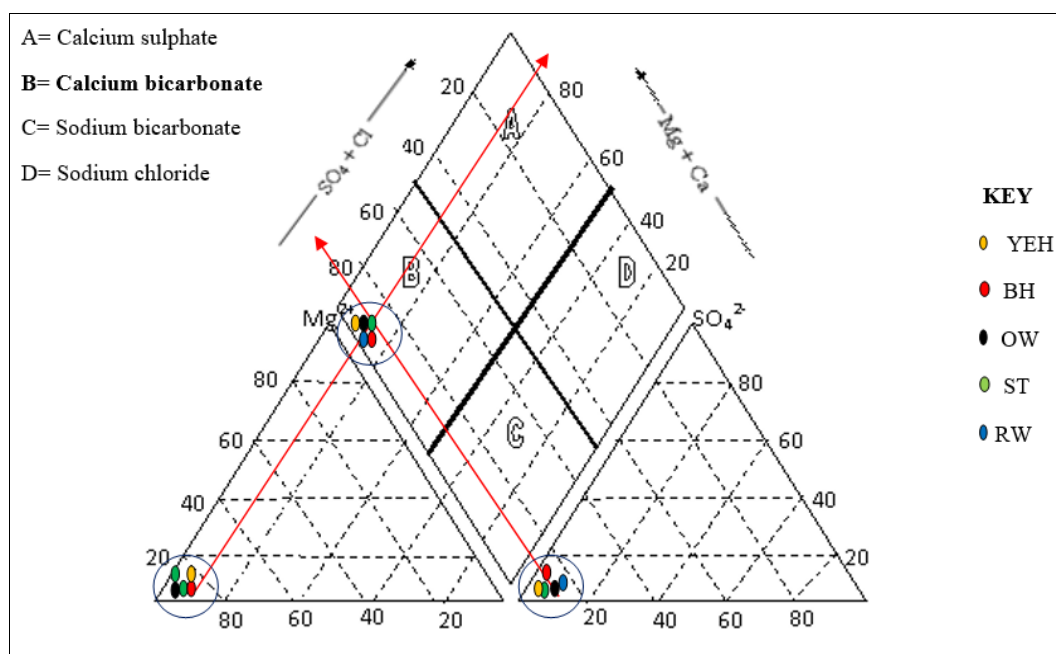

Fig 16: Water types (hydrochemical facies) (Piper, 1994) [22]

The percentage of HCO$_3^-$ was very high compared to other anions, while Ca^{2+} was the dominant cation. The observation prevailed in all the water sources during the different expeditions.

4.3. Suitability for drinking, domestic and agricultural purposes

The drinking water guidelines from Swiss Standards and European Union, (EU), Davis and DeWeist (1966) [1]; Sawyer and McCarty(1967); Freeze and Cherry (1979) [4]; Bureau of Indian Standards B.I.S (2003); WHO (1993, 2004) [18], were used to evaluate the quality of water in

Kumbo water sources for human consumption. All water samples from the various sources were suitable for human consumption as expresses in Tables VI to X wherein they are compared with standard norms.

Suitability of water for irrigation (agriculture) was assessed using various properties or ratios. These included; Pemmeability Index (PI), Percent sodium (% Na), Electrical conductivity (EC), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Kelley's Ratio (KR), Magnesium Hazard (MH). Calculated values were suitable for agricultural practices.

Table 7: Comparison of some parameters with BIS and WHO standards

Parameter	(BIS, 2003)		(WHO, 2004) [18]			
	Desirable	Permissible	Desirable	Permissible	Kumbo samples	Not permissible
pH	6.5-8.5	6.5-9.2	6.5-8.5	6.5-9.2	6.-7.1	0.00
TH mg/l	100	600	100	500	108.2-108.7	0.00
% Ca^{2+} mg/l	75	200	75	200	75.5-80.6	0.00
Mg^{2+} mg/l	30	100	50	150	8.31-8.46	0.00
Cl mg/l	250	100	200	600	0.0-0.02	0.00
SO$_4^{2-}$ mg/l	150	400	200	400	13.5-13.6	0.00
Na$^+$ mg/l	---	---	---	200	0.03-0.14	0.00

Table 8: Water type based on TDS mg/l

TDS mg/l	Water type	Number of samples	Percentage
< 1.000	Fresh	00	100
1.000-10.000	Brackish	00	00
10.000-1.00.000	Saline	00	00
>1.00.000	Brine	ALL	100

Source: (Freeze and Cherry, 1979) [4]

Table 10: Classification based on TDS mg/l

TDS mg/l	Classification	Number of water samples analysed	Percentage
< 500	Desirable for drinking	ALL permisssible	100
500- 1000	Permissible for drinking	Not applicable, no sample in the range	00
1.000 -3.000	Useful for irrigation	Not applicable, no sample in the range	00
>3.000	Unfit for drinking and irrigation	Not applicable, no sample in the range	00

Source: (Davis and DeWeist, 1966) [1]

Table 11: Comparison of Kumbo water catchment samples with SWISS and European Union (EU) standards, based on chemical/physical parameters

Substance	Unit	Commonly acceptable value (MSDA) (1)	Tolerable value (OSEC) (2)	Limit value	Indicator parameter (3)	Parametric value	Mean values (3)
Al	mg/l	< 0.05	0.2	……..	0.2	….	0.16
(NH$_4$, NH$_3$)	mg/l	<0.05	0.2- 0.5	……..	0.5	….	0.2
Cl	mg/l	……..	0.1	……..	……..	….	0.01
Cr	mg/l	……..		……..	……..	0.05	0.01
Cu	mg/l	<0.005	1.5	……..	……..	….	……….
Fe	mg/l	<0.05	0.3	……..	……..	….	0.21
Mn	mg/l	<0.02	0.05	……..	0.05	0.02	0.005
NO$_3^-$	mg/l	<25	40	……..	……..	50	16.95
Pb	mg/l	<0.001	……..	0.01	……..	0.01	…...
K	mg/l	<5	……..	……..	……..	….	0.6
Na	mg/l	< 20	……..	……..	200	….	0.08
SO$_4$	mg/l	< 50	……..	……..	250	….	0.01
Zn	mg/l	<0.01	5	……..	……..	….	0.0
Temp	^{0}C	……..	……..	……..	……..		……………………………
Cond	µs/cm	200-800	……..	……..	……..	….	0.11- 0.31
pH		>6.8 & < 8.2	……..	……..	> 6.5 & <9.5	….	6.4 – 7.1

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2. OSEC; Ordonance sur les substances Etrangere et les composants dans les denrées alimentaires (EU, 1998).
3. Directive 98/83/CE du conseil du 3 Nov, (1998) à la qualité des eaux destinées a la consummation humaine (EU, 1998).

5. Conclusion and Recommendations
The objectives set for this studies were attained as the data obtained was used for water quality evaluation, and classification in Kumbo municipality. The water sources were overwhelmingly calcium bicarbonated and suitable for drinking, domestic and agricultural purposes. The population of Kumbo municipality is recommended to always give cleanliness of water sources a priority and avoid anthropogenic practices such as farming and application of chemical fertilizers within the vicinity of the water sources. With the aid of HI83200 Multiparameter Photometer, water quality parameters should be monitored at regular intervals in a bid to propose mitigation strategies to curb any adverse effects linked to possible water evolution.

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