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Geochemical Investigation of Soil and Stream Sediment Quality around Porgo and Its Environs, Niger State, North-Central Nigeria

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Abstract
The study investigated the geochemical characteristics of soil and stream sediment quality in Porgo and its environ in Niger state, North central Nigeria. The soil samples were collected at depth of 3-meter and 5-meter interval while the stream sediments samples were collected along the moderate flow and dried river channels at 500m intervals. The samples were geochemically analyzed using X-ray Fluorescence (XRF). The results obtained shows that the soil and stream sediments are rich in SiO_2, Al_2O_3, Fe_2O_3, K_2O, CaO, Cl, P_2O_5, BaO, SO_3, Cr_2O_3, V_2O_3, CuO, Ta_2O_5, TiO_2, ZrO_2, MnO, Nb_2O_3, MgO. The order of abundance of element in the study area is Si > Fe > Al >K > Ca > Ti > Mn> Ba > Cr > S > V> Cu > P > Ta > Zr >Nb > Cl with a mean of 33.36, 6.14, 5.66, 3.04, 1.60, 0.51, 0.09, 0.33, 0.08, 0.22, 0.07, 0.06, 0.05, 0.05, 0.04, 0.01 and 0.01 respectively. Contamination Factor (CF) was used to determine the level of contamination in the soil and stream sediment samples. The enrichment of the heavy metals in the area indicates a low contamination except for Fe metal which was moderately contaminated in the stream sediments. The low to moderate contamination shows that anthropogenic activities such as mining, chemical fertilizers, pesticides and waste disposal are not dominant in the area. The Fe contamination could be caused by natural processes such as bedrock dissolution, chemical weathering and erosion of iron bearing rocks and minerals, these can in turn have effects on the water resources of the area that can lead to pH alteration, water hardness, discoloration and toxicity in water.

Keywords: Geochemistry, Soil and Stream Sediments, Porgo Niger State, North-Central Nigeria.

INTRODUCTION

The critical importance of soils and stream sediments in environmental sustainability is well-established. They function as both carriers and sinks for various materials circulating within ecosystems, including anthropogenic substances. The accumulation of pollutants in soils can reach levels that pose significant health risks to communities. Geochemical studies of soils

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and sediments offer valuable insights into their composition and the impacts of natural and human activities on environmental quality.

Geochemical mapping, with its diverse media ranging from stream and soils to water bodies such have been employed across different nations. Sediment quality is a good indicator of pollution in water column, where it tends to concentrate the heavy metals and other organic pollutants (Amadi *et al.*, 2017; Amadi *et al*., 2016; Waziri, 2014; Saeed *et al*., 2008). Sediment represents one of the ultimate sinks for heavy metals discharged into aquatic environment and it is an important source for the assessment of an anthropogenic contamination in water and pollution control.

The researches on geochemical analysis of samples taken on soil and stream sediments by Ayodele and Akunyemi, (2015) in the surroundings of Arinta and Olumirin explained that the catchment basin weathering and erosion products are combined to form stream sediment, which is then carried into and along the stream channels. Their findings attributed variations in sediment composition to differences in weathering processes, sediment transport, and deposition patterns. Similarly, recent studies have examined heavy metal distribution in stream sediments, revealing the significant role of anthropogenic activities such as mining and agriculture in altering geochemical profiles. Once the soil is polluted, metals can be transferred from soil to other environmental media, such as underground water or crops, and this pose a threat to human health as a consequence of inhalation or ingestion through the water supply and food chain (Culbard *et al.,* 1988; Folinsbee, 1993).

Despite these research efforts, a significant gap remains in understanding the geochemical characteristics of soil and stream sediments in Porgo and its environs. While several studies have focused on other areas of North-Central Nigeria, limited data exist on heavy metal concentrations, pollution indices, and potential environmental risks specific to Porgo. Additionally, there is a lack of comprehensive studies that integrate both soil and stream sediment analyses to evaluate contamination levels and the interplay of geological and anthropogenic factors influencing their geochemistry.

This research aims to bridge this gap by conducting a geochemical investigation of soil and stream sediment quality along Porgo and its environs. The study seeks to determine the extent of heavy metal contamination, identify pollution sources, and assess potential environmental implications. Unlike previous studies, this work will employ advanced geochemical mapping techniques to provide a more precise evaluation of contamination trends. The findings of this research will contribute valuable data for environmental monitoring, pollution control, and sustainable land-use planning in Niger State, North-Central Nigeria.

The Study Area's Geological Setting and Location

The study area is situated within Porgu, Paikoro, in the north-central region of Nigeria. Specifically, it lies between latitudes 09°28′N and 09°30′N and longitudes 006°27′E and 006°38′E, corresponding to the Minna sheet 164SW. The study encompasses the villages of Gidan Biri, Kwanaye, Porgo, and Tungan Makun, which are accessible via footpaths, minor roads, and seasonal river channels. Nigeria experiences a distinct dry season (November to February), characterized by the harmattan winds, and a rainy season (April to October), with peak rainfall in August (Adakayi, 2012). Annual rainfall ranges from 900-1000mm to a maximum of 1300mm (Ahmed et al., 2020). The vegetation is characterized by tall grasses and sparse trees, varying in density between the dry and wet seasons. Local agriculture focuses on crops like millet, sorghum, maize, cowpea, and groundnut. Seasonal streams dominate the landscape, indicating water's significant role in weathering and erosion. The area's soils are predominantly clayey to sandy clay, supporting local agriculture (FDALR, 2010).

Geologically, the study area falls within the Basement Complex of North Central Nigeria (Belts et al., 2024). Outcrops consist primarily of metamorphic and meta-sedimentary rocks. The metamorphic suite shows a compositional variation of 33.33% transitioning from granite to gneiss, 16.67% granite gneiss, and 50% granite, schist, and phyllite. These rocks, predominantly composed of quartz, feldspar, biotite, and mica, exhibit medium to coarse-grained textures. Observed geological structures include fractures/joints, veins, foliation, and folds. The topography is characterized by high, flat, rugged, and gently undulating terrain, with well-exposed outcrops, particularly around the villages. The average elevation reaches up to 65m above sea level.

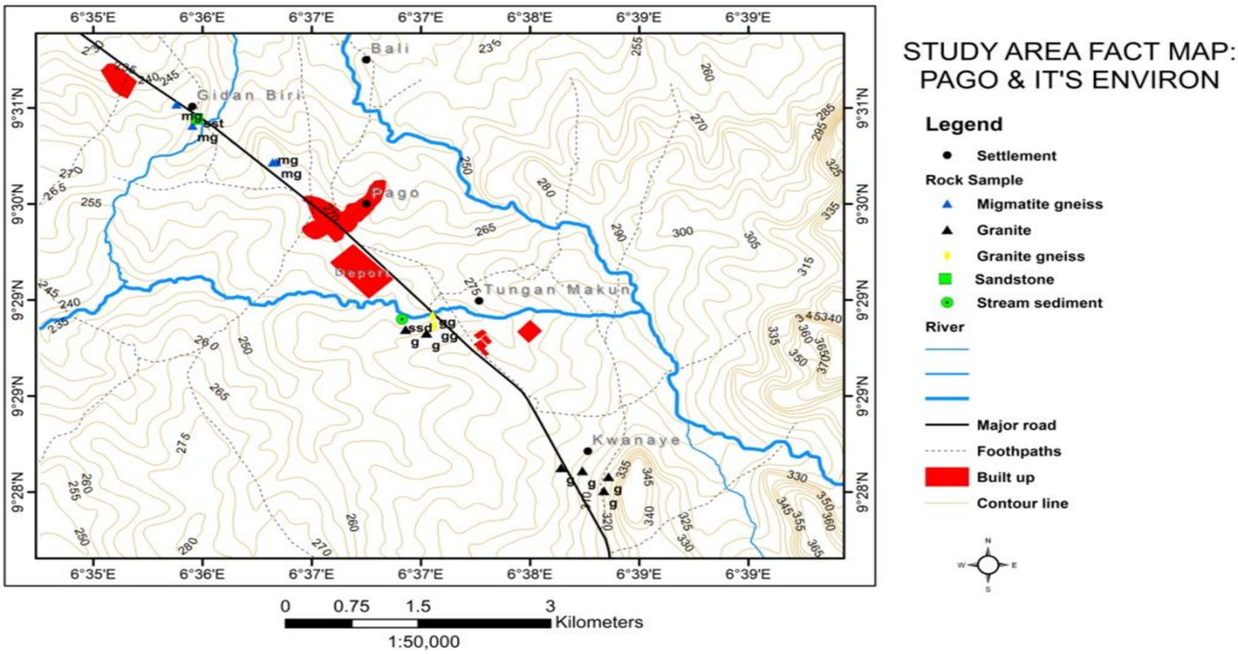

Figure 1: Location of the study area.

METHODOLOGY

Sample Preparation

In line with the study objectives, soil and stream sediments samples were collected in polythene bags for the present study. The collected soil and stream sediments were air-dried and crushed, then split into two equal halves. One crushed portion was pulverized to 100% passing through 75um sieve, split into two portions with one portion further submitted for X-ray fluorescence (XRF) analysis. The geochemical analysis was carried out at the National Steel Raw Material Agency, Kaduna. Apparatus used for sample preparation include: Jaw crusher: used in crushing the samples to smaller pieces, Pulverizer: used for milling the crushed rock samples to powderish form, acetone: colourless liquid used for further cleaning of equipment, brush: for dusting out powdered sediments from the machine, cotton wool: used together with the acetone, aid in cleaning, water and towel: for cleaning the equipment to avoid contamination of the next sample to be prepared.

Geochemical Analysis of Soil and Stream Sediments

The pulverized sediments were analyzed using Genius IF - Xenemetrix XRF Equipment. Duplicate analysis was performed to obtain average values. This method of analysis detects the concentration of the heavy metals and major oxides in the soil and stream sediments. In order to determine total trace element concentration, 7.5 g of the sieved, oven-dried sample was mixed with three (3) cellulose tablets and the mixture was pulverized in an agate mill (Retsch RS 200) for 1 minute. This was followed by pressing the powder into 25 mm pellets using a hydraulic press at a pressure of 20 tons. The cellulose serves dual purposes as a binder and also reduces absorption of the target material (Potts *et al.,* 1992). Glass beads were prepared by mixing approximately 7.60g Lithium borate flux with 0.40g of the sample in a platinum crucible. The mixture was then fused on an air-acetylene flame (800 to 1200o C) for fifteen (15) minutes so that the flux melts and the sample dissolves Funtua, (2001); the melt was allowed to cool into a one-phase glass bead. The result of geochemical studies was used to deduce the possible environmental contamination.

Environmental Pollution Indices

Pollution indices, which compare elemental concentrations in samples to background levels, were used within the Contamination Factor framework to assess the degree of metal contamination in soil and stream sediments.

Contamination Factor (CF): CF is obtained by dividing the concentration of each element by the background value of the element (Chandrasekaran *et al*., 2015).

$$CF = \frac{Cm\ (Sample)}{Cm\ (Background)} \ldots\ldots\ldots..Eqn\ 1$$

Where Cm (sample) is concentration of the metal in a sample
Cm (background) is the reference value for each element.

Table 1: Classes of degree of contamination, (Rudnick and Gao, 2003).

Contamination factor	Contamination level
CF < 1	Low contamination
1 ≤ CF < 3	Moderate contamination
3 ≤ CF < 6	Considerable contamination
CF ≥ 6	Very high contamination

RESULTS AND DISCUSSION

Geochemical Result

The research work studies the geochemistry of soil and stream sediments to examine the major and minor oxides (wt%) present. The geochemical data from the laboratory analysis are presented in Table 1. Table 2 and 3 depicts the major & minor oxides concentration respectively.

Table 2: XRF Result of oxide concentration of soil and stream sediment in the research area (wt. %)

SAMPLE ID	2A (SS)	2B (S0IL)	1A (SS)	1B (SOIL)
SiO_2	69.30	69.79	82.74	63.93
V_2O_5	0.06	0.05	0.06	0.09
Cr_2O_3	0.17	0.12	0.15	0.07
MnO	0.12	0.01	0.09	0.28
Fe_2O_3	13.11	5.79	6.31	9.93

CuO	0.09	0.05	0.05	0.05
Nb_2O_3	0.01	0.02	0.01	0.01
P_2O_5	0.45	0	0.02	0.026
SO_3	0.24	0.52	1.07	0.39
CaO	2.32	2.98	0.84	2.81
MgO	0	0	0	0
K_2O	3.62	5.08	1.14	4.78
BaO	0.31	0.12	0.12	0.09
Al_2O_3	8.52	13.31	6.04	14.90
Ta_2O_5	0.06	0.05	0.06	0.03
TiO_2	0.48	1.12	0.40	1.42
Cl	0.96	0.72	0.81	0.73
ZrO_2,	0.06	0.15	0.02	0.15
SnO_2	0	0	0	0
SrO	0	0	0	0

The normal abundance of the analyzed oxides is listed in their descending order as geochemical studies from X-ray fluorescence reveals major & minor oxides available in the soil and stream sediment. The soil and stream sediments are rich in SiO_2, Al_2O_3, Fe_2O_3, K_2O, CaO, Cl, P_2O_5, BaO, SO_3, Cr_2O_3, V_2O_3, CuO, Ta_2O_5, TiO_2, ZrO_2, MnO, Nb_2O_3, MgO, SnO_2 and SrO. Location 1A (Stream sediment sample) has the highest amount of SiO_2 which occur as the predominant oxide, with a concentration within the range of 63.93wt% to 82.74wt% and has a mean value of 71.44%. The highest amount of Al_2O_3 was recorded in Location 1B (Soil) with a concentration ranging from 6.04wt% to 14.90wt% and an average mean of 10.69%. Fe_2O_3 has a concentration ranging from 5.79wt% to 13.11wt% and has a mean value of 8.785%. K_2O have a concentration value with ranges from 1.14wt% to 5.08wt% with an average value of 3.655% with CaO having a concentration ranging from 0.84wt% to 2.98wt% with a mean value of 2.238%. The remaining oxides recorded a low concentration that rarely make up to 1wt% of the total concentration.

Table 3: Major oxide concentration of soil and stream sediment in the research area (wt. %), Sample 1A (SS), 1B (Soil), 2A (sediments) & 2B (Soil)

SAMPLE ID	1A(Sediment)	1B (Soil)	2A (Sediment)	2B (Soil)
SiO_2	82.74	63.93	69.30	69.79
MnO	0.09	0.28	0.12	0.01
Fe_2O_3	6.31	9.93	13.11	5.79
CaO	0.84	2.81	2.32	2.98
MgO	0	0	0	0
K_2O	1.14	4.78	3.62	5.08
BaO	0.12	0.09	0.31	0,12
Al_2O_3	6.04	14.90	8.52	13.31
TiO_2	0.40	1.42	0.48	1.12
ZrO_2,	0.02	0.15	0.06	0.15
SnO_2	0	0	0	0
SrO	0	0	0	0

The data shows that the soil and stream sediments sample of Porgo area (Table 2) above has a high concentration of SiO_2 in sample 2B (Soil) of about 69.79 (wt.%), Fe_2O_3, CaO, K_2O, Al_2O_3 and TiO_2 has a high concentration of 13.11wt.% (sediments), 2.98wt.% (soil), 5.08wt.% (soil), 13.31 wt.% (soil) and 1.12wt.% (soil) respectively. The remaining oxides recorded a low concentration that rarely make up to 1wt% of the total concentration. From the geochemical data provided in sample 1A (Sediments) &1B (Soil) above (Table 3), SiO_2 recorded a high concentration of 82.74(wt.%) in the sediment sample, with Fe_2O_3, CaO, K_2O, Al_2O_3 and TiO_2 having high concentration of 9.93wt.% (soil), 2.81wt.% (soil), 4.78wt.% (soil), 14.90 wt.% (soil) and 1.42wt.% (soil) respectively, with the remaining oxides recording a low concentration that does not make up to 1wt% of the total concentration.

Table 4: Minor oxide concentration of soil and stream sediment in the research area (wt. %)
Sample 2A (sediments) & 2B (soil)

SAMPLE ID	1A (Sediment)	1B (Soil)	2A (SS)	2B (Soil)
V_2O_5	0.06	0.09	0.06	0.05
Cr_2O_3	0.15	0.07	0.17	0.12
CuO	0.05	0.05	0.09	0.05
Nb_2O_3	0.01	0.01	0.01	0.02
P_2O_5	0.02	0.026	0.45	0
SO_3	1.07	0.39	0.24	0.52
Ta_2O_5	0.06	0.03	0.06	0.05
Cl	0.81	0.73	0.96	0.72

From the data in Table 4 above, all the minor oxides in sample 2a (Sediment) and 2B (Soil) rarely made up to 1 wt. % of the total concentration.

The data above indicates that, SO_3 recorded a concentration of 1.07(wt. %) in sample 1A (Sediments) with the remaining oxides all reading values lesser than 1(wt. %). Table 5 below shows that the concentration of the major and minor oxide found in the soil and stream sediment recorded the highest Si mean average value of 33.39 wt.% with Fe, Al, K and Ca having a mean average of 6.14wt.%, 5.66wt.%, 3.04wt.% and 1.60wt.% respectively. The remaining element recorded an average that barely made up 1wt. %.

Table 5: Element concentration (wt. %) of major and minor oxides in the study area in soil & stream sediment samples (Converted to single element)

SAMPLE ID	2A (SS)	2B (S0IL)	1A (SS)	1B (SOIL)
Si	32.39	32.62	38.67	29.88
V	0.05	0.04	0.05	0.08
Cr	0.12	0.08	0.10	0.05
Mn	0.09	0.01	0.07	0.22
Fe	9.17	4.04	4.41	6.95
Cu	0.07	0.04	0.04	0.04
Nb	0.01	0.01	0.01	0.01
P	0.19	0.00	0.01	0.01
S	0.09	0.20	0.42	0.16
Ca	1.66	2.13	0.60	2.01
Mg	0.00	0.00	0.00	0.00
K	3.00	4.22	0.95	3.97
Ba	0.28	0.11	0.11	0.80
Al	4.51	7.04	3.19	7.89
Ta	0.05	0.04	0.05	0.02
Ti	0.29	0.67	0.24	0.85
Cl	0.01	0.01	0.01	0.01
Zr	0.04	0.11	0.01	0.11
Sn	0.00	0.00	0.00	0.00
Sr	0.00	0.00	0.00	0.00

Soil and Stream Sediment Pollution indices

Contamination factor indices was employed to assess the pollution levels in the soil and stream sediment samples of the Study area. The results of the heavy metals and the level of contamination in each sample is presented in the tables 6, 7, 8 and 9 below.

Table 6: Shows the Contamination Factor (CF) of heavy metal studied in Sample 2a (Sediment) of the research area.

Elements	Concentration	Background value	CF	Intensity of Pollution
Cr	0.12	10	0.012	Low Contamination
Mn	0.09	90	0.001	Low Contamination
Fe	9.17	4.72	1.942	Moderate contamination
Cu	0.07	2	0.035	Low Contamination
Ba	0.28	14	0.02	Low Contamination

Table 7: Shows the Contamination Factor (CF) of heavy metal studied in Sample 2b (Soil) of the research area.

Elements	Concentration	Background value	CF	Intensity of Pollution
Cr	0.08	10	0.008	Low Contamination
Mn	0.01	90	0.0001	Low Contamination
Fe	4.04	4.72	0.8559	Low contamination
Cu	0.04	2	0.02	Low Contamination
Ba	0.11	14	0.008	Low Contamination

Table 8: Shows the Contamination Factor (CF) of heavy metal studied in Sample 1a (Sediment) of the research area.

Elements	Concentration	Background value	CF	Intensity of Pollution
Cr	0.07	10	0.007	Low Contamination
Mn	0.04	90	0.0004	Low Contamination
Fe	0.04	4.72	0.008	Low contamination
Cu	0.10	2	0.05	Low Contamination
Ba	0.11	14	0.008	Low Contamination

Table 9: Shows the Contamination Factor (CF) of heavy metal studied in Sample 1b (Soil) of the research area.

Elements	Concentration	Background value	CF	Intensity of Pollution
Cr	0.22	10	0.022	Low Contamination
Mn	0.04	90	0.0004	Low Contamination
Fe	0.04	4.72	0.008	Low contamination
Cu	0.05	2	0.025	Low Contamination
Ba	0.80	14	0.057	Low Contamination

The results of the calculated contamination factor (CF) of all the samples collected are shown in Table 6-9, this was calculated by comparing the heavy metals with the soil and stream sediments background values. On average, the CF found are in the following order Fe>Cu>Ba>Cr>Mn. The result ranges from Moderate to low contamination with Fe in stream sediments Sample 2a (Table 6) having a moderate contamination, Cu, Cr, Mn and Ba, all recorded values with low contamination intensity. The samples from 2b (soil), 1a (Sediments) and 1b (Soil) all recorded CF < 1 in the study area. This indicates low contamination of heavy metals (Cr, Mn, Fe, Cu and Ba) in the study area. This shows that anthropogenic activities (mining, chemical fertilizers and pesticides) are not dominant in the area due to the low contamination result.

CONCLUSION

The results of the geochemical analysis of soil and stream sediments from Porgu and its environs shows that the mean concentration of the oxides are enriched in the following order SiO_2> Fe_2O_3> CaO> K_2O> Al_2O_3 and TiO_2 and depleted in some base cations. Contamination Factor calculations for heavy metals in soil and stream sediments shows a moderate contamination of Fe in the stream sediments and low contamination of Cu, Ba, Cr and Mn in the soil & stream sediment. The enrichment in silica and Fe contamination, relative to the upper continental crust is consistent with the findings of other workers in Nigeria. This is attributed to intensive tropical chemical weathering, coupled with physical removal of fine clay minerals through the combined effect of wet season overland runoff and dry season winds on the one hand, and the movement of base cations into deeper horizons of soils through leaching. The samples were found to have low to moderate contamination which shows that anthropogenic activities such as (mining, chemical fertilizers and pesticides) are not dominant in the area.

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