Geochemical properties of kaolin deposits in the Central Region, Ghana: A multivariate statistical approach

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Abstract

The Central Region of Ghana is endowed with rich kaolin deposits with immense potential industrial application which largely remain untapped due to limited information on geochemical properties. This paper assessed the geological composition of kaolin deposits with the view of elucidating their use in the formulation of climate-smart Portland cement. Four kaolin deposits in the Central Region were randomly selected and 20g each of 90mm of the kaolin samples from the selected deposits were analysed using X-ray diffraction (XRD) for the mineralogical composition and X-ray fluorescence (XRF) for the elemental composition. The results from the XRF determination were used in the principal component analysis. It was also used to compute geochemical indices, such as chemical index of alteration (CIA), chemical index of weathering (CIW) and the index of compositional variability (ICV) to determine the intensity of weathering of the kaolin as well as identify the different rock types from which they originated. The chemical index of alteration (CIA) values ranges from 86.7% (kaolin deposits in Ekon) to 95.8% (kaolin deposits in Saltpond), which suggest an extreme silicate weathering of feldspars; the chemical index of weathering (CIW) values obtained also ranged from 96.6% to 98.6%, which indicate an increasing degree of weathering; index of compositional variability (ICV) varies from 0.19 to 0.66 as well as low K_2O/Al_2O_3 ratios indicate that kaolin deposits in the study area is compositionally mature and are rich in kaolinite. The geochemical characteristics of studied kaolin suggest that, they can be used in the ceramic, cosmetic, pharmaceutical, paper and other industries. Also, the high concentration of titanium dioxide found as anatasse reduce the quality of the kaolin which needs to be removed. The removed titanium dioxide can then be used in the formulation of climate-smart cement.

1.0 Introduction

Ghana is endowed with rich clay mineral resources. The extraction and use of these clay minerals pre-dates the arrival of the Europeans in the 14th Century (Kesse, 1985). The clay deposits stretches from the coast to the northern part of the country. There are different types of clay minerals have been discovered in different parts of the country. Examples of clay minerals found in Ghana are feldspar, quartz, macrite, kaolin just to mention a few.

Kaolin originated from the Chinese word Kau-ling. It is a common phyllosilicate mineral of chemical formula $Al_2Si_2O_5OH_4$ (Jamu and Abu, 2014). It is formed either from primary (residual) or secondary (sedimentary) rocks and composed of alternating layers of silicate (Si_2O_5) and gibbsite $Al_2(OH)_4$) (Newman, 1987). According to Jamo and Abu (2014), kaolin clay contain kaolinite and other minerals like feldspars, quartz, calcite in addition to aluminosilicates. It is mostly white, but it also can be grey, yellow or red (Jamu and Abu, 2014).

Murray (2000) has noted that kaolin is used in different industries, notable ones are ceramic, cement production, bricks, paper, paints, rubber, plastics, cosmetics, and pharmaceuticals among others. While Schupp et al., (2004) have suggested that, kaolin is used in the manufacturing of toothpaste as well as in the formulation of insecticide or pesticide for vegetable and fruit farms.

However, scientist who have investigated mineralogical and geological properties of kaolin argues that, the use of kaolin in the aforementioned industries is based on their chemical composition, mineralogy as well as geology. For example, in the ceramic industries, the chemical constituents, firing characteristics and colour of the kaolin is very important (Cases et al., 1986; Cravero et al., 1997; Ekosse, 2000; Pinheiro et al., 2005; Siddiqui et al., 2005; Loez-Galindo et al., 2007), and to a large extent determines the use of the kaolin.

Also, particle size distribution of kaolin and its colour is a key property that determine how much it is sold commercially. Kaolintic clay in kaolin is perhaps the major raw material in the ceramic industries, especially in the manufacture of sanitary wares, wall tiles, floor tiles, electrical and industrial porcelain insulators (Ekosse, 2000).

In Ghana, kaolin deposits stretches from the coast to the northern part of the country. Studies so far conducted on kaolin deposits in the country has largely centred on the use of the kaolin in the manufacturing of bricks, refractory bricks, porcelain for electric wares among others (Efavi et al., 2012; Yaya et al., 2012; Dodoo-Arhin et al., 2013; Agyei-Tuffour et al., 2015). While Tahbor et al., (2015) have determined the pozzolanic properties of kaolin in Anfoega in the Volta Region of Ghana. However, not much has been done in understanding the geochemical composition of the kaolin deposit in the Central Region and for that matter the whole of kaolin deposits in Ghana to ascertain their potential domestic and industrial use.

Ariffin et al., (2008) and Kearyey (2001) have both suggested that if geochemical assessment of kaolin reveals high levels of Fe_2O_3 and TiO_2 then they are not suitable for paper, ceramic, pharmaceutical and other allied industries. Bukalo et al. (2017) therefore opined that, the high titanium dioxide concentrations may impact negatively on industrial applications of kaolin in the aforementioned industries needs to be removed. However, the titanium dioxide removed from the kaolin has been shown in other studies in playing key roles in the manufacturing of climate-smart cement, solar panels among others (Jamu and Abu, 2014; Teoh et al., 2012; Gates et al., 2012).

It is within this context that, the study focussed on assessing the geochemical properties of kaolin from selected deposits in the Central Region. This paper set out to characterise kaolin deposits and their possible industrial applications in the formulation of climate-smart cement based on their geochemical and mineralogical properties.

2.0 Experimental

2.1 Geology of the study areas

According to Kesse (1985), kaolin deposits in Ghana occurs in different locations in the country. However, the major kaolin deposits occur in:

- Teleku Bokazo – Aluku in the Western Region;
- Kibi deposits located within the Atewa Forest Reserve in the Eastern Region;
- Saltpond – Ekon – Waagkron and Assin Foso in the Central Region; and
- Anfoega in the Volta Region.

Geologically, the Saltpond – Waagkron – Ekon deposits as well as the Assin Foso deposits (Fig. 1) have been formed by an in situ weathering granite, pegmatite, phylite and schist intrusions in the area (Kesse, 1985). The mineralogical compositions of kaolin from the aforementioned deposits include kaolinite, quartz and mica. In most of these deposits, kaolinite is the principal mineral which constitute between 60–100 percent of the rock mineral. The estimated reserve of kaolin from these deposits is 610,000 metric tonnes which has largely not been exploited on commercial basis (Kesse, 1985).

As shown in Fig. 1.0, the Saltpond, Ekon and Waagkron deposits are made up of 2% quartz, 1% muscovite and about 97% kaolinite; whilst the Assin Foso deposits are mainly made of kaolinite and undifferentiated granitoid rocks.

2.2 Sampling techniques, collection and preparation of koalin Samples

The purposive sampling techniques were adopted in collecting kaolin samples from the four study sites shown in Fig. 1.0. The kaolin samples were collected both from the lateral and vertical position, respectively. Approximately, 600g of kaolin samples from each of the four study sites were collected into a well-labelled jute bag and transported to the Chemistry Department Laboratory, University of Cape Coast for analysis.

In the laboratory, the samples were air dried to remove the moisture content and also impurities such as pieces of stone and other unwanted materials were removed. The air dried samples from each of the study areas were milled in a jaw crusher and sieved through 90 µm mesh. The milled samples were stored in well-labelled containers for further analysis.

2.3 Determination of elemental composition and oxides in the samples using XRF

4g of the powdered sample (≥ 90 µm) and 0.9g of the binder are weighed using the balance. The two are put together in the mixing container and homogenized using the mill. The mixture is then poured into the die and pressed at 15 tons to a 32mm pellet using the hydraulic press. Acetone is used to clean the mixing container and die set with the help of the tissue paper to prevent contamination. Acetone is preferred because it is very volatile. The samples were loaded in the XRF machine model (XRF Bruker S4 Pioneer) for elemental analysis at the Ghana Geological Survey Authority. The machine was operated at maximum voltage and current 60 KV and 1 mA respectively to generate the X-rays which will energise the sample for a particular time (specifically, 10 mins) with X-ray tube of rhodium anode and scintillation detector of current 40 mA and voltage 40 mV.

2.4 X-Ray Diffraction (XRD) Analysis

X-ray powder diffraction analysis was carried out using CuKα1 (= 1.54060 Å) radiation at 0.3/min scanning rate of 2 range of 5–40° in a signal mode, with 0.03 phase size at room temperature on XPERT-3 powder diffractometer fortified with a curved position-sensitive detector. The configurations were verified at 40 mA, 40 kV, and tests were positioned on flat bottom holder.

2.5 Data Analysis

The data obtained from the determination of major oxides in kaolin samples from the study areas were subjected to multivariate statistics such as factor analysis to examine and interpret hidden structure within data set (Reghumath et al., 2012) as well as liner regression using SPSS IBM version 21. The concentrations of major oxides found in kaolin samples from the study areas were compared to those obtained from other well-known kaolin deposits in the world.

According to Omo-Irabor et al., (2008), Eq. (1) is used in the determination of factor analysis:

$$zij = a_{f1}f_{1i} + a_{f2}f_{2i} + a_{f3}f_{3i} + \cdots + a_{m}f_{mi} + e_{fi}$$

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Where:

z = the measured variable;

a = the loading factor;

f = the factor score;

e = the residual score accounting for the error;

i = the sample number;

m = the total number of factors;

The chemical index of alteration (CIA), the chemical index of weathering (CIW), plagioclase index of alteration (PIA) and the index of compositional variability (ICV) for each sample were calculated. The results obtained for CIA and CIW were compared to the CIA and CIW of well-known kaolin so as to identify any variations between chemical indices of the known kaolin to those obtained from the study areas.

Chemical Index of Alteration (CIA) is defined as a measure of the extent of the conversion of feldspar to clays and it is a good measure of the degree of weathering (Shao et al., 2012). The chemical index of alteration is calculated using Eq. (2) below:

$$CIA = \left[\frac{Al_2O_3}{Al_2O_3 + CaO^* + K_2O + Na_2O}\right] \times 100 \ldots (2)$$

Where CaO* is the amount of calcium oxide incorporated into the silicate fraction of the rock sample.

The chemical index of weathering (CIW), is a measure of the conversion of feldspar to clays but does not factor in the contribution of K_2O (Fiantis et al., 2010; Nesbitt and Young, 1982). The formula for calculating CIW is summarised in Eq. (3).

$$CIW = \left[\frac{Al_2O_3}{Al_2O_3 + CaO + Na_2O}\right] \times 100 \ldots (3)$$

The index of compositional variability (ICV) was calculated according to Eq. (4). The index of compositional variability is used to measure the relative abundance of Al_2O_3 in kaolin samples.

$$ICV = \frac{CaO + K_2O + Na_2O + Fe_2O_3 + MgO + MnO + TiO_2}{Al_2O_3} \ldots (4)$$

The plagioclase index of alteration (PIA) is a measure of progressive conversion of feldspars to clay minerals. According to Fedo et al., (1995) and Armstrong-Altrin (2004), PIA values can also be used to determine to diagenesis of weathering and redistribution of elements during diagenesis of source area rocks. PIA can be calculated using Eq. (5).

$$PIA = \left[\frac{\left(Al_2O_3 - K_2O\right)}{\left(Al_2O_3 + CaO^* + Na_2O - K_2O\right)}\right] \times 100 \ldots (5)$$

Where CaO* is the amount of calcium oxide incorporated into the silicate fraction of the rock sample.

3.0 Results And Discussion

3.1 Mineralogical composition of kaolin samples from the study areas

The mineralogical composition of kaolin deposits in the Central Region is presented in Table 1. Kaolinite, quartz and anatasse were found to be the dominant minerals in the samples; while magnetite together with other minerals such as muscovite, phylites and schists were found to be in trace quantities using the summation of semi-quantitative method to determine the frequency of occurrence of these minerals in the samples; such that (+++) = 3 represents a major mineral, (++) = 2, i.e., a minor mineral and (+) = 1 or 0 which represent a mineral in trace quantities (Bukalo et al., 2017).

Table 1
Semi-quantitative mineralogy of kaolin samples from the Central Region, Ghana

Study areas	Minerals in the kaolin samples							
	Kaolinite	Quartz	Anatase	Magnetite	Muscovite	Phylites	schists	Calcite
Saltpond	+++	+++	++	+	+	+	+	+++
Waagkron	+++	+++	++	+	+	+	+	++
Ekon	+++	+++	++	+	+	+	+	+
Assin Foso	+++	++	++	+	+	+	+	+++

The percentage of frequency for the occurrence of the identified minerals in Table 1 are as follows: Assin Foso samples have kaolinite (73%), quartz (18.5%), anatase (5.29%), magnetite (2.90%), muscovite (1.14%), phylites and schists (0.76%), and calcite (2.38%); Waagkron samples have kaolinite content of 53.6%, quartz 45.0%, Anatase 14%, magnetite 13.0%, muscovite 21.0%, phylites and schists 1.72% and calcite 8.20%; Ekon kaolin samples contains 41.2% kaolinite, 38.2% quartz, 18.1% anatase, 20.1% magnetite, 13.9% muscovite, 2.3% phylites and schists, and lastly 1.11% calcite; and while Saltpond kaolin samples were found to contain 50.1% kaolinite, 33.1% quartz, 13.8% anatase, 3.8% magnetite, 3.78% muscovite, 1.23% phylites and schists, and 20.9% calcite, respectively.

3.2 Composition of major oxides in kaolin samples deposits from the Central Region, Ghana

The concentration of major oxides found in kaolin samples from the Central Region expressed as percentages have been summarised in Table 2 below. The silica content in kaolin samples from the study areas varied from 58.94% (Saltpond) to 22.51% (Waagkron). This suggests that kaolin deposits in the Central Region of Ghana contain more silica. In the case of Al_2O_3 it was found to vary from 4.033–12.61%. These findings were consistent with similar observations made by Jamo and Abdu (2014), Aroke and El-Nafaty (2014) as well as Shehu et al. (2017) who all measured high silica content and low alumina content in kaolin from Malaysia and Nigeria, respectively.

From the results in Table 2, Fe_2O_3 content in raw kaolin samples ranges from 2.102–2.253%; while the percentage of TiO_2 in the raw kaolin samples also ranges from 1.73–9.21%.

Table 2
Mineralogical composition of (XRF) of kaolin samples from selected deposits in the Central Region, Ghana.

Study Areas	Sample Chemical Composition												Total
	Al_2O_3	SiO_2	SO_4	K_2O	TiO_2	Fe_2O_3	MnO	K_2O_5	CaO	MgO	Na_2O	LOI	
Assin Foso	22.25	47.72	0.24	2.37	9.21	2.20	0.20	2.48	0.21	0.36	0.10	12.24	99.96
Ekon	20.54	58.54	0.25	2.43	6.45	2.14	0.22	1.71	0.09	0.45	0.64	7.205	100.0
Saltpond	28.68	58.94	0.26	0.48	1.73	2.10	0.218	0.16	0.12	0.28	0.12	7.531	100.7
Waagkron	19.74	49.43	3.31	0.55	2.72	2.25	0.19	0.92	0.48	2.51	0.48	13.35	95.46
Capim River[a]	39.46	42.34	0.00	0.06	0.06	0.65	0.00	0.00	0.04	0.08	0.04	13.92	99.84
Pugu River[b]	36.93	46.37	0.00	0.11	1.07	0.00	0.00	0.00	0.15	0.09	0.15	15.22	99.94
Makoro River[c]	32.03	51.06	0.00	0.07	1.43	1.80	0.03	0.00	0.08	0.15	0.08	11.95	98.60
Kgwakgwe[d]	28.57	45.34	0.00	3.87	0.68	2.65	5.02	0.00	0.08	1.06	0.08	12.28	99.55
Malaysia[e]	37.76	57.63	-	1.80	0.605	0.86	-	-	0.35	0.60	-	-	99.91
Theoretical kaolin[f]	39.50	46.54	-	-	-	-	-	-	-	-	-	13.96	100.0

Note: 0.00 means below detection limit; 1 weight % = 10,000ppp; LOI means Loss on Ignition; [a]Costa et al., (1998); [b]Robertson et al., (1954); [c]Schwaighofer and Muller, (1987); [d]Ekosse, (2000); [e]Shehu et al., (2017); and [f]Deer et al., (1992)

A graphical comparison of major oxides found in the kaolin samples from the study areas with other known kaolin deposits has been presented in Fig. 2. It can be seen in both Table 1 and Fig. 2 that, the percentage by weight concentration of Al_2O_3 in kaolin samples from the study areas were found to be lower than those obtained in the Capim River reported by Costa et al., (1998) and other known kaolin deposits in Africa and Malaysia as well as theoretical kaolin recorded by Deer et al., (1992). Also, the percentage by weight concentration of SiO_2 in the kaolin samples from this work were found to be comparable with those recorded in well-known kaolin deposits in Africa such as Capim River, Pugu River, Makoro and Kgwakgwe (Ekosse, 2000; Costa and Moraes, 1998; Robertson et al., 1954; Schwiaghofer and Muller, 1987; Ekosse, 2001).

As noted by Garcia-Valles et al., (2020), the ratio of Al_2O_3/Fe_2O_3 is used to define the industrial uses of a given clay or kaolin sample. That is, if the $Al_2O_3/Fe_2O_3 \geq 5.5$, it means that, they are rich in alumina and have a whitish colour. This type of clay can be used in the manufacturing of refractory ceramics. However, if the Al_2O_3/Fe_2O_3 ratio ≤ 5.5, it means that they are rich in iron and have a reddish-brown coloration. This type of clay can be used in the manufacturing of building materials such as bricks, tiles, etc. The ratio of Al_2O_3/Fe_2O_3 for kaolin samples in this study varies from 8.77 to 13.7, as noted by Garcia-Valles et al., (2020), they are very suitable for the manufacturing of refractory ceramics.

A result from the factor analysis is shown in Table 3. From Table 3, three factors were extracted which account for 85.2% of the total variance. Factor 1 shows loadings that account for 42.2% of the total variance is dominated by MnO (0.495), CaO (0.991), MgO (0.947) and LOI (0.872); while factor 2 represent 30.5% of the total variance has loadings from K_2O (0.858), TiO_2 (0.982) and K_2O_5 (0.995); and factor 3 shows loadings from Al_2O_3 (0.395), Fe_2O_3 (0.917) and SiO_2 (0.522) which account for 12.5% of the total variance.

Table 3
Factor Analysis

Elements	Components		
	1	2	3
Al_2O_3	-0.523	− 0.451	0995
SiO_2	-0.648	− 0.405	− 0.522
SO_4	0.922	− 0.235	0.060
K_2O	− 0.273	0.858	0.321
TiO_2	-0.144	0.982	0.047
Fe_2O_3	0.182	0.256	0.917
MnO	0.495	-0.212	0.178
K_2O_5	0.018	0.995	− 0.087
CaO	0.991	− 0.092	− 0.002
MgO	0.947	-0.231	0.009
LOI	0.872	0.204	− 0.155

The significant loading of the various major oxides in each of the three components suggest that those oxides have some commonalities. The loadings in factor 1 is attributed to the weathering of K-feldspars and Ca- bearing clay minerals such as smectite, while the loadings in factor 2 could be attributed to weathering of K-feldspars and muscovite; whereas factor showing strong loadings for Al_2O_3, SiO_2 and Fe_2O_3 could have originated from the weathering of aluminium-silicate minerals.

3.2 Geochemical composition of kaolin samples from the Central Region

The results of computation of geochemical indices such as; chemical index of alteration (CIA), chemical index of weathering (CIW) and index of compositional variability (ICV) as well as the ratio of K_2O/Al_2O_3 for kaolin deposits in the Central Region is shown in Table 4.

Table 4
Geochemical composition of kaolin samples

Study Areas	K_2O/Al_2O_3	Chemical index of alteration (CIA)	Chemical index of weathering (CIW)	Index of compositional variability (ICV)	Plagioclase index of alteration (PIA)
Assin Foso	0.11	88.9%	98.6%	0.66	98.5%
Ekon	0.12	86.7%	96.6%	0.60	96.1%
Saltpond	0.02	95.8%	97.3%	0.19	100%
Waagkron	0.03	94.2%	96.7%	0.45	94.9%
Capim River[a]	0.02	99.6%	99.7%	0.03	99.8%
Pugu River[b]	0.03	99.1%	99.4%	0.04	99.2%
Makoro River[c]	0.02	99.1%	99.6%	0.12	99.5%
Kgwakgwe[d]	0.13	87.6%	99.0%	0.46	99.4%

[a]Costa et al., (1998); [b]Robertson et al., (1954); [c]Schwaighofer and Muller, (1987); [d]Ekosse, (2000)

The K_2O/Al_2O_3 ratio plays an important role in understanding the source of Al and its distribution between clay minerals and feldspars among sedimentary rocks (katongo et al., 2004). It can also be used to describe the chemical composition of ancient sediments (Bayegunhi et al., 2017). To Cox and Lowe (1995), if K_2O/Al_2O_3 ratio ranges between 0.0 to 0.3 suggest clay minerals; whilst values between 0.3 to 0.9 indicate the source of Al to be originating from feldspars. Hence, in Table 4, the K_2O/Al_2O_3 ratio of kaolin deposits from the Central Region and that from the Capim River, Pugu River, Makoro River and Kgwakwe shows that, Assin Foso and Ekon kaolin have the highest K_2O/Al_2O_3 ratio of 0.11 and 0.12 respectively. All the kaolin deposits in the Central Region have K_2O/Al_2O_3 ratio of less than 0.03, which indicate incomplete kaolinsation of K-feldspars and micas in the study area. This observation is consistent with findings made by Lee (2002) and Valiani and Rezzaee (2014).

The geological composition of kaolin deposit is mainly dependent on the composition of its source rock as well as the extent and nature of its weathering (Fedo et al., 1995; Nesbitt and Young, 1984; Junije et al., 2014). The intensity and nature of chemical weathering of the source rocks is usually dependent on the composition of the source rock, the time taken for weathering to take place, climatic conditions of the area as well as the rates of tectonic uplift of source region (Wronkiewicz and Condie, 1987). As noted by Junjie et al., (2014), elements such as Ca, Na and K are released from the source rock as part of the chemical weathering process. Hence, the elemental concentration of Ca, Na and K can serve as good indicator in determining the intensity of chemical weathering.

Chemical indices such as; chemical index of alteration (CIA), chemical index of weathering (CIW), plagioclase index of alteration (PIA) and index of compositional variability (ICV) have been used to quantitatively determine the degree of weathering of source rocks by scientists such as Nessbitt and Young, (1984), Fedo et al., (1995) and Cox et al., (1995). The results of geochemical indices such as CIA, CIW, PIA and ICV have been summarised in Table 4.

As shown in Table 4, the chemical index of alteration (CIA) values recorded in this study ranges from 86.7% (Ekon) to 95.8% (Saltpond). This observation is similar to CIA values recorded for kaolin deposits in the Capim River (Brazil), Makoro River, Pugu River and Kgwakgwe River in Bostwana and Tanzania, respectively. The CIA is a measure of the ratio of original/primary minerals and secondary products such as clay minerals in the kaolin. According to Baiyegunhi et al. (2017), CIA values usually range from 50% in the case of fresh rocks to 100% for completely weathered rocks. That is CIA values increases with an increase in the weathering intensity, and when it reaches 100%, it means all the Ca, Na and K in the rock have been completely leached from the weathered residue. Hence, it can be said that, all the Ca, Na and K in the kaolin deposit have been completely weathered and leached from the residue. Similarly, CIA values reaches 100%, when the rocks suffers serious weathering releasing large quantities of kaolinite and/ or gibbsite rich clay minerals (Junije et al., 2014). Thus, confirming the fact that rock source in the study areas have undergone complete weather and therefore have released kaolinite – and /or gibbsite rich clay minerals.

The results of plagioclase index of alteration (PIA) summarised in Table 4 is similar to that of the chemical index of alteration. The PIA values in Table 4 suggest that there is no redistribution of K and the source rocks are not freshly weathered. According to Fedo et al. (1995), if the PIA value is 50%, then it is freshly weathered; and if it is 100%, just like the CIA, it is completely weathered. Hence, in this study, the PIA value is approximately 100% which confirms the presence of clay minerals such as kaolinite, illite and smectite already discussed in Table 1.

The chemical index of weathering (CIW) is used to provide detailed information about the intensity of chemical weathering source rocks (Fedo et al., 1995). The CIW values shown in Table 3 varies from 96.6% (Ekon) to 98.8% (Assin Foso) indicate strong and intense chemical weathering. This observation is consistent with findings made by Ekosse (2000) for kaolin deposits in the Kgwakgwe River. Similarly, the CIW values found in this study compares favourably with those obtained for other kaolin deposits in the Capim River, Pugu River and Makoro River respectively.

Cox et al., (1995) propose the use of index of compositional variation (ICV) to determine the maturity, original character as well as the prevailing climatic conditions of sediments. According to Cox et al., (1995), ICV values are high for minerals that are highly weathered and low in minerals that less weathered or more stable. The ICV values decreases in montmorillite group of clay minerals and tends to be very low (i.e., less than 1.0) in the kaolinite group of minerals (Cox et al., 1995). Since the ICV values for kaolin deposits in this study (Table 4) ranged from 0.19 to 0.66, it can be inferred that the kaolin deposits in the study areas are compositionally mature and were obtained from granitic or rhyolitic and basaltic rocks.

Prasad et al., (1991), have observed that chemical and geochemical characteristics of kaolin influence their industrial applications. Hence, Table 5 compares the chemical composition of kaolin deposits in the Central Region with standard chemical composition of kaolin required for various industries.

Table 5
Chemical Composition of kaolin in the study area with standard chemical composition required for industries that uses kaolin

Chemical composition	Standards for Industries that uses kaolin				This study			
	Paper Coating*	Paper Filler*	Ceramics*	Pharmaceuticals & Comestics*	Assin Foso	Ekon	Saltpond	Waagkron
SiO_2	45–49	46–48	48–50	44.6–46.4	47.7	58.5	58.9	49.3
Al_2O_3	36–38	37–38	36–38	38.1–39.5	22.3	20.5	28.7	19.7
TiO_2	0.5–1.3	0.5–1.5	0.02–0.1	0.0–1.5	9.21	6.45	1.73	2.72
SO_4	-	-	-	-	0.24	0.25	0.26	3.31
K_2O	0.5–1.5	0.5–1.5	1.2–2.7	0.0–0.2	2.37	2.43	0.48	0.55
Fe_2O_3	0.5–1.0	0.5–1.0	0.6–1.0	0.1–0.2	2.20	2.14	2.10	2.25
MnO	-	-	-	-	0.20	0.22	0.22	0.19
K_2O_5	-	-	-	-	2.48	1.71	0.15	0.92
CaO	-	-	-	0.1–0.2	0.21	0.09	0.12	0.48
MgO	-	-	-	0.1–0.2	0.36	0.45	0.28	2.51
Na_2O	-	-	-	0.0–0.1	0.66	0.10	0.64	0.19
LOI	-	-	11.2–12.5	13.8–13.9	12.24	7.21	7.53	13.35

*the standards were derived from Prasad et al., (1991)

As shown in Table 5, kaolin from this study cannot be used in paper, ceramics, pharmaceuticals or cosmetic industries due to the high levels of TiO_2 found in them. In order to improve upon the quality of kaolin from the study area, there is the need to remove TiO_2 so as to bring it to appreciable levels in Table 5.

The titanium dioxide removed as waste product in the benefaction of kaolin in this study can be used to formulate climate – smart cement; which in recent times, its importance in the formulation of titanium dioxide climate – smart cement has been highlighted by many researchers (Chen and Poon, 2009; Atta-ur et al., 2018). These researchers argue that, due to the photocatalytic nature of TiO_2, when it is used to formulate climate-smart cement and used in buildings, it helps the building to self-cleans itself from deposition of urban pollutants, improves the building to withstand sulphate attack which usually affect buildings constructed from the use of only ordinary Portland cement (Chung, 2000; Akinyemi et al., 2014).

Conclusion

Geochemical assessment of kaolin deposits in the Central Region, Ghana has been carried in this study. It was observed that, geochemical properties of the kaolin deposits in the study area are dependent on the chemistry of the source rocks and their minerals. For example, the K_2O/Al_2O_3 ratio of the kaolin deposits in this study were found to be between 0.02 to 0.11, which compared favourably with other known kaolin deposits in Capim River (Brazil), Pugu River (Tanzania), Makoro and Kgwakgwe (Botswana); which also had K_2O/Al_2O_3 ratio ranging from 0.02 to 0.13.

As noted by Akyinyemi et al., (2014), Al in kaolin deposits are usually immobile whereas K, Ca and Na are very mobile. The mobility of K, Na and Ca tends to increase the degree of chemical weathering, i.e., CIW values. Hence, in this study, the high CIW values recorded (approximately 100%) resulted in the decrease of ICV values. This occurred as a result of conversion of feldspars to aluminium bearing clays such as kaolin. Based on ICV and K_2O/Al_2O_3 values, it can be concluded that the source rocks in the Central Region are compositionally mature and are also rich in kaolinite.

It can also be concluded that, the high levels of TiO_2 found in kaolin deposits in the Central Region which may affect their uses in the paper and other related industries should be removed. The TiO_2 removed can also be used in the production of climate-smart cement, solar panels among others as a way of ensuring sustainable resource use in line with the SDG goals.

Declarations

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Data availability statement

The underlining data for this paper has not been published

Conflict of interest

Authors declare no conflict of interest or competing interest either with the donors or any institution as well as individual that may have an interest in this work.

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Figures

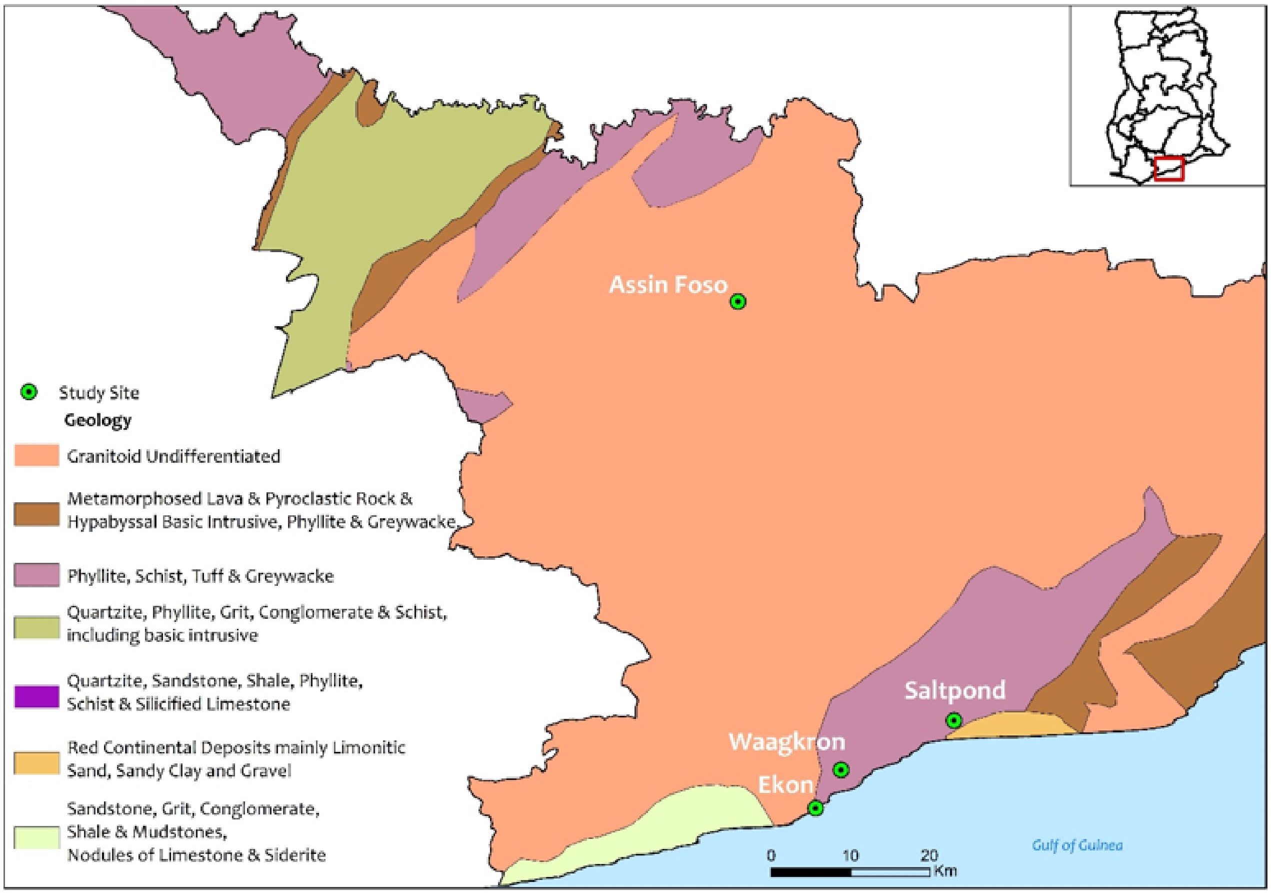

Figure 1

Geological map showing sampling sites in the study area. (Source: Field Data)

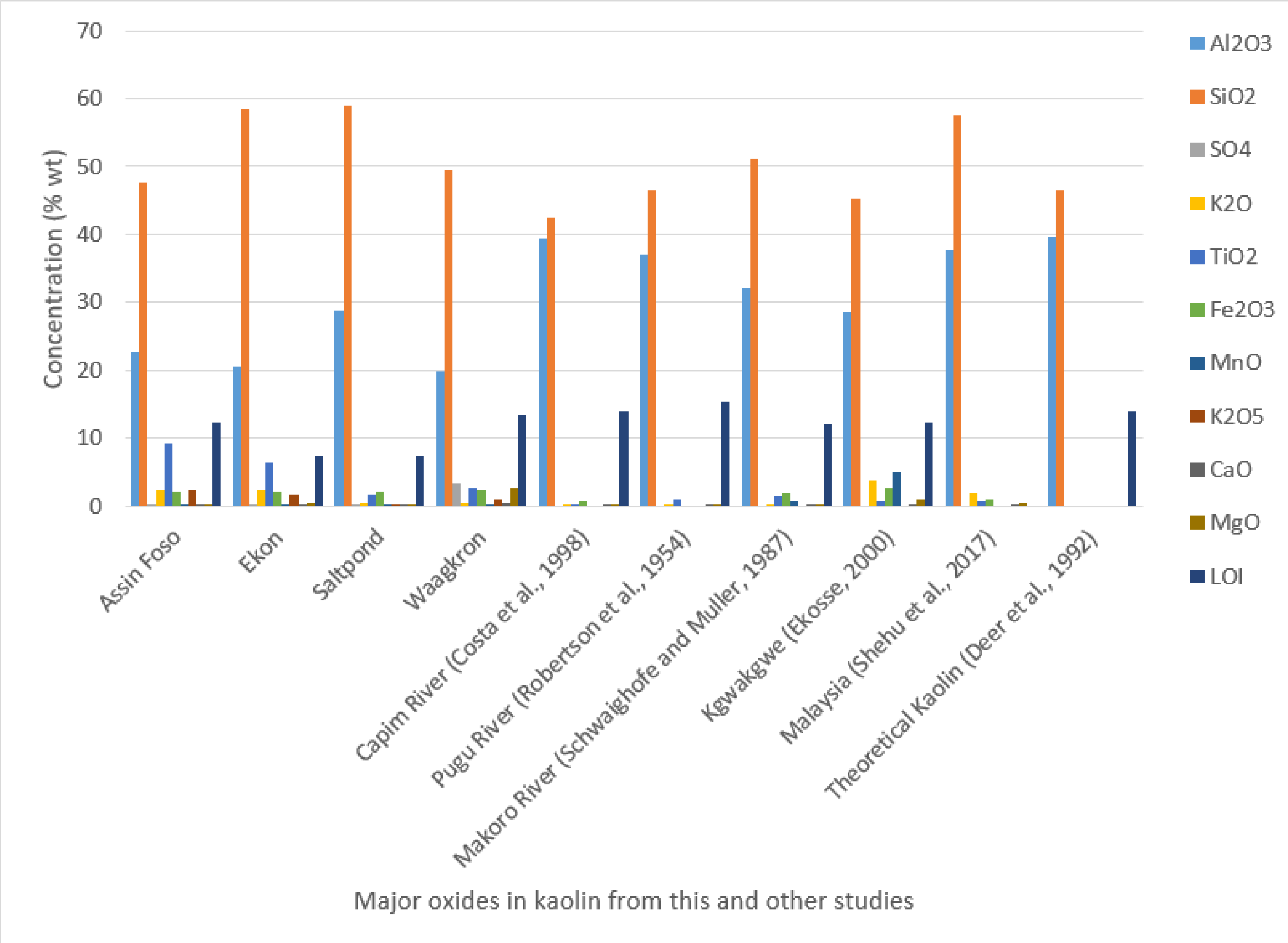

Figure 2

A graph showing the plot of major oxides found in kaolin samples from the study areas and other kaolin deposits in published literature