



NIGERIAN MINING JOURNAL

ISSN 1117 - 4307



Volume 22

Number 1

September 2024



**A Publication of
NIGERIAN SOCIETY OF MINING ENGINEERS**

NIGERIAN MINING JOURNAL

Volume 22 Number 1 September 2024

Table of Contents

Pages

Title and Author

1 – 9	Evaluation of Rock Slope Stability using Flacslope Software: A Case Study of Jolex Open-pit Mine, Bassa, Plateau State, Nigeria Idowu, K. A. and Benedict E.
11 – 18	Assessment of the Impact of Mining Activities on Water Quality in Kujama, Southern Kaduna – Nigeria Bello Abubakar ¹ , Olajide Ganiyat Bukola ¹ and Lamido Sani Inuwa
19 – 26	Reduction of the Ash Content of Lafia/Obi by Jigging Operation O. A. W. Oyeladun, D. G. Thomas and S. Tolu
27 – 35	Design of Drainage System at Maiganga Coal Mine in Gombe State, North-Eastern Nigeria, Using Pumpsim Software L. K. Salati and M. Lawal
37 – 44	Statistical Distribution of Major and Trace Elements in Stream Sediments Tributaries into River Oyun and River Awun, Kwara State, Northcentral Nigeria A. J. Oyetunde and Y. S. Agunleti
45 – 52	Evaluation of Some Quarry Dusts Treated Soils Obaro R. I., Iheme, K. O., Agbalajobi S. A., Hammed, A., and Obaro, N. T.
53 – 58	Physico-Chemical and Mineralogical Characterization of Dutsen wai cassiterite ore Oyeladun O. A. W., Agbo A. N. and Tolu S.
59 – 65	Geochemical Studies and Industrial Features of Talcoose Rock in Alla Area, North - central Nigeria Obaro R. I., Agbalajobi S. A., Odediran, O.A., Hammed, A., and Obaro, N. T.
67 – 74	Economic Potential of Stream Sediments in Share Sheet 202SW, Northcentral Nigeria Agunleti, Y. S. and Adeleke, J. O



NIGERIAN MINING JOURNAL

ISSN 1117-4307

Volume 22

Number 1

September 2024

A PUBLICATION OF THE NIGERIAN SOCIETY OF MINING ENGINEERS

Editor-in-Chief

A. D. Bida

Publisher

Nigerian Society of Mining Engineers (NSME)
NSME Secretariat, Bukuru,
P.M.B. 2036, Jos, Plateau State, Nigeria

(c) Nigerian Society of Mining Engineers

All rights preserved. No part of this publication may be reproduced, stored, in a retrieval system or transmitted in any form or by any means without the prior permission of the Nigerian Society of Mining Engineers

Editorial Address

Department of Mineral and Petroleum Resources
College of Engineering,
Kaduna Polytechnic, Kaduna.
Tel: 08030495371, 08023636689
Email: nigerianminingjournal@gmail.com
Website: www.nsme.org.ng

NIGERIAN MINING JOURNAL		NIGERIAN SOCIETY OF MINING ENGINEERS (NSME)	
Editorial Board Editor - in - Chief Engr. A. D. Bida Department of Mineral and Petroleum Resources, College of Engineering, Kaduna Polytechnic, Kaduna		Council Executive Members	
Editors		President	Engr. Dr. U. A. Hassan, FNSME, FNMGS
B. S. Jatau , Nasarawa State University, Keffi, Nigeria.		1st Vice President	Engr. Prof. S. A. Yaro, FNSME
E.O.A.Damisa , Ahmadu Bello University, Zaira, Nigeria		2nd Vice President	
D. G. Thomas , Ahmadu Bello University, Zaira, Nigeria		Secretary – General	Engr. Prof. D. G. Thomas, FNSME
Idris Ozigis , University of Abuja, Abuja, Nigeria.		Assistant Secretary	Engr. Henry T. Abolarinwa, FNSME
I. S. Amoka , Kaduna Polytechnic, Kaduna, Nigeria		Treasurer	Engr. Jimada Abdulkadir Muhammed, FNSME
S. A. Yaro , Ahmadu Bello University, Zaira		Financial Secretary	
S. Waziri , Federal University of Technology, Minna, Nigeria		Publicity Secretary	Engr. Apollos Samchi
T. A. Afeni , The Federal University of Technology, Akure		Social Secretary	Engr. Charles Uka
O. A. W. Oyeladun , Kaduna Polytechnic, Kaduna, Nigeria		Auditor	Engr. S. A. Agbalajobi
L. K. Salati , Kaduna Polytechnic, Kaduna, Nigeria		Editor – in – Chief	Engr. A. D. Bida, FNSME
Editorial Advisers		Members – in – Council Engr. Dr. L. K. Salati Engr. Tarfa Dzarma Garba Engr. Dalhatu Dikko Engr. Tafa Abubakar Engr. Abdulkadir Usman	
Engr. Musa Nashuni Engr. Dr. Nuru A. Yakubu, OON Engr. Goni M. Sheikh Engr. M. K. Amate		Fellows – in – Council Engr. A. U. Ojile, FNSME Engr. Princess F. Diejomaoh FNSME	
		Institutional Members in Council <i>BUA Cement Plc</i> <i>Lafarge Africa PLC, AshakaCEM</i>	



INFORMATION FOR AUTHORS

Scope: NIGERIAN MINING JOURNAL is the technical publication of Nigerian Society of Mining Engineers. The Journal publishes peer-reviewed papers covering various fields of mining, mineral processing and extractive metallurgy. The papers provide in-depth information on research findings from various aspects of actual exploitation of minerals and related engineering practice. Researches based on local technology are particularly welcome.

Manuscripts: Manuscripts submitted for publication must represent original contributions and should not have been proposed for publication elsewhere. The papers should be based on original research, innovations and field experience in mineral exploration, mining, mineral processing, extractive metallurgy and equipment maintenance, relevant to the minerals industry. The manuscript must be prepared preferably in Microsoft Word environment, and should be submitted by email to nigerianminingjournal@gmail.com

Abstract: The manuscript must include an abstract summarizing the main aspects of the paper in not more than 200 words. The main results/findings must be stated clearly.

Keywords: A minimum of 5 and maximum of 7 keywords should be included.

Text: Papers should be typewritten with double-line spacing and margins of 25 mm on all sides. Each page should be numbered. The first page should include a concise title of the paper and the author(s) full name(s), affiliation(s) and address(es). In order to maintain consistency, titles such as Mr, Mall, Mrs, Miss, Engr, Dr, Prof, etc., should be avoided, as they frequently change. The author(s) should secure the right of reproduction of any material that has already been published elsewhere.

Units: The S.I. unit is mandatory. However, in isolated accepted cases, authors should insert conversion factors or nomographs for units other than S.I.

Mathematical symbols and formulae: All characters available on a normal typewriter must be typewritten in the text as well as in the equations. Subscripts and superscripts should all be clear. Equations referred to in the text should be placed between parentheses at the right hand margin.

Figures: All illustrations should be drawn using black ink, or suitable computer software, on good quality paper. The originals or good quality photographic prints (maximum 210 x 297mm) should be submitted together with the manuscript. Each figure should carry a brief title *under* it. Figures must be referred to in the text with the number clearly written on the back of the photograph or drawing. Lettering of figures should be large enough to ensure clarity of reproduction after reduction.

Tables: Each table should be typed on a separate sheet as the authors expect it to appear in print. Tables should carry a brief title on top, and should be numbered and referred to in the text.

References: References should be in APA system and must be listed at the end of the article, in alphabetical order of the first author's surname. Citation of papers in the reference list should be as follows:

Books:

Hartman, H.L. & Mutmansky, J.M. (2002). *Introductory Mining Engineering* (2nd Ed.). New Jersey: John Wiley & Sons.

Journals:

Zimbovsky, I.G., Ivanova, T.A., & Chanturia, V.A. (2015). Complexing collecting agent for selective flotation of chalcopyrite. *Journal of Mining Science*. 51(3), 562-567.

Unpublished work:

Arubisan, A.P. (2013). *Amelioration of grain size and its effect on iron ore concentrate in Itakpe, West Central Nigeria*. Unpublished M.Tech. Thesis, Federal University of Technology, Minna.

Proceedings:

Oyeladun, O.A.W, Abubakar, S. & Adewuyi, E.A.A. (2012). Application of Igoli mercury-free gold extraction for recovery of Wamba gold. *Proceedings of Nigerian Society of Mining Engineers*, Ilorin, 2012, 67-70.

Assignment of Copyright Ownership: Submission of a manuscript for possible publication in the Nigerian Mining Journal carries with it the understanding that the manuscript has not been published nor is being simultaneously considered for publication elsewhere. On submission of a manuscript, the author(s) agree that the copyright to their articles is assigned to the Nigerian Society of Mining Engineers (NSME) if and when the articles are accepted for publication.

Evaluation of Rock Slope Stability using Flacslope Software: A Case Study of Jolex Open-pit Mine, Bassa, Plateau State, Nigeria

Idowu, K. A. and Benedict E.

Department of Mining Engineering, University of Jos, Nigeria

Abstract

Throughout the life cycle of an open pit mine, an important component is the stability analysis of the slope. Slope designs in recent years is based completely on field knowledge while a better approach can be carried out through the safe design of slopes. Slope failure in a mine area can lead to socio-economic catastrophe as well as great safety catastrophe. The failure mechanisms are greatly dependent on local geology, which varies according to location of rock mass. The basic failure conditions are very diverse and complicated. This study undertakes an investigation into the assessment of rock slope stability, employing a dual approach that integrates findings from both triaxial machine tests and FLACSlope software simulations. In the empirical analysis, triaxial machine tests were conducted to discern the mechanical properties of the rock material in question. The obtained results revealed a cohesion value of 24.08 kPa, signifying the material's inherent strength under shear stress, while an angle of internal friction measuring 34 degrees offered insights into the material's resistance to sliding along internal planes. These parameters serve as pivotal inputs for subsequent stability calculations. Concurrently, employing computational methodologies, the FLACSlope software was employed to simulate the rock slope's behaviour under varying conditions. The software generated a spectrum of factors of safety (FOS), a key indicator of slope stability, spanning a range from 2.26 to 1.23. This FOS range was correlated with a corresponding variation in slope angles, encompassing degrees from 35 to 70. The software's capacity to model and predict slope stability under different scenarios serves as a complementary technique to the empirical approach.

Keywords: *Rock slope, Open-pit mine, FLACSlope, and Factor of safety (FoS)*¹

Introduction

The term "slope stability" describes the condition in which an inclined slope can support its own weight and outside forces without moving. According to Qiao and Li (2004), the stability is heavily influenced by the mass of the rock, joint and fissure and the vibration. There is a close relationship that exists in the geological structure characteristics, the rock mass structure feature, the slope deformation and failure mode (Aladejare *et al.*, 2024).

Throughout any open pit mining operation lifespan, there must be a slope stability analysis (Idowu and Saliu, 2014; Idowu *et al.*, 2022). However, the design techniques are majorly based on common sense and field experience. On critical engineering judgement, the idea of slope stability analysis has emerged in the field of rock engineering over the past few decades, primarily to address the challenges associated with designing and stabilizing excavated slopes (Bauer and Calder, 1971). An open pit wall's geotechnical slope design begins at the bench scale configuration. Structurally controlled failures like planar, wedge, circular or toppling

(as shown in Figure 1) should be considered to ensure a safe slope design (Idowu *et al.*, 2022; Aladejare *et al.*, 2024). This is because the rock slope stability is determined primarily by the geological discontinuities within the rock mass. The various degrees of variability and uncertainty frequently encountered in rock properties are not taken into account by conventional slope stability analysis and design methods (Call and Savely, 1990). The displacement of rocks through sliding, flowing, and falling occurs when a number of variables, including slope angle, rock strength, ground vibration, and others, pass through an unstable situation (Chalhoub, 2006; Idowu and Adamu, 2024).

In comparison to underground mines, the number of operational open pit mines is rapidly increasing and it has been attributed to higher productivity, shorter gestation period, and a faster investment rate. Open pit mining, however, raises a number of environmental issues, including land degradation, loss of biodiversity, socio-economic issues and solid waste management.

Additionally, a significant number of open pit

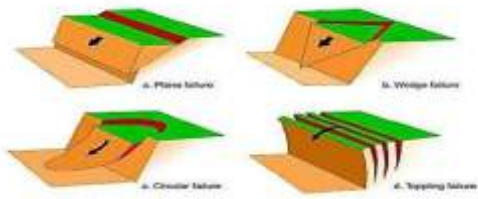


Figure 1: Modes of Slope Failures
(Hoek and Bray, 1981)

mines, both big and small, are presently attempting to reach greater mining depths. As a result, it is increasingly important to analyse the stability of working slopes and design the final pit slope. To keep stripping costs as low as possible, which will directly affect the cost of mining operations, it is crucial to maintain a minimum steep slope angle in the pit (Coates, 1977). The strength and stability of rock mass in addition to the ore grade distribution and production costs influences the final pit limit design (Idowu *et al.*, 2021). Therefore, every possible mining strategy must be evaluated for its likelihood of failure, and this information should be incorporated into the design of the final pit. Given the foregoing, it is imperative to ensure a proper slope design and management practices so that corrective measures can be easily carried out in the future to minimize any type of slope failure (Corbyn, 1978).

Quarry operations involve extensive excavation of rock slopes to extract valuable minerals and resources. However, the stability of these slopes is crucial to ensure the safety of workers, equipment, and surrounding areas (Idowu *et al.*, 2021). The statement of the problem focuses on developing a framework to evaluate the stability of slopes made of quarry rock. This involves analyzing geological formations, rock properties, and ongoing stresses caused by mining activities. By addressing these problems, quarry operators can make informed decisions regarding slope design, mining methods, and safety protocols. This proactive approach minimizes the risk of slope failures, rockfalls, and other hazards, safeguarding not only the mining operation but also nearby communities and the environment. The research evaluated the rock-slope stability in the Jolex Open Pit Mine, using FLACSlope



Figure 2: Structural Failure Condition at Jolex
Open Pit Mine

software. Figure 2 shows the structural failure condition at Jolex Open pit mine.

1.2 Slope Stability

A significant challenge in most open-pit mining industries is the slope stability. Open-pit mining encompasses the static stability and the slope's dynamic analysis (Brady and Brown, 2006). The slope stability analysis in rocks can be carried out with numerous tools such as Galena, Oasys, Rockfall, Udec, Clara-W, Dips, Slide, Alope/W, PFC2D/3D, SVoffice, Flac3D, Elfen, Geo-studio and 3Dec. Stability problem are categorized basically into two, namely; Local Stability problem and the Gross Stability Problem.

- i. Local Stability Problem: this refers to a smaller-scale issue that does not typically affect more than a few benches at a time. It mainly results from shear plane joints or slope erosion caused by surface drainage.
- ii. Gross Stability Problem: this is an overall problem of slope stability that result from a large shear failure in deeply weathered rock.

Slope stability is greatly influenced by numerous factors such as Angle of internal friction (ϕ) (see figure 3). Others include; Geometry of slope, Geology (i.e., Geological structure), Ground water table, Dynamic forces, Cohesion, Lithology and methods of mining equipment used (Hoek and Bray, 1981; Ghasemi *et al.*, 2021). In rock slope stability, surface geometry and designated slip horizon play major roles. θ = angle of internal friction

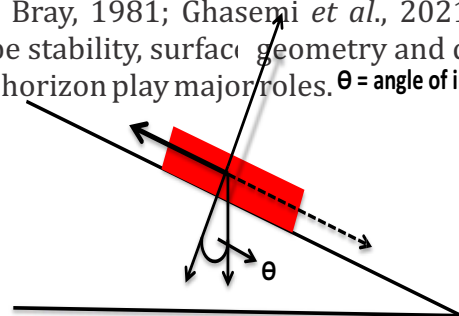


Figure 3: Diagram Showing the Angle of
Internal Friction

1.3 Location of the Study Area

Jolex Open Pit mine is situated in Mista Ali of Bassa Local Government Area of Plateau State, Nigeria. It occupies an area of approximately 282

km² and is located roughly between latitudes N9°56'45" and longitude E8°56'28". The location of the Jolex open pit mine is shown in Figure 4.

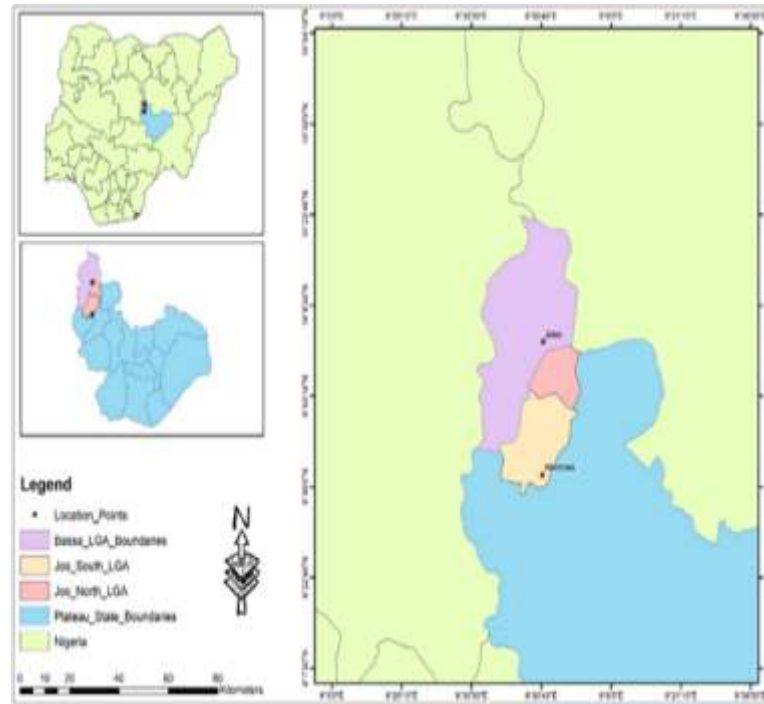


Figure 4: Map of the Study Area

1.3.1 Geology of the study area

The study area is a basement complex in North Central Nigeria. It consists of granite rocks that extends toward the westward and continues to the Dahomey-Togo-Ghana region. The basement complex to the east and south is covered by the Mesozoic recent sediments of the Dahomey and Niger Water Basin. The charnockitic, gabbroic, dioritic rocks, magmatic and granite gneiss, quartzites, slightly migmatized-meta sedimentary schist and meta-igneous rocks are major constituents of the Nigeria's basement complex. According to Kogbe (1979) granite gneisses are widely distributed in the centre of Nigeria.

2. Materials and Method

For designing a stable slope to enable various operations safely, two main parameters that are mechanical in nature were considered. These are cohesion and angle of internal friction. Both parameters displayed the areas of engineering characteristics for consideration.

The materials used are rock samples from the field and the Tri-axial testing machine. The sample preparation and the Tri-axial testing are two main operations that were used for data processes.

Sample preparation

Prior to carrying out the test, rock samples were cut into the required dimensions of Length to Diameter ratio of 2.5:1 for coring in accordance with the international standard (ISRM, 1999).

The Tri-axial Testing

The tri-axial testing is one of the most popularly used methods for evaluating the strength and mechanical features like stress-strain characteristics of rocks. It is divided into different types namely; Consolidated drained, Consolidated undrained and Unconsolidated undrained.

The tri-axial device as shown in figure 5 was used to test the rock samples in accordance with the international standard (ISRM, 1999). It is

characterised by a built-up cell that helps to withstand lateral pressure of 150Kg/cm^2 , and it can be used with the AIM-050, which has a load frame of 500KN capacity. A constant pressure system can be used to apply lateral pressure using the AIM-246.



Figure 5: Tri-Axial Testing Machine.

Testing procedures

The testing procedures are highlighted below:

- a. Using Allen keys, the chamber is removed and cleaned.
- b. A thin layer of oil was applied after the base cleaning
- c. The sample is kept inside the oil-filled chamber, which is then loaded with a loading pad and pedestal of the same size. The chamber is then secured in the locating pin and fastened to the base using the supplied Allen bolts.
- d. The system for maintaining constant pressure is kept at a load of 0.2 MPa.
- e. The same load is then transferred to the oil-filled chamber by raising and lowering the system's handle which serves as the '3' for the test sample.
- f. If the system develops a load of the same quantity, the load is applied from the loading ram until the ram's needle cannot advance any further.
- g. The sample has been tampered with if the needle does not advance further.
- h. After noting the reading, the sample is given the value "1".
- i. For loads of 0.4 MPa and 0.6 MPa, the same process is used.
- j. The readings (cohesion and angle of internal friction) are tabulated.

Numerical Analysis Procedures

The majority of slope instability are generally related to the complexity of material anisotropy,

non-linear behaviour, geometry, in-situ stresses and the presence of several coupled processes (e.g., seismic loading, pore pressure etc). When conventional methods fail to solve a problem, the numerical modelling approach is a good option. Three major sub-categories can be used to further divide up numerical methods: Hybrid, discontinuum, and continuum modelling.

The motive behind using the Numerical analysis was to assist in shedding light on the explanation of the physical geological behaviours of the slope. Numerous failure modes, geological models and design options can also be evaluated using numerical analysis. When compared to analytical models, important geological features such as faults and groundwater are included in numerical analysis to give a more accurate approximations for the behaviours of the real slopes.

FLACSlope

The FlaCSlope is a scaled-down version of FLAC which is designed to specifically perform factor of safety counts for slope-stability analysis. However, the version can only be used with FLAC's graphical user interface (GIIC), that makes it easier to quickly create models for rock slopes or soils and describe the conditions associated with stability.

Limit equilibrium codes use an unpleasant process that is typically centred on the slice method. It helps to make a range of assumptions (for example, the angle and area of interslice forces). The basic approach recommended to FLACSlope for Numerical Analysis in Geomechanics is shown in Table 1.

Table 1. Suggested Steps for Carrying out a Fruitful Numerical Experiment

Step	Description
I	Defining the aim of the model analysis
II	Conceptualization of the physical system
III	Simple ideal models are created and run
IV	Problem-specific data are put together
V	A series of detailed model runs are prepared
VI	Model calculations are carried out
VII	Thus, the results obtained are interpreted

There is a comparison between the time taken by FLAC3D to select a safety factor and the limit equilibrium. Figure 6 shows the modelling stage toolbars for each stage.

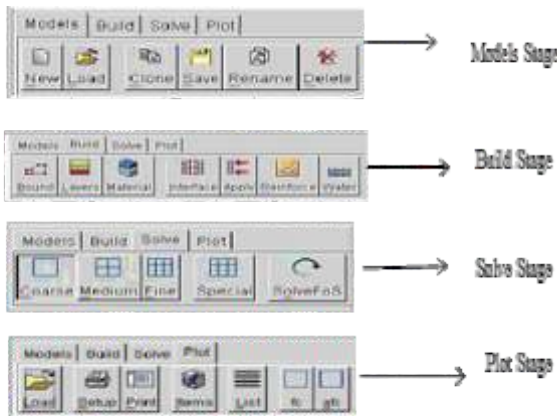


Figure 6. Modelling-Stage toolbars for each stage (User's Guide, 2002)

Analysis procedure

FLAC3D is specifically made to run a variety of analyses and studies based on various parameters for the slope program's stability. The program's structure makes it possible to efficiently create, store and access multiple models in a project for the purpose of directly comparing model results. A FLAC3D analysis typically has four stages and they are as follows:

a) Model Stage

In the Models stage, there is identification and listing in a tabbed bar for each model in a project which can be removed at any time during the project study. Models can also be "restored" or "loaded" from, which makes it simple to access any model and produces a project. The tabbed bar may be updated with new models, or current projects may be updated with models from earlier ones. For each model, the slope boundary is now defined as well.

b) Build Stage

The slope conditions are specified in the Build stage for a particular model. This entails altering the slope's geometry, adding layers, defining weak points and materials, applying surface loading, placing a water table, and adding reinforcement. Additionally, the model's spatial regions can be left out of the calculation of the safety factor. Any time during this stage, the build-stage conditions can be added, removed, or changed.

c) Solve Stage

The safety factor is computed in the Solve stage. The factor-of-safety calculation is often done after choosing the resolution of the numerical mesh (coarse, medium, or fine). To calculate the safety factor using the strength reduction approach, various strength parameters can be chosen. Therefore, the material cohesion and friction angle are applied by default.

d) Plot Stage

The Plot stage offers a number of output options for displaying the failure surface and logging the results after the solution is complete. The output of the model is accessible for later access and comparison with other models in the project. The project files can then be easily restored, and the results can be viewed over time. Therefore, all models created within a project can be saved along with their solutions.

3. Result and Discussion

The rock mass bench parameters for eight varied samples used for the modelling have the following constant characteristics;

Density = 2000 kg/m³

Cohesion = 2.408×10^4 Pa

Angle of internal friction = 34°.

Table 2 shows the results of the factor of safety (FoS) for all the samples after analysis. The slope angles of these samples were varied at an interval of 5°.

Table 2. The Results from FoS Analysis

S/N	Slope Angle (Degree)	The angle of internal friction(Φ) (Degree)	Cohesion C (kPa)	The factor of safety (FoS)
1	35	34	24.08	2.26
2	40	34	24.08	2.03
3	45	34	24.08	1.85
4	50	34	24.08	1.69
5	55	34	24.08	1.56
6	60	34	24.08	1.44
7	65	34	24.08	1.33
8	70	34	24.08	1.23

The results of FLAC3D analyses of samples 1 to 4 are shown in Figures 7 to 14. The results of samples 5 to 8 are of course, insignificant and cannot be practicable. Thereby, they were not included.

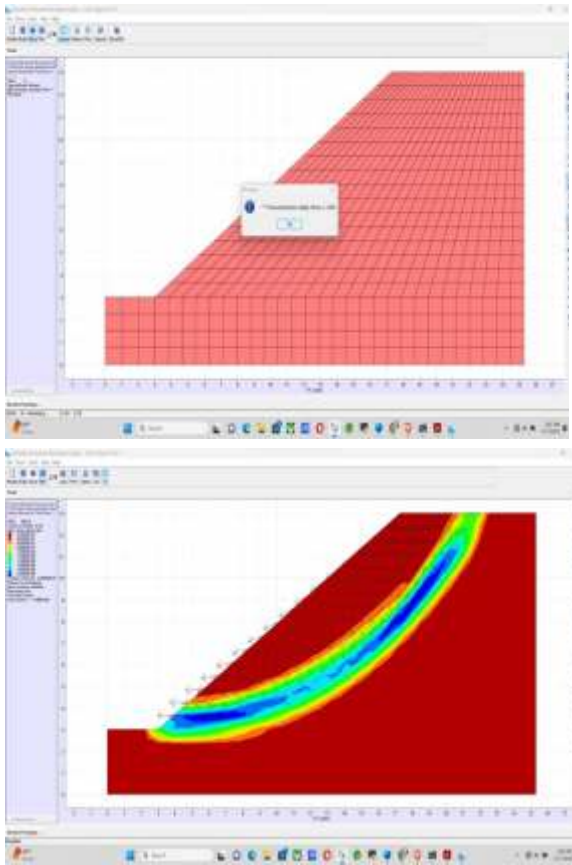


Figure 7. FLACSlope Result for Slope Angle 35°,
FoS = 2.26

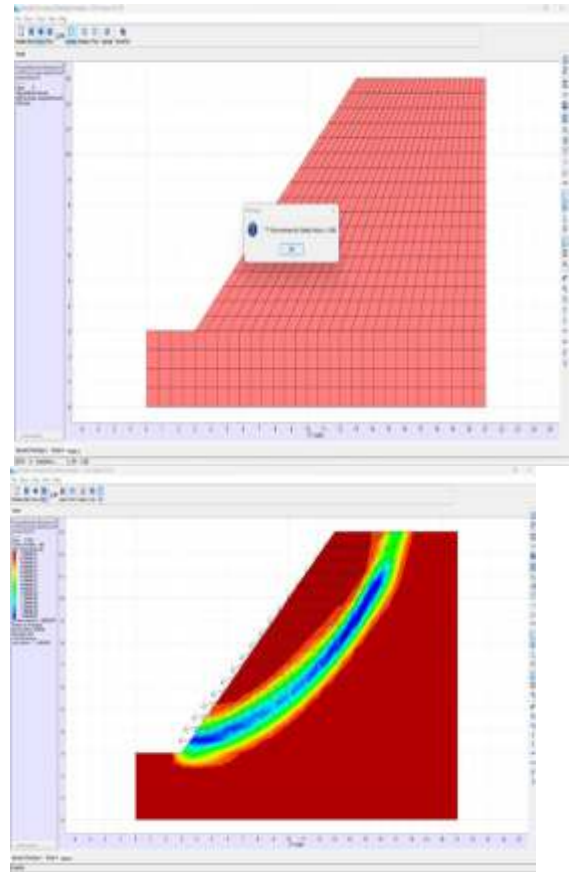


Figure 9. FLACSlope Result for Slope Angle 45°,
FoS = 1.85

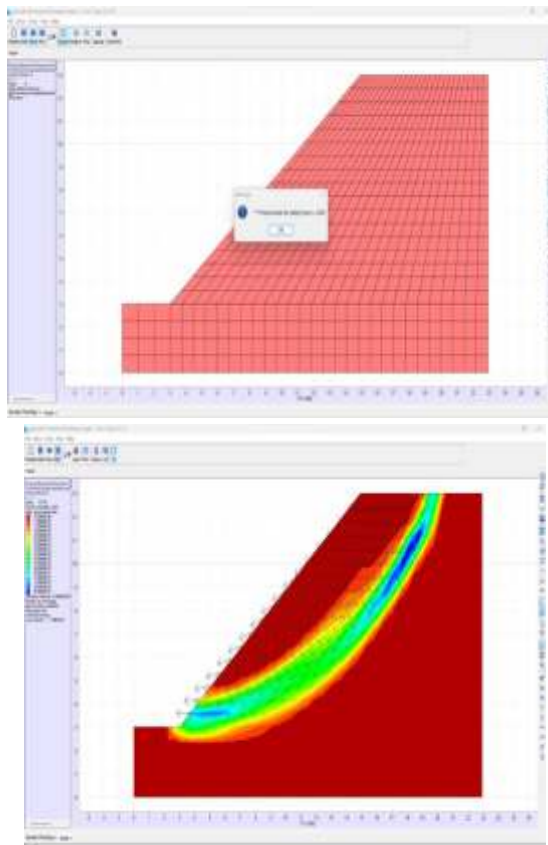


Figure 8. FLACSlope Result for Slope Angle 40°,
FoS = 2.03

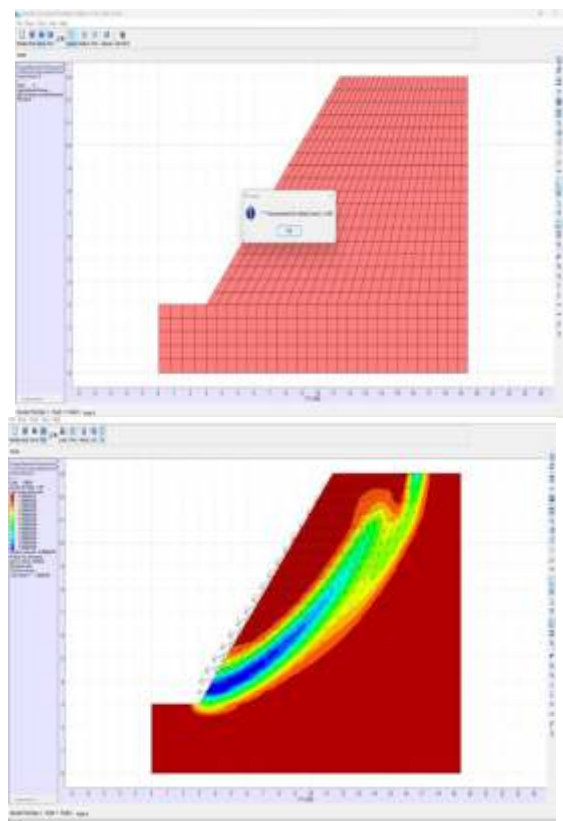


Figure 10: FLACSlope Result for Slope Angle
50°, FoS = 1.69

Figures 7, 8, 9, and 10 illustrate the respective FoS between the slope angles 35 and 50 degrees for selected slope angles. Hence, the nexus between the varying angles and Factor of Safety are given in Figure 25.

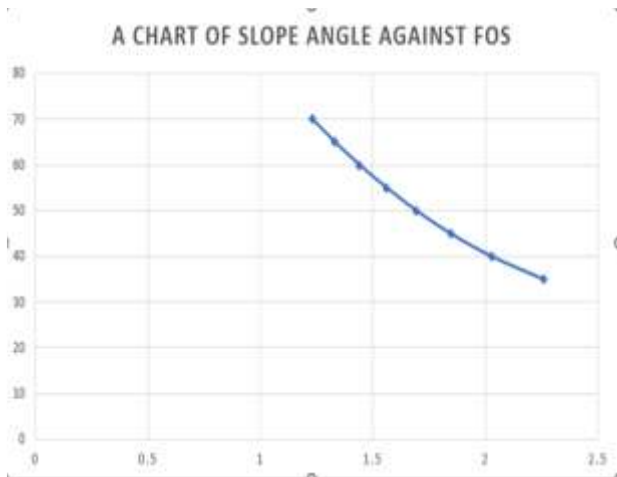


Figure 11. A Chart showing the Relationship between the Slope Angles and FoS

The Tri-axial test revealed that the cohesion and internal friction angle were 24.08 kPa and 34° , respectively. It was discovered that when the resolution of the numerical mesh (coarse, medium, and fine) is changed while running the numerical model, FLACSlope, the factor of safety is altered. While the factor of safety in the case of fine mesh converges to the closest possible value, making it more accurate, the factor of safety in the case of coarse mesh is quite approximative. The calculation speed in coarse mesh, however, is greater than that of the fine mesh. Therefore, the mesh must be chosen based on the modeler's needs and time constraints. It is clear from Figure 11 that, for FLACSlope, the factor of safety decreases from 2.26 to 1.23 as the slope angle of the pit increases.

4. Conclusion

The rock slope stability evaluation in Jolex open pit mine using FLACSlope revealed that, the open pit slope is prone to planar failure with progressive sustained condition. The findings have shed important light on the safety factor for a variety of slope angles ranging from 35 to 70 degrees. The findings show a significant decline in the safety factor, which goes from 2.26 to 1.23 as the slope angle rises.

A slope is considered stable if its factor of safety

is greater than 1.25; otherwise, it may be unstable and at risk of failing. A value of less than 1.0 denotes potential instability. It is clear from this study that as the slope's angle steepens, it becomes more prone to failure.

The stability of the slope is significantly influenced by the angle of internal friction and cohesion of the granite rock set at 34 and measured at 24.08 kPa respectively. The effect of these parameters on the factor of safety intensifies as the slope angle rises, causing stability to significantly decrease. This research has adequately fed Jolex Construction Company Limited (JCC) with information on the best practices when it comes to properly designing bench slope angles that are compatible with the rock slope stability and the overall safety operation in its mine. This advantage will surely boost the business operation of granite extraction not just at Jolex mine but other mines globally. It will also give adequate information and general knowledge about slope stability to the mining industry.

Recommendations

The following recommendations are suggested based on this research findings to mining industries for a guaranteed stability and safety in mines.

- i. **Slope Angle Optimization:** Given the observed drop in the factor of safety with increasing slope angles, it is advisable to optimize the slope angle to maintain stable conditions. Consideration for reducing the slope angle within a range that guarantees an adequate factor of safety to minimize the risk of slope failure.
- ii. **Engineering Design:** Employ detailed engineering design and geological investigations to determine the most appropriate slope angle for specific site conditions. Geological mapping and geotechnical data should be used to accurately characterize the rock mass properties and assess the impact of discontinuities on slope stability.
- iii. **Reinforcement and Stabilization:** In areas where steeper slope angles are unavoidable due to operational or other constraints, consider implementing

slope reinforcement and stabilization measures. Techniques such as rock bolts, shotcrete, and geogrids can enhance the slope's stability and increase the factor of safety.

- iv. Monitoring and Early Warning Systems: Implement a comprehensive monitoring program to continuously assess the slope's performance and detect any signs of instability. Early warning systems, such as inclinometers and piezometers, can provide valuable data to trigger appropriate actions in case of potential slope movements.
- v. Safety Protocols: Develop and enforce strict safety protocols for workers and personnel operating in and around the quarry slopes. Educate staff about potential hazards and evacuation procedures in case of emergencies.

Reference

- Aladejare, A. E., Idowu, K. A. and Ozoji, T. (2024), "Reliability of Monte Carlo Simulation Approach for Estimating Uniaxial Compressive Strength of Intact Rock", *Earth Science Informatics, Springer Nature*. <https://doi.org/10.1007/s12145-024-01262-1>
- Bauer, A., and Calder, P.N. (1971), "The Influence and Evaluation of Blasting on Stability", *In Stability in Open Pit Mining, Proc. 1st International Conference on Stability in Open Pit Mining (Vancouver, November 23-25, 1970)*, New York: Society of Mining Engineers A.I.M.E, pp.83-94
- Brady, B. H. G., and Brown, E. T. (2006). *Rock mechanics for underground mining*. Springer Science and Business Media.
- Call, R. D., and Savely, J. P. (1990), "Open Pit Rock Mechanics", *In Surface Mining, 2nd Edition (ed. B. A. Kennedy)*, Society for Mining, Metallurgy and Exploration, Inc., pp.860-882.
- Chalhoub, M. (2006) "Apports des méthodes d'homogénéisation numériques la classification des massifs rocheux fractures", *Thèse de doctorat, Ecole Nationale Supérieure des Mine de Paris, spécialité géologie de l'ingénieur*, pp. 39–45.
- Coates, D. F. (1977), "Pit Slope Manual", *CANMET (Canada Centre for Mineral and Energy Technology), CANMET REPORT*, pp 126p.
- Corbyn, J.A. (1978). "Stress Distribution in Laminar Rock during Sliding Failure", *Int. J. Rock Mechanics*, Vol. 15, pp.113-119.
- FLACSlope User's Guide, (2002), *Itasca Consulting Group Inc., Minnesota*, pp: 9-12.
- Ghasemi, E., Mikaeil, R., Esmaeilpour, R., and Momeni, M. (2021). "A review of the comparison of underground and open-pit mining". *Journal of Mining and Environment*, 12 (2), 339 - 353. <https://doi.org/10.22044/jme.2020.10217.1948>.
- Hector, G.P., Syed S.A., Guodong J. (2015) "Mapping Geomechanical State of Unconventional Shale-A method of Improving Multi-Stage Triaxial Tests" *Abu Dhabi International Petroleum Exhibition and Conference*, pp 3-6.
- Hoek, E. and Bray, J.W. (1981), "Rock Slope Engineering", *Institute of Mining and Metallurgy, London*, pp.45-67.
- Idowu, K. A. and Saliu, M. A. (2014), "Determination of Fracture Index and Blast Efficiency for Effective Blast Operation- a case study of Kopec Granite Quarry South-western, Nigeria", *iSTEAMS Conference, ABUAD*, pp.1033-1038.
- Idowu, K. A., Olaleye, B. M. and Saliu, M. A. (2021), "Application of Split-desktop Image Analysis and Kuz-Ram Empirical Model for Evaluation of Blast Fragmentation Efficiency in a Typical Granite Quarry", *Ghana Mining Journal*, 21(1), pp. 45-52.
- Idowu, K. A., Olaleye, B. M. and Saliu, M. A. (2022), "Prediction of Blast Efficiency of a Typical Granite Quarry", *7th UMaT Biennial International Mining and Mineral Conference, Tarkwa, Ghana*, pp. 1-8.
- Idowu, K. A. and Adamu, Z. (2024), "Models Development for Prediction of Blast Efficiency and Total Charge in a Typical Quarry", *AJERD*, 7(2), pp. 69-77.
- International Society for Rock Mechanics (1999), "Committee on Standardization of Laboratory and Field Tests Suggested Methods: Rock Characterization, Testing and Monitoring", *E. T. Brown, ed., Pergamon Press, London, Great Britain*, 21.

- Itasca., (2001), "Version 5.0. Manual", *Minneapolis: ICG*.
- Kogbe, C. A. (1979). "Geology of Nigeria", Elizabethan Publishing House Lagos, Nigeria pp.1:1-10.
- Nordlund, E. and Radberg, G. (1995). "Bergmekanik. Kurskompendium", *Tekniska Hogskolan iLulea*, p.191.
- Qiao, L., Li, Y. (2004) "Engineering geological model of high-steep slope damage in open cutmines. J. Univ. Sci. Technol. Beijing 26(5), pp.461-464.
- Sage, R., Toews, N. Yu, Y. and Coates, D.F., (1977) "Pit Slope Manual Supplement 5-2 — Rotational Shear Sliding: Analyses and Computer Programs", *CANMET (Canada Centre for Mineral and Energy Technology), CANMETREPORT* pp.77-17,92.
- Singh, D, (2010," Principle and Practices of Modern Coal Mining", *New Age International (P) Limited, New Delhi*, pp: 612- 617.

Assessment of the Impact of Mining Activities on Water Quality in Kujama, Southern Kaduna – Nigeria

Bello Abubakar¹, Olajide Ganiyat Bukola¹ and Lamido Sani Inuwa²

¹Department of Mineral and Petroleum Resources Engineering, Kaduna Polytechnic, Kaduna.

²Department of Chemical Engineering, Kaduna Polytechnic, Kaduna.

Abstract

A Geochemical Assessment of the impact of Rock Quarrying on Groundwater quality in Kujama area of Kaduna was carried out. Fourteen (14) water samples were collected from hand dug wells and boreholes. Physical parameters such as pH, temperature, TDS and FC were measured in-situ. The pH ranges from 6.2 – 9.3, Temperature 28°C – 33°C, while EC is from 0.05 – 4.3 Us/m suggesting low mineralization of the groundwater. Hydrogeochemistry revealed average concentrations of Ca as 12.96, Mg 1.53, K 12.38mg/L and Na 27.4 mg/L. The relative high value of Na suggests dissolution of Sodic-rich feldspar by groundwater. Average concentration of Anions indicated CL (233.05 mg/L), Sulfate (13.18mg/L) Bicarbonate (HCO₃) range 0.4 – 4.6 mg/L; while Nitrate is 0.448mg/L suggesting pollution free in terms of anion and human discharge. Heavy metals levels of Fe, Cd, Pb, Cr, Ni were found to be potentially high. The Piper diagram classified the water as Na⁺ - K⁺ - Cl⁻ - SO₄²⁻ type based on the major cations and anions. The overall quality of the groundwater in the area is poor based on the Environment Water Quality Index (CCME WQI) used in this study.

KEYWORDS: Geochemical, Hydrogeochemistry, Groundwater, Heavy metal, Pollution

1.0 Introduction

In general, the natural environment is composed of land/soil, water, and air. The major challenge is the release of industrial waste into any one of these components or the excessive modification of one of these components of the environment resulting in pollution the presence of these pollutants affects the natural balance of the environment which in turn affects the functionality of the environment (air, land and water) thus affecting plants, animals and human life. The overall objective of this work is assessment of the impact of mining activities on water quality in Kujama, Kaduna State, using the physicochemical properties of the water samples and comparing these values with the acceptable standards in Nigeria and the world.

The most significant impact of mining activities is its effect on the water quality and availability of water resources within the mining area. The degree of impact depends upon many factors, in particular the mining type and method, and the operation size. Mining activities in the past have generated uncontrolled waste and tailings deposit, and today they are a major source of acid mine drainage (Navarro-Torres *et al.*, 2011). Mining activity mainly disturbs and changes topography of land which ultimately affects the

hydrogeological conditions (Baba and Gungor, 2002).

Negative water impact could be described as those that lead to a decline in the quality of natural water to the extent that it is not suitable for use by man or other forms to live. The impacts degrade water by alteration of biological, physical and chemical properties of water (Magombedze, 2006). Previous research associates the presence of chemical pollutants in water to the extraction industry since the extraction of mineral ores affects the hydrology of the water catchment area. Research has documented a relationship between mining activities and water pollution (Aigbedion and Iyayi, 2007). It is argued that water pollution occurs when metals contained in the excavated rock comes into contact with water. Mining also affects water bodies when seepage from tailings and waste rock impoundments come into contact with the water bodies.

According to Miranda and Sauer (2010), water related impacts can arise at nearly every stage in the mining process and could have significant impact on groundwater resources with potential for generation of acid mine drainage. The mining process and activities such as drilling, extraction, beneficiation, dewatering of the

subject area: leaching from the waste rock piles and tailing dams cause changes in the water quality and quantity. Water contamination also occurs when the pollutants are directly introduced to the water bodies by the miners.

The discharge seeps through the waste rock piles, tailing dumps and country rocks, dissolving metals along its flow path, eventually finding its way to water bodies (Vermeulen and Bester, 2010).

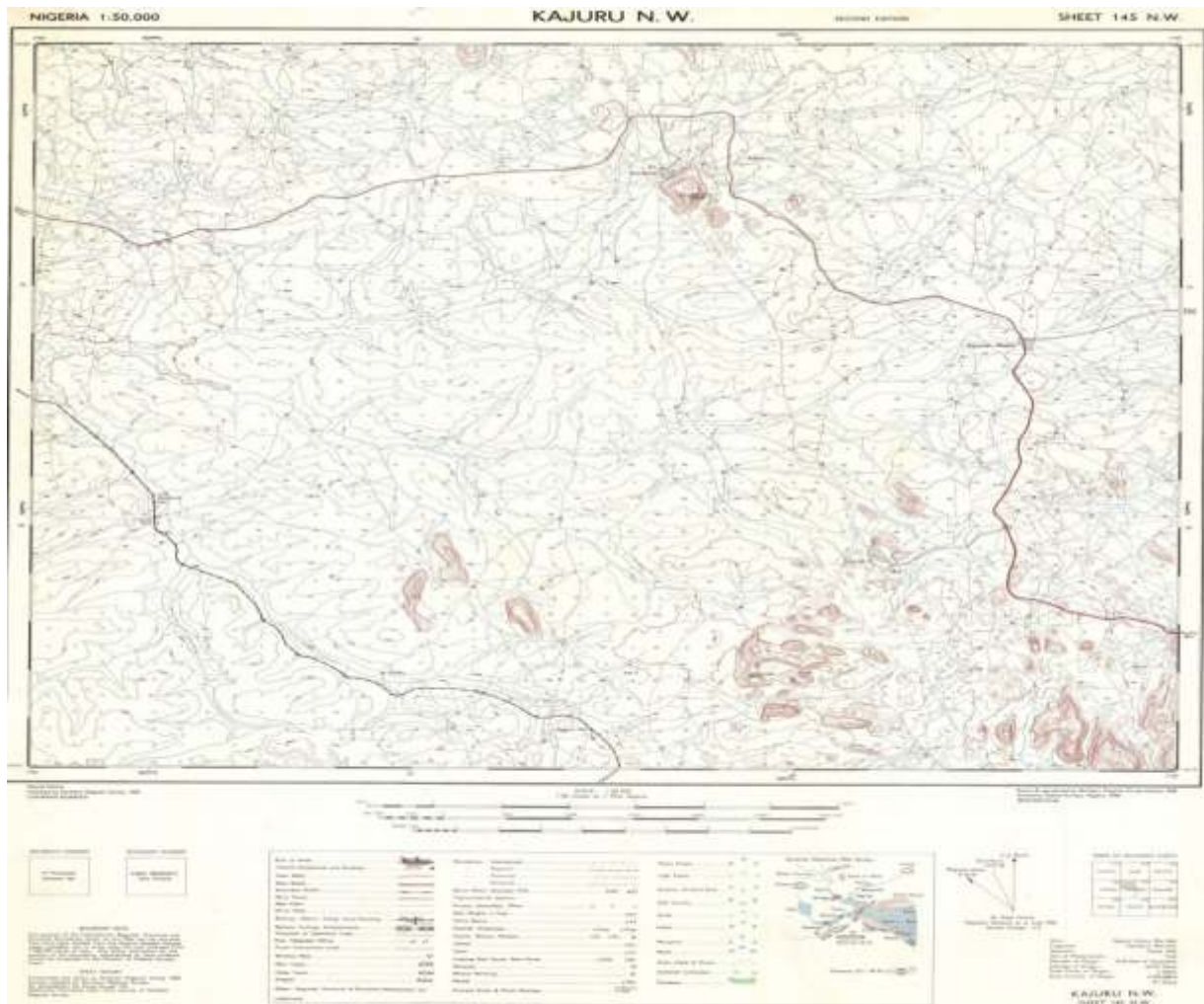


Figure 1: Topographical map showing Kaduna State (sheet 145 NW) (from: Federal Survey of Nigeria, 1974, modified).

1.1. Location and extent of Kaduna State.

Kaduna State occupies almost the entire mid-central portion of the northern parts of Nigeria. The state is located globally between latitudes $9^{\circ}03'N$ to $11^{\circ}32'N$ and longitudes $6^{\circ}05'E$ to $8^{\circ}38'E$. It shares boundaries southward with the Federal capital Territory (FCT) and Nasarawa state, eastward and with Plateau states, and westward with Niger State, northward it shares with Kano state (Figure 1)

2.0 Literature

Though studies have been conducted on some

aspects of the geology and hydrogeology of Kujama by several researchers, very little data are available on the quality of water within the study area. The previous work done is based on work carried out locally and abroad on the effect of quarrying on water quality.

Natural water resources are subjected to pollution comprising of organic and inorganic constituents. The stone quarrying industry greatly contributes as a major source of water pollution which eventually becomes hazardous to various environmental attributes. The environmental impact of mining/quarry

activities is very complex and it not only destroys the existing vegetation but also affects the surface and groundwater quality. The wastes from industry like dusts, solutions, and variety of minerals such as tailing containing trace and toxic elements pollute water environment. Hine Khan, K.N. (2002)

Hine Khan, K.N. (2002) studied the groundwater quality of iron-ore mining area in Gao and reported that the groundwater in mining area has low pH due to pyretic rocks at the bottom. In few cases of accumulation of water in the pits, the water becomes turbid leading to the contamination of groundwater.

Offodile (1992) did a case study of Nigeria and reported that tropical countries like Nigeria, high temperature partially account for the water dissolving more minerals. Elements like lead, copper, cadmium, chromium are regarded as toxic elements. Therefore, their presence in water above permissible limits stipulated by WHO (2021) and NAFDAC which are peculiar to Nigeria can affect the central nervous system.

Barnes and Clarke (1964), in their work on the geochemistry of groundwater in mine drainage problems concluded that mines can produce a variety of groundwater pollution problems.

Enrich and Merritt (1969) worked on the effects of mine drainage on groundwater and effects of early day mining operations on present day water quality. They all concluded that the pollution depends on the material being extracted and the milling process; coal, uranium and phosphate mines are major contributors while metallic ores for production of iron, copper, zinc and lead are also important.

3.0 MATERIALS AND METHOD

3.1 MATERIALS

The field equipment used during geological field work and sampling programme include; geological hammer, geological compass, sampling bags, masking tape, permanent marker, water sampling bottles (polyethylene), Global Positioning System (GPS), and water kit technology (for measuring water physical parameters).

3.2 SAMPLING AND ANALYTIC METHOD

Fourteen (14) water samples were collected

from different optimum sampling locations for analysis of heavy metals in the groundwater in the study area. Measurements of physical water parameters including pH, temperature, Total Dissolved Solids (TDS), and electrical conductivity (EC) were carried out in-situ on each sample. In addition, sampling procedure described in Willis (2008) and Todd (1959) were adopted for the collection of water samples in the area.

Apart from the heavy metal analysis, major cations (Mg^{2+} , Ca^{2+} , Na^+ , and K^+) and anions (SO_4^{2-} , Cl^- and HCO_3^-) that constitute the bulk chemistry of the water were also determined in order to characterize the groundwater based on the water-rock interaction. The heavy metals analysed for each sample include iron (Fe), manganese (Mn), chromium (Cr), cadmium (Cd), zinc (Zn), lead (Pb), and nickel (Ni).

Water samples were collected from hand pump and motorized boreholes after minutes of constant pumping and hand dug wells using bailers. Plastic polyethylene bottles used were thoroughly rinsed with the water to be sampled. Each sampling bottle was labeled and precise sampling point was recorded using global positioning system (GPS) for reference purposes. The samples were carefully stored in the sampling container and transported to the laboratory while ensuring that they were not contaminated.

4.0 RESULTS AND DISCUSSION

4.1 Geology

The result of geological mapping reveals that biotite granite and diorite are the main lithological units in the area (Figure 2). The biotite granite dominates the area and occurs in different forms such as inselberg, whaleback and boulders. The outcrop exposures are mostly weathered and eroded. Outcrops of diorite occur mostly as intrusions within the biotite granites. Both rocks exhibited fractures, pegmatites and quartz veins in various degrees. The measurements of strike and dip from joints and other structural features indicated a general trend of NNW-SSE direction which points to the possible trend of mineralization in the study area (Figure 2).

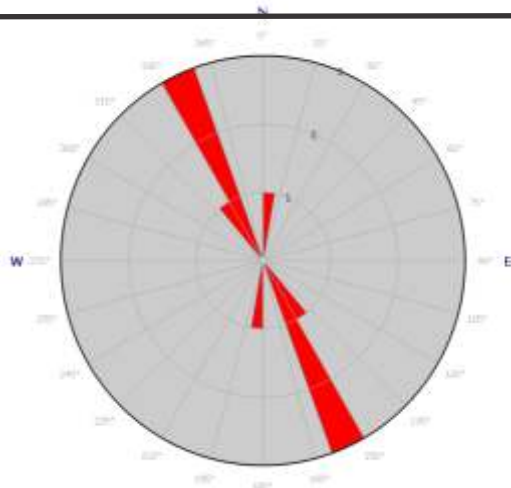


Figure:2 Rose diagram of joints showing NNE-SSW as the dominant orientation.

4.2 Groundwater Composition

4.2.1 Physical Parameters

Table 1 presents the results of the physico-chemical parameters of the water samples collected from the study area. The pH values range from 6.2 to 9.3 with a mean of 7.19 indicating slightly both acidic and basic character (Todd, 1959). Measured values for temperature in all the water samples vary from 28.2° to 33.1° with an average of 29.97°. The electrical conductivity of the water samples appears to be infinitesimal which range from 0.05 to 4.3 with an average of 0.66 μ S/cm. This, however, suggests low mineralization of the groundwater in the area. Although total dissolved solids (TDS) is closely related to electrical conductivity (EC) because both parameters point to the dissolved substances in water but TDS values (1029 to 1 with a mean of 258.2 mg/l) of the water samples from the study area appeared to be higher compared to the values of EC.

4.2.2 Cation Chemistry

The chemical components composed of cations are presented in Table 1. The results show highest concentration of calcium of about 73.902 to a minimum of 0.048 with an average value of 12.96 mg/l. The ranges of Magnesium are 2.745 to 0.29 averaging about 1.53 mg/l. Potassium values are varied and range from 35 to 2.4 with a mean value of 12.38 mg/l. Sodium, on the other hand, varied from 136 to 2.9 recording average value of 27.4 mg/l. In particular, based on the average values of the major cations present in the water samples, sodium appears to be the dominant ion which indicates the dissolution of sodic-rich feldspar by groundwater.

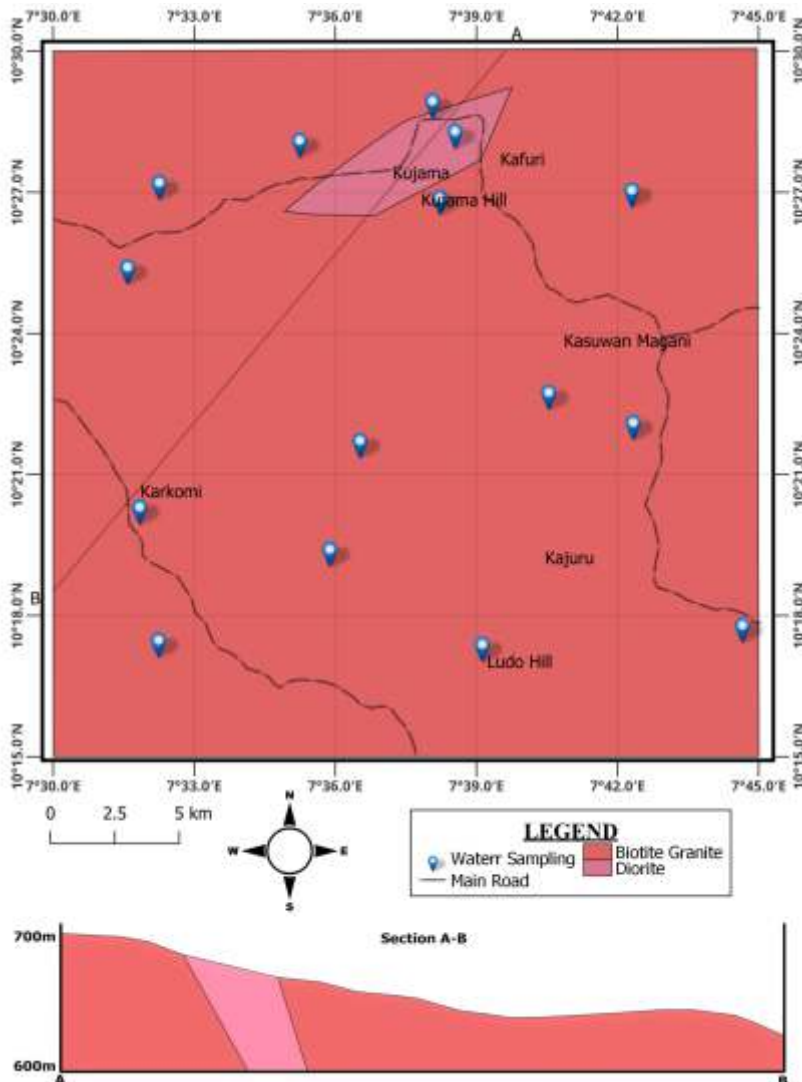


Figure 3 Geological map of the study area showing water sampling points

Table-1: Analytical values of groundwater samples in the study area.

Physical Parameters					Major Cations				Major Anions			
Sample ID	pH	Temp (°C)	EC (µs/cm)	TDS (mg/l)	Ca ⁺² (mg/l)	Mg ⁺² (mg/l)	K ⁺ (mg/l)	Na ⁺ (mg/l)	SO ₄ ⁻² (mg/l)	Cl ⁻ (mg/l)	HCO ₃ ⁻ (mg/l)	NO ₃ ⁻ (mg/l)
SA	8.3	29.4	1.38	1029	49.86	2.607	12.8	42.6	10.344	488.874	1.8	0.448
SB	8.7	28.1	4.3	1	73.902	2.745	24.1	136	7.523	1523.303	0.6	0.294
SC	9.3	30	0.48	345	13.09	2.35	9.3	26.5	3.997	170.043175	2.4	0.084
SD	6.5	28.8	0.05	53	0.048	1.44	7	10.6	4.467	17.71283073	1.4	0.112
SE	6.8	28.2	0.32	231	3.369	1.651	11	15.4	3.527	113.3621167	0.8	0.098
SF	6.3	29.3	0.05	46	1.186	0.301	35	2.9	4.702	17.71283073	2.2	0.098
SG	6.6	30.1	0.15	112	0.175	0.884	4	12.5	4.467	53.1384922	1	0.098
SH	6.2	29.1	0.13	100	0.776	0.881	2.4	9.4	5.878	46.0533599	0.4	0.154
SI	8.2	33.1	0.88	633	26.119	2.661	32.5	35	4.467	311.7458209	4.6	0.154
SJ	7	29.6	0.19	138	0.713	0.644	5	19.6	3.291	67.30875678	0.6	0.112
SK	6.6	28.8	0.11	84	1.347	0.29	4.2	11.1	3.056	38.96822761	1.4	0.28
SL	6.8	29.3	0.74	528	9.4	2.395	15	40.2	3.291	262.1498948	1	0.126
SM	6.3	32.7	0.19	138	0.646	0.582	6.5	15.1	61.361	67.30875678	1	0.238
SN	7.1	33.1	0.24	177	0.777	2.036	4.5	12.8	64.182	85.02158751	2	0.273

4.2.3 Anion Chemistry

The major anions analyzed in this work are presented in the table above and consist of sulfate, chloride, nitrate, and bicarbonate. Of these ions, chloride constitutes the highest concentration which varies from 1523.303 to 17.713 with an average value of 233.05 mg/l. Sulfate values varied from 64.182 to 3.056 mg/l (with average of 13.18 mg/l). Bicarbonate (HCO_3^-) ranges from 4.6 to 0.4 mg/l. Nitrate concentrations are less with about 0.448 mg/l being the highest recorded in sample SA and the lowest concentration of about 0.098 observed in three samples (SE, SF, and SG). This indicates that the groundwater in the study area is pollution-free in terms of animal excrements and plant debris (Todd, 1959). On the average, chloride concentration dominates the rest of the anions.

4.3.4 Hydrochemical Facies

The major cations and anions discussed above constitute about 99% composition of natural waters and can be used to understand the hydrochemical facies of water by portraying their composition on a Piper (1994) diagram. The chemistry of natural water is best displayed on a piper diagram because multiple samples can be shown. Both cations and anions are presented on either triangle at the base and their combination is displayed on the diamond plot at the center. In general, water can be classified as: (1) $\text{Ca}^{2+}\text{-Mg}^{2+}\text{-Cl}^-\text{-SO}_4^{2-}$, (2) $\text{Na}^+\text{-K}^+\text{-Cl}^-\text{-SO}_4^{2-}$, (3) $\text{Na}^+\text{-K}^+\text{-HCO}_3^-$, and (4) $\text{Ca}^{2+}\text{-Mg}^{2+}\text{-HCO}_3^-$. The results of the chemical constituents of the water samples are portrayed in the Piper diagram (Figure 4).

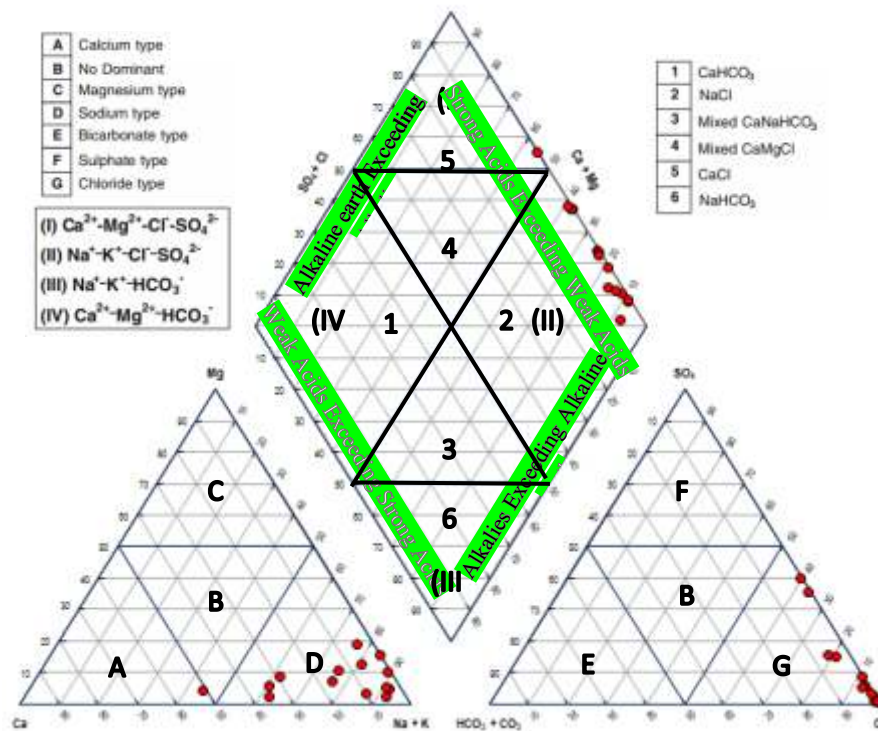


Figure 4: Piper diagram for water samples.

Figure 4 (piper) shows all the water samples collected from the study area. As can be seen, majority of the water samples fall within sodium and chloride (NaCl) type based on the dominant ions. Furthermore, the water belongs to $\text{Na}^+\text{-K}^+\text{-Cl}^-\text{-SO}_4^{2-}$ group with the exception of one sample (SB) which belongs to $\text{Ca}^{2+}\text{-Mg}^{2+}\text{-Cl}^-\text{-SO}_4^{2-}$. The table below further explains the water specie based on the illustration in the Piper diagram.

Discussion

The study area is underlain by biotite granite and diorite. These rocks exhibited fractures, pegmatites, and quartz veins in various degrees. The geometrical measurements of dip and strike of joints indicated a trend of mineralization to be predominantly in the NNW-SSW direction. The geochemical analysis of the rock sample obtained from the study area show a strong

depletion is silica and enrichment in alumina and alkali. The rock was found to be peraluminous with high iron content. Petrographic description also showed the bulk mineralogical composition of the rock samples collected from the study area.

The results of pH of all the water samples were within the Nigerian Standard for Drinking Water Quality (NSDWQ) except for two samples (SB with 8.7 and SC with 9.3) which were slightly above the standard of 8.5. The levels of Electrical Conductivity in the study area were within the prescribed limit (NSDWQ: 1000 μ S/cm) which makes the water portable for both domestic and irrigational purposes.

In this investigation, TDS values of the majority of the water samples were within the permissible limit with the exception of sample SA (1000), SI (633), and SL (528) which were found to be above the guideline (NSDWQ: 500mg/l). When TDS values are high it is an indication of strong interaction between the groundwater and its host lithology, therefore the residence time is high and the dissolution of constituent minerals by the groundwater must have taken place.

In particular, the major cations and anions that invariably make about 99% of the natural composition of groundwater were found conform to the permissible limit of NSDWQ. However, chloride values reported from three samples (SA, SB, SI, and SL) were observed to be above the permissible limit. When chloride concentration exceeds 100mg/l in water a salty taste will result and values above 100mg/l are not only desired by industries but affect physiological damage (Todd, 1980). In terms of pollution, the concentration of nitrate in all the water samples were below 50mg/l which makes the water pollution-free and can be safely used even by infants.

Based on the hydrogeochemical facies as portrayed on the Piper diagram (Figure 1), the dominant water type is $\text{Na}^+ - \text{K}^+ - \text{Cl}^- - \text{SO}_4^{2-}$ and the major mechanism driving the chemistry of the groundwater in the area is rock dominance. Of particular concern in this work is the level of heavy metal concentrations observed in all the water samples in the study area. The levels of lead (Pb), nickel (Ni), cadmium (Cd), and chromium (Cr) were found to be potentially high,

far exceeding the permissible limits of not only NSDWQ but virtually all drinking water guidelines worldwide.

Certain health problems such as poisoning, tiredness, irritability, anemia, behavioral changes, and impairment in intellectual functions and convulsions to mention a few associated with the exposure of water with high concentrations of lead have been reported in areas where sulfide-bearing minerals are mined and in numerous communities practicing inappropriate waste disposal. The concentrations of iron (Fe) and manganese (Mn) were all found to be within the standard of domestic water utility.

The Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) was employed to determine the overall quality of the water samples based on the analyzed parameters. Based on the computation of the CCME WQI, the overall quality of the water in the study area is very poor, displaying a negative value of about -117.

CONCLUSION

Based on the average pH values, the groundwater in the area was found to be slightly acidic and basic which makes it suitable for most uses. The response of the groundwater to electrical conductance was very low as indicated from the values of electrical conductivity. Thus, this is further corroborated by the average values of the total dissolved solids (TDS) which also point to the low mineralization and a residence time. The Piper diagram classified the water as $\text{Na}^+ - \text{K}^+ - \text{Cl}^- - \text{SO}_4^{2-}$ type based on the major cations and anions. The ratios for both cations and anions to the total dissolved solids (TDS) as presented in the Gibb's diagram indicates that rock dominance is the main mechanism controlling groundwater chemistry, having moderate concentration of TDS values.

The concentration of most heavy metals analysed in the groundwater samples was found to be above the standard of the Nigerian Standard for Drinking Water Quality (NSDWQ, 2015). Although, even at higher concentrations iron tends not to be harmful to human health, the concentrations of iron in the groundwater were within the permissible limit of NSDWQ. The

levels of lead (Pb), nickel (Ni), cadmium (Cd), and chromium (Cr) were found to be potentially high, far exceeding the permissible limits of not only NSDWQ but virtually all drinking water guidelines worldwide. Certain health problems such as poisoning, tiredness, irritability, anemia, behavioral changes, and impairment in intellectual functions and convulsions to mention a few associated with the exposure of water with high concentrations of lead have been reported in areas where sulfide-bearing minerals are mined and in numerous communities practicing inappropriate waste disposal.

References

- Aigbedion, I.N and Iyayi, S.E., (2007) Environmental effect of mineral exploitation in Nigeria. *International Journal of Physical Science* Vol. 2 (2) pp033-038
- Baba, A and Gungor, T. (2002). Influence of goldmine on groundwater quality Efemcukuru, Izmir, Turkey, *Environmental Geology*. 41: 621-627
- Barnes I. and Clarke F.E. (1964) *Geochemistry of groundwater in mine drainage problems*, U.S. Geological Survey Prof. Paper 473-A
- Eduvie M. O, Olabode, T and Yaya, O. O. (2003), Assessment of groundwater potentials of Abuja environment, *Proceeding of the 29th international conference held in Abuja, Nigeria*
- Enrich G.H and Meritt. G. L (1969), *Effect of mine drainage on Groundwater*, Volume 7, No.3 pp. 27-32
- Hine Khan, K.N. (2002). *Environmental impact of iron ore mining on the ground water quality and utilization and domestic purposes*. ISAS Shillong proceeding, pp178-189
- Magombedze, C. (2006) *Geochemical Process controlling the generation and environmental impacts of acid mine in Zimbabwe*. PHD dissertation, Norwegian University of Science and Technology.
- Miranda, M and Sauer, A (2010) *Mine the gap: Connecting Water Risks and Disclosure in the Mining*. World Resources Institute: Washington D.C
- Navarro-Torress, V. F., Aduvire, O. and Singh, R.N. (2011). Assessment of natural attenuation of acid mine drainage pollutants in El Bierzo and Odiel basins: A case study. *Journal Of Mining and Environment*. 2 (2): 78-85
- Offodile, M.E. (1992) *An Approach to Groundwater Study and Development in Nigeria*. Mecon Geology and Engineering Services Ltd. Jos
- Piper, A.M (1944). *A Graphic Procedure in the Geochemical Interpretation of Water Analyses*. *Transactions Am. Geophys. Union* 1944, 25, 914-928.
- Todd, D. K. (1980). *Groundwater hydrology* (2nd ed., p. 315). New York: Wiley.

Reduction of the Ash Content of Lafia/Obi by Jigging Operation

O. A. W. Oyeladun¹, D. G. Thomas² and S. Tolu³

¹Department of Metallurgical Engineering Technology, Kaduna Polytechnic, Kaduna

²Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Zaira

³Department of Mineral and Petroleum Resources Engineering, Kaduna Polytechnic, Kaduna

Corresponding Author email: oawoyeladun@gmail.com

Abstract

Reduction of the ash content of Lafia/Obi by jigging carried out. The coal was crushed using sledge hammer and ground using ball mill to 125 μ m. The analysis of the coal sample was carried out using proximate, ultimate analyses and bomb calorimetry method. The proximate analysis revealed that Lafia/Obi sample contain moisture content of 3.80%, volatile matter 35.5 %, ash content 16.6% and fixed carbon content 44.1%. The calorific value of the coal sample was recorded as 26.1 MJ/Kg. The coal was subjected to coal washing to reduce the ash content towards efficient coal properties and clean coal for electricity power generation and metallurgical use. The coal sample underwent jigging operation. The proximate analysis of the concentrate was carried out and it was revealed that the ash content was reduced from 16.6% to 12.0%, thereby, the coal content improved from 44.1% to 61.9% fixed carbon. The ultimate analysis of the clean coal revealed that Lafia/Obi sample contains Carbon of 73.43%, Oxygen 16.43%, Hydrogen 3.80%, and Nitrogen 1.90%, and traces of Sulphur 1.656% using ultimate analysis. The theoretical calculation of calorific value of Lafia/Obi was found to be 27.5MJ/kg. The Lafia/Obi was found to have calorific value of 26.9MJ/Kg using bomb calorimetry method. This indicates that Lafia/Obi coal can be upgraded to rank of bituminous (High Volatile C). It is recommended that Lafia/Obi can be used in cupola furnace.

Keywords: Lafia/Obi, proximate analysis, jigging operation, ultimate analysis, bomb calorimetry, calorific value.

1.0 Introduction

Coal is a naturally occurring sedimentary rock formed from vegetative matter through the process of coalification. This process is driven by the application of pressure and heat, through the application of those agents, vegetative matter is converted to peat, then to lignite and finally to Coal. Increase in heat and pressure as a result of increase in burial depth, progressively changes the rank of the coal from sub bituminous to bituminous and finally to anthracite. The higher the rank of the coal, the lower the moisture and content of volatile matter (Behre, 2006).

The technical problem encountered in combustion are primary concerned with ash-fusion characteristics and viscosity of the molten ash. The behaviours of the molten ash residue at high temperature are critical factor in coal selection for steam power generation because most furnaces are designed to remove ash as powder residue. Coal which has ash that from clinker is usually unsatisfactory in furnaces because it leads to fouling of heat exchanger pipes (USGS 2008) and the furnace

requires cleaning or special furnace designed.

Coal ash is composed primary of oxides of silicon, aluminium, iron, calcium, magnesium, titanium, sodium, potassium, arsenic, mercury and sulphur plus small qualities of uranium and thorium. This reduces the coal spontaneous combustion (Qing-Wei, 2020). Disposal of coal ash is becoming a major issue because of its potential to contaminate surface and ground water with arsenic, born etc. (Mudel et al, 1996, Kim and Kagonich 1999)

It is common to state that coal contain various minerals which are incombustible part of the coal, but technically that minerals matter yields ash on combustion the minerals originated from the vegetal mass from which the coal was formed hence the need for ash content would enhance the efficiency and the economic value of the coal. Therefore, this research focused on the determination and reduction of the ash content of Obi-Lafia Coal.

The scope of this project is limited to determine ash content reduction of Obi/Lafia coal using

Jigging operation in order to enhance the efficiency, suitability and economic value. Then determine the ash content using proximate analysis.

1.1. Types of Coal

As geological processes apply pressure to dead biotic material over time, under suitable conditions, its metamorphic grade or rank increases successively into:

- i. **Peat:** This is an accumulation of partially decayed vegetation or organic matter. It is unique to natural areas called peatlands, bogs, mires, moors, or muskegs (Joosten *et al*, 2002). Sphagnum moss, also called peat moss, is one of the most common components in peat, although many other plants can contribute.
- ii. **Lignite:** Lignite is the lowest rank of coal, most harmful to health when burned, used almost exclusively as fuel for electric power generation. Lignite is a soft, brown, combustible, sedimentary rock formed from naturally compressed peat. It has a carbon content around 25–35%, (EIA, 2020) and is considered the lowest rank of coal due to its relatively low heat content.
- iii. **Sub-bituminous coal:** Sub-bituminous coal is a lower grade of coal that contains 35–45% carbon (Bell, 2011). The properties of this type are between those of lignite, the lowest grade of coal, and those of bituminous coal, the second-highest grade of coal. Sub-bituminous coal is primarily used as a fuel for steam electric power generation. whose properties range between those of lignite and those of bituminous coal, is used primarily as fuel for steam-electric power generation
- iv. **Bituminous coal:** Bituminous coal is a type of coal containing a tar-like substance called bitumen or asphalt. Its coloration can be black or sometimes dark brown; often there are well-defined bands of bright and dull material within the seams. It is typically hard but friable. Its quality is ranked higher than lignite and sub-bituminous coal, but lesser than anthracite. It is the most abundant rank of coal, with deposits found around the world, often in rocks of carboniferous age. Bituminous coal is formed from sub-bituminous coal that is buried deeply

enough to be heated to 85 °C (185 °F) or higher (Bell, 2011). Bituminous coal is used primarily for electrical power generation and in the steel industry. Bituminous coal suitable for smelting iron (coking coal or metallurgical coal) must be low in sulphur and phosphorus (EIA, 2017).

v. **Anthracite coal:** Anthracite is a hard, compact variety of coal that has a submetallic lustre. It has the highest carbon content, the fewest impurities, and the highest energy density of all types of coal and is the highest ranking of coals. Anthracite is the most metamorphosed type of coal, but still represents low-grade metamorphism, in which the carbon content is between 86% and 97% (Bell, 2011).

1.2. Coal Classification by Rank

The following four systems of classification of coals by rank are internationally standardized as follows (Ishii, 2006; Bell, 2011; Zhu, 2014):

- (i) ASTM D 388: Classification of Coals by Rank,
- (ii) International Classification of Hard Coals by Type,
- (iii) International System for Classifying Brown and Lignites,

ISO 2950: Brown Coals and Lignites - Classification by Type on the Basics of Total Moisture Content and Tar Yield (Zhu, 2014) (see Table 1)

1.2. Coal in Nigeria

The major types of coal in Nigeria are Lignite, Sub-bituminous and bituminous (Idris, Onaji, Aberemi, & Aroke, 2016). A little below bituminous, in terms of quality, is sub-bituminous (see Table 2).

1.2. Coal Analysis

Coal analysis techniques are specific analytical methods designed to measure the particular physical and chemical properties of coals (Zhu, 2014). These methods are used primarily to determine the suitability of coal for coking, power generation, production of cast iron or for iron ore smelting in the manufacture of steel. Coal has certain set of physical parameters which are by moisture, volatile content (in terms of

Table 1: The Classification of Coal Base on Rank

Class	Group	Fixed Carbon %	Volatile Matter %	Heating Value (MJ/Kg)
Anthracite	Meta Anthracite	> 98	< 2	
	Anthracite	92 – 98	2 – 8	
	Semi Anthracite	86 – 92	8 – 14	
Bituminous	Low Volatile	78 – 86	14 – 22	
	Medium Volatile	69 – 78	22 – 31	
	High Volatile A	< 69	> 31	> 32.6
	High Volatile B			30.2 – 32.6
	High Volatile C			26.7 – 30.2
Sub- Bituminous	Sub-Bituminous A			24.4 – 26.7
	Sub-Bituminous B			22.1 – 24.4
	Sub-Bituminous C			19.3 – 22.1
Lignite	Lignite A			14.7 – 19.3
	Lignite B			< 14.7

Source: Ishii (2006); Bell (2011); Zhu (2014); MMSD (2012)

Table 2: The Chemical Characteristics of Some Nigerian Coal Deposits

Ore	Parameters					
	Moisture (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Sulphur (%)	Gross Calorific (KJ)
Enugu Coal	6.2	10.1	39.2	44.5	0.8	32, 769.2
Okaba Coal	6.9	7.0	41.0	45.1	1.0	29, 865.6
Orukpa Coal	7.2	8.8	51.9	32.1	0.8	31, 110.0
Ogboyoga Coal	10.6	9.6	41.0	38.8	0.7	20, 449.64
Lafia/Obi	14.3	14.7	31.7	39.3	1.78 – 6.83	36, 087.6

Source: MMSD (2012)

aliphatic or aromatic hydrocarbons) and carbon content. These analyses of coal are proximate and ultimate analysis.

- i. **Moisture Content:** Moisture is an important property of coal, as all coals are mined wet. Groundwater and other extraneous moisture is known as adventitious moisture and is readily evaporated.
- ii. **Volatile Matter:** Volatile matter in coal refers to the components of coal, except for moisture, which are liberated at high temperature in the absence of air. This is usually a mixture of short- and long-chain

hydrocarbons, aromatic hydrocarbons and some sulphur. Volatile matter also evaluates the adsorption application of an activated carbon.

- iii. **Ash Content:** Ash content of coal is the non-combustible residue left after coal is burnt. It represents the bulk mineral matter after carbon, oxygen, sulphur and water (including from clays) has been driven off during combustion
- iv. **Fixed Carbon:** The fixed carbon content of the coal is the carbon found in the material which is left after volatile materials are driven off. This differs from the ultimate

carbon content of the coal because some carbon is lost in hydrocarbons with the volatiles. Fixed carbon is used as an estimate of the amount of coke that will be yielded from a sample of coal.

1.3. Combustion Test

Aside from physical or chemical analyses to determine the handling and pollutant profile of a coal, the energy output of a coal is determined using a bomb calorimeter which measures the specific energy output of a coal during complete combustion (Balachandar et al, 2020). This is required particularly for coals used in steam generation.

1.4. Jig Operation

Jigs are continuous pulsating gravity concentration devices (Halder, 2018). Jigging for concentrating minerals is based exclusively on the differences in density of the particles. The elementary jig (Fig. 2.2) is an open tank filled with water. A thick bed of coarse heavy particles (ragging) is placed on a perforated horizontal jig screen. The feed material is poured from the top. Water is pulsated up and down (the jigging action) by pneumatic or mechanical plunger. The feed moves across the jig bed. The heavier particles penetrate through the ragging and screen to settle down quickly as concentrate. The concentrate is removed from the bottom of the device. The jigging action causes the lighter particles to be carried away by the crossflow supplemented by a large amount of water continuously supplied to the concentrate chamber. Jig efficiency improves with relatively coarse feed material having wide variation in specific gravity. Jigs are widely used as an efficient and economic coal-cleaning device.

1.0 Materials and Methods

2.1. Materials

The material required for this research was about 1 kg of Lafia/Obi coal sample.

2.2. Equipment

The equipment required are Sledge hammer, Ball mill, Pulveriser, Muffle oven, Ceramic Crucible, Carbon-Sulphur analyser, C/H/N Analyzer, jigging machine and weighing machine.

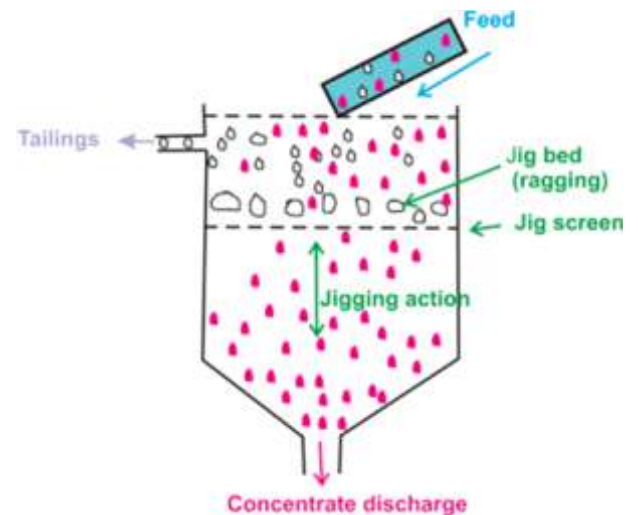


Figure 1: Conceptual Diagram illustrate the basic principles of a jig operation. (Source: Halder, 2018)

2.3. Methods

2.3.1. Collection of Sample and Preparation

The coal samples were collected from Lafia/Obi using grab method. The sample collected was sealed in polythene bag and transferred into polyvinyl chloride (PVC) canisters for Laboratory analyses. The coordinate of the sample area was taken to be 8°14'5.09"N 8°39'20.50"E using GPS (Figure 2).



Figure 2: Map of Nasarawa State indicating Lafia-Obi Coordinate

2.1.1. Preparation of Coal for Analysis and Test

The coal sample from Lafia/Obi deposit sites crushing using sledge hammer and pulverized. The representative head sample was to be

assayed using some of the above-mentioned analytical equipment (SANS standard).

2.1.2. Proximate Analysis: Determination of Moisture, Volatile Matter, Ash and Fixed Carbon of Lafia/Obi Samples.

Procedure

- i. The moisture test was performed by heating 1 gm of coal sample at 104°C to 110°C for 1 hour in an oven and finding the loss in weight in line with SANS 17426 (2006) standard.
- ii. The volatile matter was determined by heating 1 gm of coal sample in a covered crucible at 950°C for 7 minutes and determining loss in weight, from which the moisture content as found from moisture test is deducted.
- iii. Ash content was found by completely burning the sample of coal in a muffled furnace at 700°C to 750°C and weighing the residue. The percentage of fixed carbon is determined by difference when moisture, volatile matter and ash have been accounted for.

2.1.3. Ultimate Analysis: Determination of Total Carbon, Hydrogen, Oxygen, Nitrogen and Sulphur in Lafia/Obi Sample.

- i. **Procedure for Carbon and Sulphur Analysis:** The sample was weighted in ceramic boats and was placed directly in the furnace for combustion. The combustion gases pass through the infrared cells for detection. The signals was evaluated and results was displayed automatically on the screen of computer.
- ii. **Procedure for Carbon, Hydrogen and Nitrogen Analyses:** The sample was heated to a temperature range of 900°C – in accordance with ASTM method D5373 – 08. Combustion products interfere with the subsequent gas analysis will be removed. Oxides of nitrogen (NO₂) was reduced to N₂ before detection. The carbon dioxide, water vapour and elemental nitrogen in the stream was

determined by C/H/N analyser

iii. Procedure for Analysing Coal Samples

Ash Contents: The coal sample was pulverised to fine homogenous size and then was pelletized, packed and labelled. The coal was heated up gradually to 500°C in 1 hour and 750°C in 2 hours (SANS Standard). Heating continues at 750°C until the sample reaches constant weight. The ash produced was allowed to cool, ground to pass 74µm standard sieve, and reignited at 750°C for 1 hour and then was cooled.

2.1.4. Determination of Calorific Value of Coal

The crucible filled with 100 gm of coal was placed in the calorimeter (SANS). The initial temperature of the water was taken and recorded. The sample was ignited using electrical current passed into the crucible to let sample burn in presence of oxygen. The heat released during combustion of the coal was taken by water and hence the temperature was increased. The final temperatures were taken and recorded (Hosokai, 2016).

Higher Calorific Value of coal

$$= (m_1 + m_2) \times (T_c + T_1 + T_2) \times \frac{C_w}{m_f} \quad \text{Equation 1}$$

Where m₁ and m₂ are mass of water in the copper calorimeter and water equivalent of bomb calorimeter respectively; m_c is mass of the coal sample whose calorific value is to be determined; T₁ and T₂ are the final and initial temperature of the water sample. T_c is temperature correction for radiation losses, C_w is specific heat capacity of water.

1.5. Jigging Operation

500 gm of ore sample be used in the preparation of feed for jigging operation. The pulp of 60% water was produced and introduced into the jigging machine using the sieve size of 100µm. The feed material was poured from the top. Water is pulsated up and down (the jigging action) by pneumatic or mechanical plunger.

The feed moves across the jig bed. The heavier particles penetrate through the ragging and screen to settle down quickly as concentrate. The products were overflow (coal concentrate) and underflow (coal tailings). The products were allowed to settle down and dewatered, then dried in an oven for 5 hours at 60°C (Ambros, 2020). Both concentrate and tailings were analyzed using proximate analysis to determine amount of ash removed.

3.0. Result and Discussion

3.1. Proximate Analysis of Lafia/Obi Coal Sample

Table 3 present the result of proximate analysis of Lafia/Obi coal sample as – received.

Table 3: Proximate Analysis of As-received Lafia/Obi Sample

Preparties	Value
Moisture Content (%)	3.8 ± 0.1
Volatile matter, VM (%)	35.5 ± 0.7
Ash Content (%)	16.6 ± 0.3
Fixed Carbon	44.1 ± 0.1
Calorific Value (MJ/Kg)	26.1

The Table 3 revealed proximate of the coal that 16.6% ash content and fixed carbon presented in the Obi/Lafia coal ore. The present of high ash content will reduce the calorific value, hence to increase the calorific value of there must reduction of the ash content. This is in line with report given by MMSD (2012) that the fixed carbon of Obi/Lafia coal is 39.3%.

3.2. Proximate Analysis of As-Processed Lafia/Obi Sample

Table 4 presented the result of proximate analysis of as – processed Lafia/Obi coal sample.

Table 4: Proximate Analysis of As-Processed Lafia/Obi Sample

Preparties	Value
Moisture Content (%)	3.7 ± 0.5
Volatile matter, VM (%)	22.4 ± 0.1
Ash Content (%)	12.0 ± 0.07
Fixed Carbon	61.9 ± 0.6
Calorific Value (MJ/kg)	26.9

The Table 4 presented the result of proximate analysis of Obi/Lafia after jiggling with reduction in the ash content. This shows that the ash content was reduced from 16.6% to 12.0%. This increases the calorific value of coal, hence increases energy released.

Table 5: Ultimate Analysis of As-Processed Lafia/Obi

Element	Cr	Si	Fe	Al	C	O
% Composition	0.02	0.596	1.065	0.046	73.43	16.43
Element	H	N	S	Ca	Ti	V
% Composition	3.8	1.9	1.656	0.676	0.217	0.011

Table 5 present the result of Ultimate analysis of Lafia/Obi. The Ultimate analysis results shows that the sample contain Carbon of 73.43%, Oxygen 16.43%, Hydrogen 3.80%, and Nitrogen 1.90%, and traces of Sulphur 1.656%. The present of carbon shows that there is an increase in the energy make available during combustion (Shao, 2023). The reduction in amount component of ash content, hereby increasing the energy available for work.

3.3. Calorific Value of Coal

The calorific value of coal reveals the energy made available. Theoretical calculation of calorific value of the coal using Dulong's formula is given by (Hosokai, 2016):

$$CV = \frac{1}{100} \left(8080C + 34500 \left(H - \frac{O}{8} \right) + 2240S \right) \text{ kca/kg}$$

... equation 2

Where C = 73.43%, H = 3.80%, O = 16.43% and S = 1.656%

are the % of the corresponding elements in the fuel.

The theoretical calculation of calorific value

$$= 6572.695 \text{ kcal/kg}$$

$$= 6572.695 \times 4.184 \text{ KJ/kg} = 27500.15 \text{ KJ/kg}$$

The coal was found to have calorific value of 27.5MJ/Kg using equation 1. This data is essential for understanding the material's combustion behavior, energy content, and potential applications. This is in line with Zhu (2014) and Madugu (2015).

3.6. Jigging Operation

Table 6 presents the result of jigging operation using jig machine.

Table 6: Product of Jig Operation

Product	Weight (%)	Ash Content (%)	Coal Content (%)
Feed	500	16.6	44.1
Concentrate	300	12.0	61.9
Tailing	120	48.2	45.6

The Table 6 revealed that the coal content improved from 44.1% to 61.9% fixed carbon. This indicates that Lafia/Obi coal can be upgraded to bituminous (High Volatile C). This shows that with the washing of Obi/Lafia Coal, the grade improved tremendously and be used, when blended with other good coal, in cupola furnace for cast iron production (Tercan, 2017).

4.0 Conclusion and Recommendation

4.1 Conclusion

The reduction of ash content of Obi/Lafia coal was carried out. The following conclusions were draw:

- Lafia/Obi sample contains moisture content of 3.8%, volatile matter 35.5%, ash content 16.6% and fixed carbon content 44.1% using proximate analysis;
- Lafia/Obi concentrate contains Carbon of 73.43%, Oxygen 16.43%, Hydrogen 3.80%, and Nitrogen 1.90%, and traces of Sulphur 1.656% using ultimate analysis;
- That the ash content was reduced from 16.6% to 12.0%. and coal content improved from 44.1% to 61.9% fixed carbon.
- The theoretical calculation of calorific value of Lafia/Obi was found to be 27.5MJ/kg. while using bomb calorimetry Lafia/Obi was found to have calorific value of 26.9MJ/Kg
- This indicates that Lafia/Obi coal can be upgraded to bituminous (High Volatile C).

4.2 Recommendation

It is recommended that Lafia/Obi should be subjected to further coal washing to reduce the ash content towards efficient coal properties, clean coal for electricity power generation and to meet up for metallurgical purpose such as blast furnace requirements.

References

- Ambros, W. M. (2020) Jigging: A review of Fundamentals and Future Direction, Journal of Mineral, Vol. 10, Issue 11.
- America Society for Testing and Material 2002. Annual Book of Standards 2000 V.05, 06, 650P.
- American Society FIR Testing and Material (2002). Annual Book of Standards 2002 v.05.06,650p
- American Society FIR Testing and Material (2013). Annual book of ASTM standards Volume 05.06 Gaseous fuels coal and coke; catalyst, bioenergy and industrial chemical from biomass American society for testing and material, 880p.
- Balachandar V., Ramkumar T., Kalidasan B. et al. (2020) Experimental study on ash content & calorific value of coal used in thermal power station, Materials Today: Proceedings.
- Bell D. A Towler B. F and Fan M. (2011) Coal Gasification And Its Applications, Elsevier Inc., pp 1 – 12
- Haldar S. K. (2018): Mineral Processing, In Mineral Exploration (2nd Edition)
- Hosokai S., Matsuoka K., Kuramoto K. and Suzuki Y. (2016) Modification of Dulong's formula to estimate heating value of gas, liquid and solid fuels, Fuel Processing Technology, Vol. 152, Pages 399-405
- Jatau B.S., Amoka I.S., and Oyeladun O. A. W. (2009) Petrological and Proximate analysis of Lafia-coal deposit, Nasarawa state, Central Nigeria. Nigerian Mining Journal Vol.9 No.1 pp41-45.
- Madugu, A. I. (2015): Coal to Power or Coal as an Alternative Source of Energy, Book of

- Proceedings, Nigerian Society of Mining Engineers, Jos.
- Ministry of Mines and Steel Development (MMSD) (2012): Coal Exploration Opportunities in Nigeria.
- Qing-Wei, Yang Xiaoa, Kai-Qi Zhonga , Chi-Min Shud , Hui-Fei Lúa , Jun Denga and Shiliang Wue,(2020) Overview of commonly used materials for coal spontaneous combustion prevention, Elsevier, Fuel Vol.275
- Shao S., Ma B., Wang C., Chen Y. (2023) Thermal Behavior and Chemical Reactivity of Coal Gangue During Pyrolysis and Combustion, Fuel Vol.331, pp 125927
- Tercan, A. E. (2017). Coal Resources Estimation using Gaussian Copula, Internal Journal for Coal Geology.
- Zhu, Q. (2014): Coal sampling and analysis standards, IEA, Clean Coal Centre, London, UK.

Design of Drainage System at Maiganga Coal Mine in Gombe State, North-Eastern Nigeria, Using Pumpsim Software

L. K. Salati and M. Lawal

Department of Mineral and Petroleum Resources Engineering, Kaduna Polytechnic, Kaduna, Nigeria

Abstract

Excessive mine water increases in volume and consequently leads to mine flooding. Flooded pits lead to disruptions in excavation, loading and haulage, while changes in the water catchment area can aggravate conditions that promote flooding accompanied by huge socio-economic consequences. To address the problem, this study undertook a computer - based design of a drainage system at Maiganga Coal Mine, Gombe State, north-western Nigeria, using Pumpsim software. The study involved determining the sources of water inflow into the mine and assessing the presently adopted system using suitable software for the design and simulation of a new drainage system for the mine. Microsoft Excel was used as an interface to analyse, convert and transfer data to Surpac in a usable form, which was then imported and processed the data in a suitable format for modeling. The modelled data was transmitted to pumpsim for eventual development of pipeline system simulation. The design parameters for this study included rainfall catchment surface area, rainfall data and prediction, and calculation of maximum runoff. The study considered heavy rainfall classifications of the study area based on five – year rainfall data with a rainfall plan of 1309.44 mm/day and 40 mm/hour intensity respectively. The study also designed the use of a pervious sump for the collection of runoff water from the catchment area. Two pumps were suggested, one as the main sump pump and the other as a maintenance pump. Construction of two tanks beside the sedimentation pump was also proposed to be 7855.0 m³, each serving as a reserve for excess water collection at the shallow end of the sedimentation. Hence, any potential threat that could trigger flooding in the mine would be practically eliminated by adopting the proposed drainage system.

Keywords: Coal mine; mine flooding; pumpsim; runoff water; drainage system.

1. Introduction

One of the major challenges hindering the development of coal mining is flooding caused by excessive flow of water. As an essential resource, water sustains coal mining operations but also possesses the potential to disrupt the entire production process (Bargawa *et al.*, 2019; Li, 2018). Excess mine water creates an accumulation of mud from being saturated with additional rainwater. Water accumulation, mud layers, mud sediments and wet mining areas are problems that complicate coal mining operations (Bargawa *et al.*, 2019). The inevitable phenomenon of heavy rainfall is also irreversible. Several studies have been developed on mine water related to the potential problem of disruption to coal mining activities (Guo *et al.*, 2019; Sun *et al.*, 2020; Leuenberger *et al.*, 2021; Khan *et al.*, 2020; Stewart, 2020; Wu *et al.*, 2010). Opencast coal mining methods can also trigger the interaction of sulphide minerals,

water and air (Park *et al.*, 2019; Ojonimi *et al.*, 2020), causing acid mine drainage problems. Proper management is required in handling excess mine water efficiently in order to mitigate this problem (Gao *et al.*, 2017; Northey *et al.*, 2019; Punkkinen *et al.*, 2016; Agboola *et al.*, 2020). Hence, accumulation and inundation of water in the mining pits require large-capacity pumps to dewater the mine.

Mine drainage, as an auxiliary function of mine operations serving as a preventive measure for mine flooding (Nganje *et al.*, 2010; Fernandez-Rubio and Lorca, 2006), requires serious attention aimed at properly managing the inflow of water into mines. However, inadequate measures put in place to control excess water ultimately lead to mine flooding and subsequent abandonment (Banks *et al.*, 2019). Therefore, in view of the highlighted challenges confronting coal mining operations, this study attempts to design a computer-aided drainage system for

Maiganga coal mine in Gombe State, using pumpsim software. This is in consideration of the design component as well as exploring real data that provide adequate drainage to accommodate the expected maximum flow and continuous undisrupted mining operation. The design is aimed at determining the sources of water inflow into the mine, assessing the present drainage system practised by the mine management and using pumpsim simulation to design a new drainage system for the mine.

2. Materials and Methods Used

2.1 Description, Location and Accessibility of the Study Area

The study area is located in the Savannah vegetation region characterized by two seasons (Raining and dry season) in a year (Audu *et al.*, 2019). The rainfall can last for about five to six (5-6) months from May/June to October while the dry season from October can last for more than seven months (Ahmad and Ibrahim, 2017). The land is basically used for agricultural purposes for subsistence food and cash crops usually guinea corn, maize, groundnut and deans, animals like goats, cattle and sheep are reared locally to provide milk and meat the people need (Dabara *et al.*, 2019). The drainage system of the area exhibits a dendritic pattern and flow in the South-East direction (Mayomi *et al.*, 2018).

The study area falls within the upper Benue trough, and it is located in the North-East geopolitical zone of Nigeria in the Akko Local Government Area of Gombe State. Maiganga is located near Kumo town and covers a total land area of about 20.265 km² with estimated population of 261,536 inhabitants (Dabara *et al.*, 2019). It is bounded by latitude 09° 15' 13N and 55' 27" N and longitude 11° 08' 40" E and 10°00'00" E with an elevation of 441.65m. It is situated at a distance of 8km from Gombe-Yola highway. The area is accessible by main road that links Tumu, Pindiga and Rijiya communities to Kumo and other towns and villages within the area, including Baddara Burdai, etc.

2.2 Brief Geology of the Study Area

Maiganga lies within the Gombe sandstone, adjacent to and above the Pindiga Formation

(Onoduku *et al.*, 2013). The Pindiga Formation was deposited under marine conditions, while the Gombe sandstone was laid down in non-marine, possibly delta plain condition. Geological mapping shows that actually being of the Upper Continental Sequence, the Gombe Sandstone is a sequence of estuarine and deltaic sandstones, siltstone, shale and ironstones that overlie the sediments of the Zambuk ridge and the Chad Basin in the western part of the region (Ikwuagwu and Uzoegbu, 2017). The restricted outcrop of the Gombe Sandstone suggests that these rocks were deposited in a basin that lay to the west of the Zambuk ridge in late Cretaceous times. Maiganga coal mine exposes the rock units of the Gombe Sandstone. Obviously, the Gombe Sandstone is the formation that hosts most of the coal deposits found in Gombe State. The coal deposit in Maiganga is lignite in the ranking of coal in which it is delta by settling and characterised by lateral discontinuity of lithology, giving rise to lenticular coal seams of about 2 kilometres area extent. The coal seams are separated argillaceous material where three or more seams occur locally; two main seams were discovered which are named "Seam A" and "Seam B" respectively (Ikwuagwu and Uzoegbu, 2017). Figure 1 shows the geological map of Gombe State.

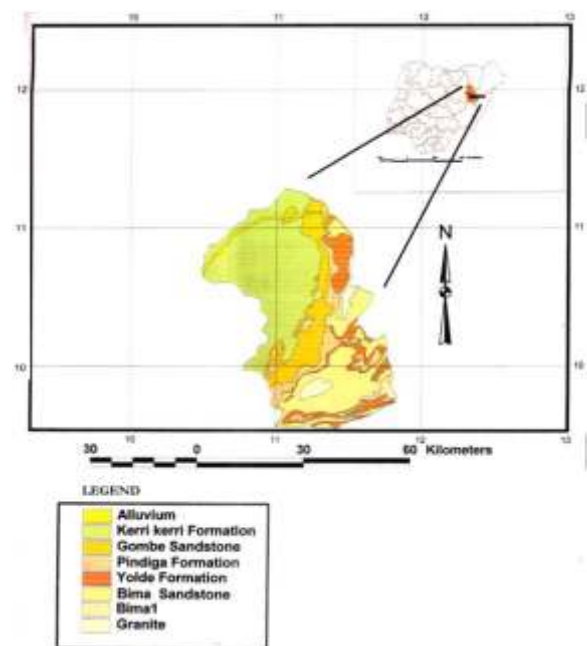


Figure 1: Geological Map of Gombe State

2.3 Field Studies and Data Collection

2.3.1 Assessment of Previous Drainage System

Data on the previous drainage system collected include the following:

- i. Pit pipe type;
- ii. Pit pipe diameter;
- iii. Pit pump Flow Rate;
- iv. Pit pump Operating Hour;
- v. Pit depth;
- vi. Water level during rainy season;
- vii. Water inrush rate into the mine during dry season;
- viii. Sedimentation pond depth;
- ix. Sedimentation pond Average area;
- x. sedimentation pump flow rate;
- xi. Pipe diameter; and
- xii. Pipe type.

2.4 Design Parameters

In the course of the design of the drainage system for this study using rainfall data, runoff, pipe, water pond and pump as design concepts, the following design parameters were considered:

- i. Rainfall catchment Surface area: This is in relation with the topography of the area. The entire area was divided into various catchments depending on the topographic nature of the area which characterizes the runoff nature of the area into the sump.
- ii. Rainfall Data: The rainfall data was collected from the review of related literature and from the Gombe State Ministry of Water Resources, most especially rainfall intensity.
- iii. Prediction and calculation of maximum runoff: The rational method for runoff water was used to estimate peak flow, volume, and rainfall run time distribution. In the hydrological analysis of a study site, there are a number of variable factors that influence the nature of runoff. The rational method for estimating the highest runoff as determined by Ali *et al.* (2021) is as

follows:

$$F/S = Q/P \quad \dots (1)$$

Where $F = P - Q$: is actual retention,

S is potential retention,

Q is actual runoff, and

P is potential runoff that is total rainfall.

A new pipeline system and pump required were designed based on efficiency and economic factors. The pipeline system was developed using pumpsim, a software for pipeline system design and simulation.

From Figures 1 and 2, the satellite imagery of the study area was captured from the field. Relatively, more than twelve thousand sample points data were collected using the google earth, and then transferred and transformed into comma-separated value (CSV) file for topo mapping. The data collected from Figure 1 was used in plotting a topographic map of the area with an illustration of the mine sump, sedimentation pond, wetland and drainage system shown in Figure 3. Figure 5 Indicates the digital terrain model for the area. The data collected were then transformed into universal transverse Mercator (UTM). From Figure 6, Pumpsim software file was used for the design, indicating the sump, pond and pipeline system labelled "Blue" representing the sump, with label "B" representing the sump and a red line indicating the pipeline system.

2.5 Model

The model of the area is one of the requirements used in the pipe simulation software. A digital terrain model (DTM) was eventually plotted in Surpac for pipe system design, modeling and simulation which was then integrated into Pumpsim for the management of the drainage system.

2.6 Pipeline System Design

The pipeline system in the case study was designed as a galvanized steel with a 9-inch diameter and a length of 633 m from the sump to the pond. The pump designed in the sump is a multi-flow pump having a capacity of $0.363194 \text{ m}^3 \text{ s}^{-1}$ and length of 53.5 meters from the pond to the two drums and a pipe of 324.2 m

length to the pond pump station.

2.7 Catchment Area Determination

The catchment area was divided into three (see Table 3). The determination of the runoff water coefficient in the mining area is influenced by several factors, including soil surface conditions. Each soil surface has a different runoff coefficient, which is calculated by the rational formula (see Table 6).

2.8 Calculations of Pump Capacity Design and Maximum Runoff

The procedure for the design and specifications of pump capacity and calculation of water inflow/outflow culminating in the eventual calculation of maximum runoff in the pit considered important data. To determine the total daily inflow of water, the summation of rainwater inflow into the sump and daily water to be pumped out was considered, thereby making the calculated total water inflow to be 26149.9392 m³ per day. According to Carravetta *et al.* (2017), the minimum pump efficiency index standard is greater than 40. Thus, Sahoo *et al.* (2014) posited that the minimum required pump flow rate is:

$$Q = \frac{\text{Total water inflow}}{\text{Maximum Daily Pump Working Hours}} \quad \dots(2)$$

The pump capacity required is also determined, as described by Jardon *et al.* (2013), as follows:

Maintenance pump capacity >25% capacity of pump ... (3)

So, sedimentation pond capacity requirement is:

= (Total Daily pit inflow + Total pond runoff) x maximum raining day ... (4)

(Zapico *et al.*, 2021).

The total pond/drum capacity required is determined to be 11,086 m³.

Hence, the total pond/drum capacity required is calculated to be 11,086 m³.

3. Discussion of Results

From Table 1, the global positioning system (GPS) coordinates indicate the position of Maiganga coal mine. The previous mine drainage was assessed and the result obtained was tabulated in Table 2 and illustrated in Figure

1. Thus, it was found that the average inflow of water during the dry season is 240,000 litres, and this flows into the pit from the water bearing zone. The pipe drainage information thus provided in this regard gives further survey data about the study area.

As shown in Table 3 as well as Figures 2, 3 and 4, the catchment areas within mines have been categorized and recognized as "A", "B" and "C" respectively. From the rainfall data presented, the types of soil in the area were identified, while the surface runoff was determined. Also as shown in Table 4, the mean values obtained from the meteoric report on the climate conditions of Kumo local government area of Gombe State, where Maiganga coal mine is located, provided useful hints on the calculation and determination of catchment areas among other benefits. From Table 5, the run-off Coefficient Table McCuen (2017) was used in computing the run-off for soil types in the study area. Hence, the total rainfall inflow into the pit was found to be the sum of run off flow into the mines A and B which is 0.299328 m³/per second.

The pit run off was also calculated to be 0.299328 m³/s and total run off of the sedimentation to be 0.3914 m³/s. The amount of water required to be removed was calculated to be 25861.94 m³ per day, while the total water accumulation in the pit was determined to be 26149.9392 m³ per day. A digital terrain model (DTM) was eventually plotted in Surpac for pipe system design, modeling and simulation, and then integrated into Pumpsim for the management of the drainage system. Hence, the designed drainage system for Maiganga coal mine is expected to adequately provide optimum dewatering of the mining pits and prevent it from being flooded. The design, therefore, suggested two tanks of 7855 m³ of dimension 3142 m² to be fixed in any available space, though it was fixed at the extreme end of the pond in the design as shown in Figure 7.

4 Conclusion and Recommendation

From the results of this study, the study area has been identified as having heavy rainfall classifications based on rainfall data for the period of five years with rainfall plan of 1309.44 mm/day and rainfall intensity of 40 mm/hour.

Table 1: The GPS coordinates of the study area

S/n	Description of the area	Relative Coordinate	
		Longitude	Latitude
1	Mine area	11° 8'47.54"E	9°59'18.13"N
2	Administrative Building	11° 9'13.62"E	9°59'24.62"N
3	Sedimentation pond	11° 9'5.81"E	9°59'14.21"N
4	Coal Stack	11° 9'8.23"E	9°59'20.12"N
5	Wetland	11° 9'9.20"E	9°59'7.55"

Table 2: Maiganga coal mine drainage data

S/No	Mines Internal Parameters	Result
1	Pit Pipe type	Iron pipe
2	Pit PIPE diameter	9-inch Pipe
3	Pit Pump Flow Rate	12,000LT/hour
4	Pit Pump Operating Hour	20 hours daily
5	Water level during rainy season	-
6	Pit depth	35 m
7	Pipe length from the sump to the sedimentation area.	633 m
Mines External Parameters		
8	Sedimentation pond departmentalization	8 m
9	Sedimentation pond average area	58,646 m ²
10	Sedimentation pump flow rate;	12,000LT/Hour
11	Pipe diameter	8-inch pipe
12	Pipe type;	Iron pipe.
13	Pipe Length	130 m

Table 3: Catchment area within research area

s/no	Catchment Area	Area, A (m ²)	Area, A (Ha)
1	A	124,145	12.4
2	B	256,903	25.7
3	C	114,876	11.5

Table 4: Mean values of meteoric report on the climate condition of Maiganga coal mine

Year	Rainfall (mm)	Relative humidity (%)
2015	1006.00	10665.40
2016	2158.00	16160.20
2017	1258.00	14253.00
2018	1147.00	1641.40
2019	978.20	21532.60
Average	1309.44	

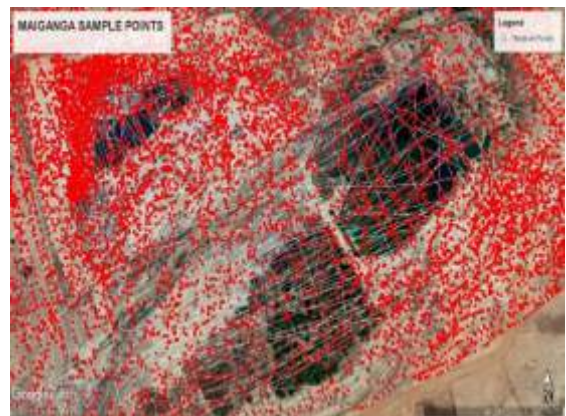
Table 5: Run-off coefficient

Run-off Coefficient (C)															
		Soil Group A			Soil Group B					Soil Group C			Soil Group D		
Slope :		< 2%	2-6%	> 6%	< 2%	2-6%	> 6%	Slope :		< 2%	2-6%	> 6%	< 2%	2-6%	> 6%
Forest		0.08	0.11	0.14	0.10	0.14	0.18	Forest		0.12	0.16	0.20	0.15	0.20	0.25
Meadow		0.14	0.22	0.30	0.20	0.28	0.37	Meadow		0.26	0.35	0.44	0.30	0.40	0.50
Pasture		0.15	0.25	0.37	0.23	0.34	0.45	Pasture		0.30	0.42	0.52	0.37	0.50	0.62
Farmland		0.14	0.18	0.22	0.16	0.21	0.28	Farmland		0.20	0.25	0.34	0.24	0.29	0.41
Res. 1 acre		0.22	0.26	0.29	0.24	0.28	0.34	Res. 1 acre		0.28	0.32	0.40	0.31	0.35	0.46
Res. 1/2 acre		0.25	0.29	0.32	0.28	0.32	0.36	Res. 1/2 acre		0.31	0.35	0.42	0.34	0.38	0.46
Res. 1/3 acre		0.28	0.32	0.35	0.30	0.35	0.39	Res. 1/3 acre		0.33	0.38	0.45	0.36	0.40	0.50
Res. 1/4 acre		0.30	0.34	0.37	0.33	0.37	0.42	Res. 1/4 acre		0.36	0.40	0.47	0.38	0.42	0.52
Res. 1/8 acre		0.33	0.37	0.40	0.35	0.39	0.44	Res. 1/8 acre		0.38	0.42	0.49	0.41	0.45	0.54
Industrial		0.85	0.85	0.86	0.85	0.86	0.86	Industrial		0.86	0.86	0.87	0.86	0.86	0.88
Commercial		0.88	0.88	0.89	0.89	0.89	0.89	Commercial		0.89	0.89	0.90	0.89	0.89	0.90
Streets: ROW		0.76	0.77	0.79	0.80	0.82	0.84	Streets: ROW		0.84	0.85	0.89	0.89	0.91	0.95
Parking		0.95	0.96	0.97	0.95	0.96	0.97	Parking		0.95	0.96	0.97	0.95	0.96	0.97
Disturbed Area		0.65	0.67	0.69	0.66	0.68	0.70	Disturbed Area		0.68	0.70	0.72	0.69	0.72	0.75

Source: (McCuen, 2017)

Table 6: Rainfall Debit Calculation for the Study Area

s/no	Catchment Area	Length	Area, A (Ha)	Slope	I* (mm/hour)	C	Q (m3/s)
1	A	752	12.4	12%	40	0.72	0.099279
2	B	500	25.7	4%	40	0.7	0.200049
3	C	108	11.5	8%	40	0.72	0.092074
Pit Run-Off							0.299328
Total Run-off accumulation							0.3914

**Figure 1: The Satellite Imagery of Maiganga Coal Mines****Figure 2: The Satellite Image of Maiganga Coal Mines indicating point of interpolation for topographic mapping.**

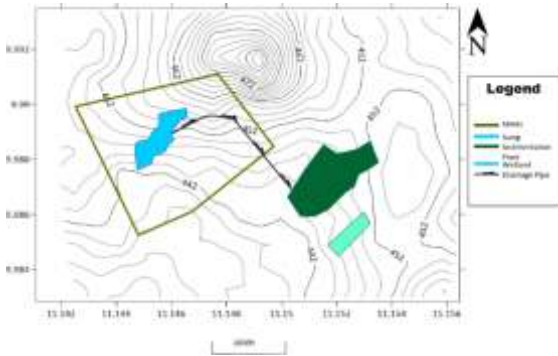


Figure 3: Contour Maps with the Detail's Illustration of the Pit Sump the Sedimentation Pond Drainage and Wetland.

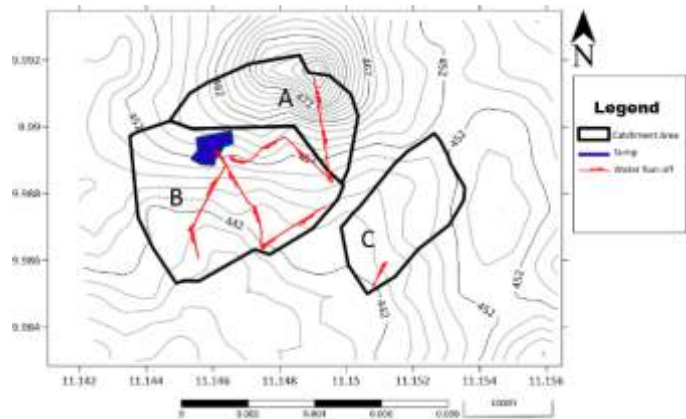


Figure 4: Catchment area within the Mines

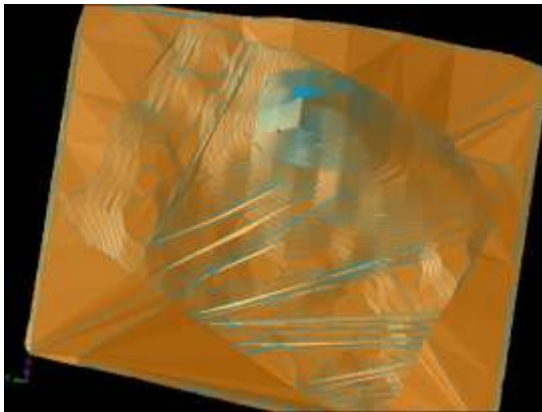


Figure 5: Digitalized Terrain Model of Maiganga Coal Mines using Surpac

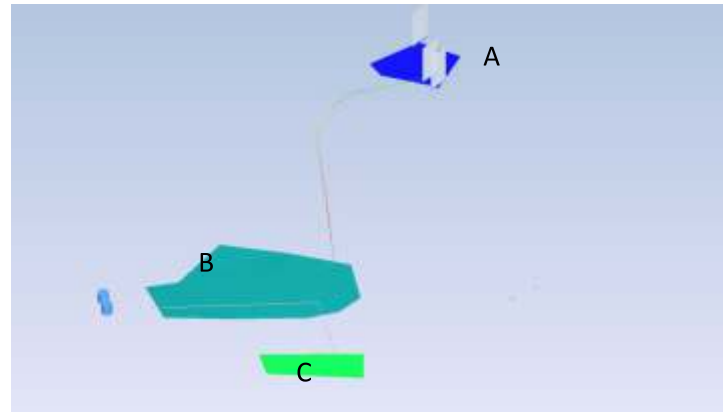


Fig. 6: A Digital Terrain Model File Indicating the Sump, Pond and Pipeline System

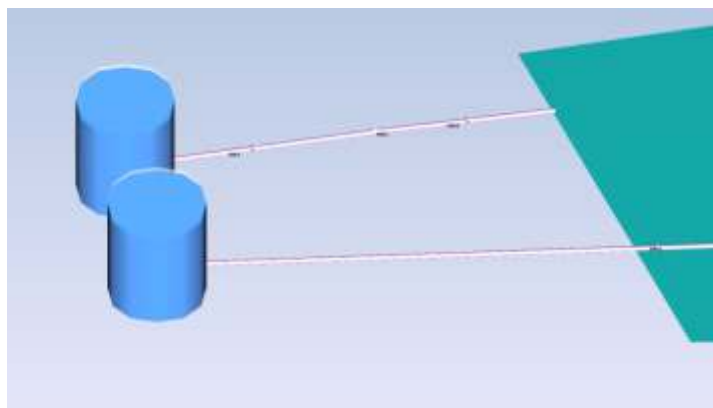


Fig. 7: Proposed Tanks for Pond Reserve Capacity

The study designed the use of pervious sump for the collection of runoff water from the catchment area. A digital terrain model (DTM) was eventually plotted in Surpac software for pipe system design, modeling and simulation, and then integrated into Pumpsim software for the management of the drainage system. The study, thus, suggested the use of two pairs of pumps, one as the main pump and the other as a

maintenance pump, with the construction of two tanks beside the sedimentation pump each with a dimension of 7855.0m^3 . This would serve as a reservoir for excess water collection at the shallow end of the sedimentation. Hence, it is recommended that other design approaches could be tried using different software.

Acknowledgements

The authors acknowledge the contribution and

assistance provided by the management of Maiganga Coal Mine Manager and engineers in the site. All the authors whose works have been used as references are equally acknowledged and appreciated.

References

- Agboola, O., Babatunde, D. E., Fayomi, O. S. I., Sadiku, E. R., Popoola, P., Moropeng, L., Yahaya, A. & Mamudu, O. A. (2020). A Review on the Impact of Mining Operation: Monitoring, Assessment and Management. *Results in Engineering*, 8, 1-23.
- Ahmad, Y. U. & Ibrahim, Y. (2017). X-Raying Rainfall Pattern in Gombe State over the Last Three Decades. *IOSR Journal of Humanities and Social Science*, 22 (6), 67-75.
- Ali, A. A. M., Al-Thamiry, H. A. & Alazawi, S. A. (2021). Estimation of Runoff for Goizha-Dabashan Watershed with Aid of Remote Sensing Techniques. *Journal of Engineering*, 17 (2), 306-320.
- Audu, H. O., Bibi, U. M., Garba, B. G., Ibrahim, A. K., Hussaini, A., Tarki, S. K. & Bulus, B. G. (2019). Determination of Onset, Cessation of Rains and Hydrological Growing Season in Dadin Kowa and Gombe for Agricultural Planning. *Nigerian Agricultural Journal*, 50 (1), 133-141.
- Banks, D., Athresh, A., Al-Habaibeh, A. & Burnside, N. (2019). Water from Abandoned Mines as a Heat Source: Practical Experiences of Open- and Closed-loop Strategies, United Kingdom. *Sustainable Water Resources Management*, 5, 29-50.
- Bargawa, W. S., Sucahyo, A. P. A. & Andiani, H. F. (2019). Design of Coal Mine Drainage System. *E3S Web of Conferences*, 76, 04006, 1-6.
- Carravetta, A., Fecarotta, O., & Conte, M. C. (2017). Minimum Efficiency Index: testing its performance, World Pumps, Minimum Efficiency Index: testing its performance, *World Pumps*, 2017 (4), 34-37.
- Dabara, D. I., Lawal, O. K., Chiwuzie, A., Omotehinshe, O. J. & Soladoye, j. O. (2019). Land Tenure Systems and Agricultural Productivity in Gombe Nigeria. *Madridge Journal of Agriculture and Environmental Sciences*, 2 (1), 51-59.
- Fernandez-Rubio, R. and Lorca, D. F. (2006). Mine Water Drainage. *Mine Water and the Environment*, 12, 107-130.
- Gao, L., Bryan, B. A., Liu, J., Li, W., Chen, Y., Liu, R. & Barrett, D. (2017). Managing Too Little and Too Much Water: Robust Mine-water Management Strategies under Variable Climate and Mine Conditions. *Journal of Cleaner Production*, 162, 1009-1020.
- Guo, W., Guo, M., Tan, Y., Bai, E. & Zhao, G. (2019). Sustainable Development of Resources and the Environment: Mining-Induced Eco-Geological Environmental Damage and Mitigation Measures — A Case Study in the Henan Coal Mining Area, China. *Sustainability*, 11, 4366, 1-34.
- Ikwuagwu, C. S. & Uzoegbu, M. U. (2017). The Maiganga Coal Deposit: Bituminous, Sub-Bituminous or Lignite? *IOSR Journal of Applied Geology and Geophysics*, 5 (1), 67-74.
- Jardon, S., Ordonez, A., Alvarez, R., Cienfuegos, P. & Loreda, J. (2013). Mine Water for Energy and Water Supply in the Central Coal Basin of Asturias (Spain), *Mine Water Environ*, 2, 139-151.
- Khan, A. J., Akhter, G., Gabriel, H. F. & Shahid, M. (2020). Anthropogenic Effects of Coal Mining on Ecological Resources of the Central Indus Basin, Pakistan. *International Journal of Environmental Research and Public Health*, 17, 1255, 1-18.
- Leuenberger, A., Winkler, M. S., Cambaco, O., Cossa, H., Kihwele, F., Lyatuu, I., Zabre, H. R., Farnham, A., Macete, E. & Munguambe, K. (2021). Health Impacts of Industrial Mining on Surrounding Communities: Local Perspectives from Three Sub-Saharan African Countries. *PLoS ONE*, 16 (6), 1-23.
- Li, P. (2018). Mine Water Problems and Solutions in China, *Mine Water and the Environment*, 37, 217-221.
- Mayomi, I., Gideon, D. & Abashiya, M. (2018). Analysis of the Spatial Distribution of Geology and Pedologic Formations in Gombe State, North Eastern Nigeria. *Journal of Geography and Geology*, 10 (1), 83-108.
- McCuen, R.H. (2017). *Hydrologic Analysis and Design*. 4nd Edition, Prentice-Hall.
- Nganje, T. N., Adamu, C. I., Ntekim, E. E. U., Ugbaja, A. N., Neji, P. & Nfor, E. N. (2010). Influence of Mine Drainage on Water Quality

- along River Nyaba in Enugu South-Eastern Nigeria. *African Journal of Environmental Science and Technology*, 4 (3), 132-144.
- Northey, S. A., Mudd, G. M., Werner, T. T., Haque, N. & Yellishetty, M. (2019). Sustainable Water Management and Improved Corporate Reporting in Mining. *Water Resources and Industry*, 21, 1-20.
- Ojonimi, T. I., Asuke F., Onimisi, M. A., Onuh, C. Y. & Tshiongo-Makgwe, N. (2020). Coal Mining and the Environmental Impact of Acid Mine Drainage (AMD): A Review. *Nigerian Journal of Technology*, 39 (3), 738-743.
- Onoduku, U. S., Okosun, E. A. & Akande, W. G. (2013). An Assessment of the Hydrocarbon Potential of the Gombe Formation, Upper Benue Trough, Northeastern Nigeria: Organic Geochemical Point of View. *Earth Science Research*, 2 (2), 203-213.
- Park, J., Kwon, E., Chung, E., Kim, H., Battogtokh, B. & Woo, N. C. (2019). Environmental Sustainability of Open-Pit Coal Mining Practices at Baganuur, Mongolia. *Sustainability*, 12, 248, 1-20.
- Punkkinen, H., Räsänen, L., Mroueh, U. M., Korkealaakso, J., Luoma, S., Kaipainen, T., Backnäs, S., Turunen, K., Hentinen, K., Pasanen, A. Kauppi, S., Vehviläinen, B. & Krogerus, K. (2016). Guidelines for Mine Water Management. *VTT Technology*, 266, 1-172.
- Sahoo, L. K., Bandyopadhyay, S. & Banerjee, R. (2014). Water and Energy Assessment for Dewatering in Opencast Mines, *Journal of Cleaner Production*, 84, 736-745.
- Stewart, A. G. (2020). Mining is Bad for Health: A Voyage of Discovery. *Environmental and Geochemical Health*, 42, 1153-1165.
- Sun, W., Song, X., Zhang, Y., Chiew, F., Post, D., Zheng, H. & Song, S. (2020). Coal Mining Impacts on Baseflow Detected using Paired Catchments. *Water Resources Research*, 56, 1-15.
- Wu, Q., Hu, B. X., Wan L. & Zheng, C. (2010). Coal Mine Water Management: Optimization Models and Field Application in North China. *Hydrological Sciences Journal – Journal des Sciences Hydrologiques*, 55 (4), 609-623.
- Zapico, I., Laronne, J. B., Meixide, C., Castillo, L. S. & Duque, J. F. M. (2021). Evaluation of Sedimentation Pond Performance for a Cleaner Water Production from an Open Pit Mine at the Edge of the Alto Tajo Natural Park, *Journal of Cleaner Production*, 280 (2),

Statistical Distribution of Major and Trace Elements in Stream Sediments Tributaries into River Oyun and River Awun, Kwara State, Northcentral Nigeria

¹A. J. Oyetunde and ²Y. S. Agunleti

¹Ibrahim Badamasi Babangida University, Lapai, Niger State

²Edulong Digital School of Mines and Geosciences, Abuja*

(*edulongschool @ gmail.com)

Abstract

The statistical investigation of the study area gave a quick insight to the elemental distribution of elements in stream sediments from the area. The methodology used in the sampling was based on sampling density of 1:28km² which involved the selection of points based on the catchment size of streams. First and second order streams were selected and each sample point is designed to represent a drainage catchment size in the range of 10-25km² offering a reasonable spatial distribution across the study area. The data generated from fieldwork and laboratory analysis was used in statistical computations of mean, minimum, maximum, standard deviation, crustal abundance and background values for some selected elements. Anomalous values within the data set were defined using the Crustal Abundance and Calculated Background values. These values are chosen as a threshold to define outliers from the data set. The statistics of regression coefficients show that elemental geochemical variables such as Au, As, Ce, La, Li, Pb, Th and Ag have a direct relationship in the stream sediments. The regression coefficients show that gold (Au) has a statistically significant at 0.265 with 0.001 ppm average value, arsenic (As) at 0.04 having average value of 0.39 ppm. Cerium (Ce) has statistical significance of 0.087 with average value of 115.79 ppm, Lanthanum (La) is 0.4407 with average value of 51.65 ppm. Lithium (Li) has average value of 3.15 ppm with statistical significance of 0.3172, lead (Pb) is 0.0836 with average value of 11.07 ppm. Thorium (Th) has statistical significance of 0.9529 with average value of 13.15 ppm while silver (Ag) has statistical significance of 0.8892 with average value of 0.02 ppm.

Keywords: Statistics, Elemental geochemical variables, Average, Background, Drainage, Tributary.

1.0. Introduction

The focus on how to locate and develop metalliferous deposits in the country has taken a centre stage. Geochemical studies have, for long, played a major contribution to mineral exploration programs from regional and reconnaissance to deposit scales. Therefore, statistical investigation of elemental distribution in stream sediments from the study gives a quick insight to mineralization potential. Gold is one of the most important elements targeted during stream sediments studies. Nonetheless, it is more effective to analyze for the spatial distribution of a suite of elements than the gold alone (Ali *et al.*, 2006; Embui *et al.*, 2013; Suh *et al.*, 2006). Other elements, such as Cu, As, Zn, Fe, Pb, W usually occurs in association with gold. This suggests that gold is associated with chalcopyrite, arsenopyrite, sphalerite, pyrite, galena, and scheelite, respectively, in hydrothermal veins. Stream sediments have

been successfully used in many prospecting projects during recent years in Africa (Salminen *et al.*, 2008).

Multivariate data analyses such as factor analysis, cluster analysis, and correlation analysis have been successfully used to analyze stream sediment geochemical data to identify threshold values by (Harris *et al.*, 2000; Xu and Cheng, 2001; Grunsky, 2010; Yilmaz, 2007; Salminen *et al.*, 2008; Cheng *et al.*, 2011; Embui *et al.*, 2013; Mimba *et al.*, 2014; Ghadimi *et al.*, 2016) and multifractal models by Carranza (2010). Recent works on stream sediment geochemistry reconnaissance survey have received greater attention in Nigeria as a quick study for potential mineralization by junior exploration companies and artisanal miners.

1.1. Location of the Study Area

The study area is located in Kwara State and bounded by longitudes (4°30'00"N to

4°45'00"N) and latitudes (8°30'00"E to 8°45'00"E). Prominent towns and villages within the study area include Shao, Ariori, Oke Oyi, Jodoma, Babadudu, Budo- Ayan and Oloru just to mention a few. Accessibility within the study area is entirely fair enough with major roads running North - South passing through the investigated area. Main paths are also available running from one settlement to another. Areas where there are no roads, the footpaths and bush paths were been made use of in-order to access out targets. To complement these, motor bikes were also engaged for quick accessibility.

The study area is characterized by a fairly dense network of rivers and streams. The drainage pattern (Figure 1) in the study area is fairly dendritic apparently in response to the uneven nature of the topographic expression of the landforms features that underline the area. However, a few of the rivers and their tributaries in the area form trellis drainage patterns. The streams are mostly seasonal and flow mainly during the rainy season.

2.0. Methodology

After a detailed desktop study from the

drainage pattern of the study area, selections of first and second order stream were focused on and in carrying this out, samples were collected from both the active channels and the curvatures upstream (Figure 2). Collapsed bank materials were avoided. Samples were taken after scraping off surface materials. Representative composite samples from the sites in the stream bed (over a length of about 50 m) were collected using the shovel. Care was taken to avoid digging into the bedrock. Stream sediments were collected upstream. Enough coarse-grained materials were collected into a plastic pan, enough to yield a minimum of 0.5kg <0.150mm material (dry weight).

A total of thirty-eight (38) selected representative samples of stream sediments were analyzed for major and trace element contents. All the samples collected after sampling exercise were conveyed to National Geosciences Research Laboratory (NGRL) at Kaduna for proper sun drying, packaging and pulverization. The samples were thereafter packaged and shipped to MS Analytical, Langley Township, Canada for geochemical analysis.

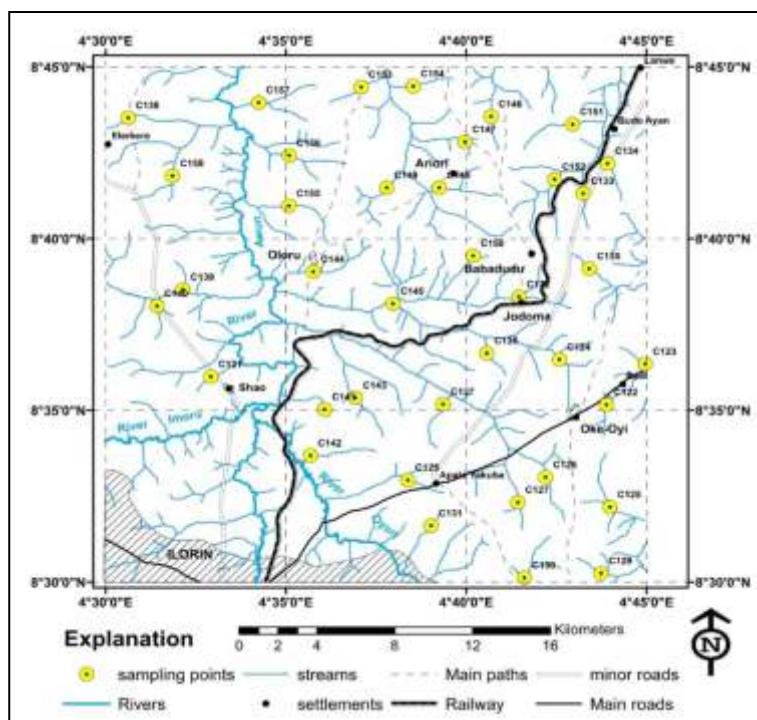


Figure 2: Sample collection and wet sieving in the field.

Figure 1: Map of the study area showing drainage pattern and stream sediments sample points

The analytical techniques for the soil were performed on the powdered samples by inductively coupled Plasma- Mass Spectrometry (ICP - MS). Non- parametric method was used for statistical distribution of the variables determined by chemical analyses to evaluate the main statistical characteristics of the individual data populations using again the Minitab 17 Software. R-mode factor analysis (FA) was applied to process logarithmic data through varimax- raw rotational technique. As a multivariate method, it facilitates the reduction, transformation, and organization of the original data leading to a simple form of the factor model. Factor analysis was also used to create a new set of uncorrelated variables which are the linear combinations of the original ones. The theoretical details of FA are given by Johnson (1998).

3.0. Results

Major elements in stream sediments from the study area are presented in (Table 1) and basic statistical parameters of trace elements in the stream sediments are presented in (Tables 2). Correlation analysis for eight elements is presented in (Table 3) and factor analysis performed on same trace elements (Table 4). Graphical presentation of averages of major elements (%) in stream sediments from the study area are presented in Figures 1 and 2.

4.0. Discussion

The statistics of major elements and other trace elements in stream sediments from the study area were carried out to elucidate their implication for mineralization (economic minerals) worthy for further exploration and environmental implication for elevated ones. Results shows that magnesium ranges from 0.01-0.47 %, sodium ranges from 0.01-0.06 %, aluminium ranges from 0.31-3.01 %, calcium ranges from 0.02-0.39 %, iron ranges from 0.65-3.02 %, potassium ranges from 0.05-0.44 % and sulphur is fixed at 0.01 detection limit. The content of phosphorus in the stream sediments ranges from 38-835 ppm, manganese ranges from 93-1471 ppm, molybdenum ranges from 1.31-7.23 ppm, copper ranges from 2.6-26.3 ppm, boron ranges from 5-18 ppm and zirconium ranges from 4-47 ppm.

The statistics of regression coefficients show that operational geochemical variables such as Au, As, Ce, La, Li, Pb, Th and Ag has a direct relationship in the stream sediments.

The regression coefficients show that gold (Au) has a statistically significant at 0.265 with 0.001 ppm average value. The statistical significance of arsenic (As) in the stream sediments is placed at 0.04 having average value of 0.39 ppm. Cerium (Ce) has statistical significance of 0.087 with average value of 115.79 ppm. The statistical significance of Lanthanum (La) is 0.4407 with average value of 51.65 ppm. Lithium (Li) has average value of 3.15 ppm with statistical significance of 0.3172. The statistical significance of lead (Pb) is 0.0836 with average value of 11.07 ppm. Thorium (Th) has statistical significance of 0.9529 with average value of 13.15 ppm. Silver (Ag) has statistical significance of 0.8892 with average value of 0.02 ppm.

Basic statistical parameters that were determined on the basis of chemical analyses of 38 stream sediments samples revealed that median and arithmetic mean for the samples is considerably different from each other and this indicates a log-normal distribution. Cerium (Ce) and Lanthanum (La) show a log-normal distribution having high anomaly contrasts. Ag log-normal frequency distribution of the elements reveals a positively skewed distribution. Skewness and kurtosis coefficients for Au, As, Ce and Li are considerably higher when compared to element such as Ag. Gold (Au) and Arsenic (As) which show slightly high skewness and kurtosis coefficients are concluded to be due to the presence of multi-mineralization sources.

Elements that correlate with each other in the stream sediment samples from the study area were also investigated using statistical correlation to check for inter-element relationship. Pearson correlation analysis was performed for Au, As, Ce, La, Li, Pb and Th. From the correlation analysis, Au shows a high correlation only with La ($r = 0.332$) and Ag ($r = 0.291$) but with negative correlation with Th ($r = -0.002$). Other element pairs with high positive r values include As- (Ce, Pb, La, Li), Ce-

Table 1: Major elements contents in stream sediments from the study area

Sample I.D.	Mg (%)	Na (%)	Al (%)	Ca (%)	Fe (%)	K (%)	S (%)	P (ppm)	Mn (ppm)	Mo (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
C121	0.02	0.01	0.6	0.03	1.15	0.11	0.01	65	180	5.29	5.4	5	14
C122	0.03	0.02	0.48	0.04	1.05	0.13	0.01	50	166	6.06	3.6	5	5
C123	0.47	0.05	2.04	0.39	2.68	0.14	0.01	57	628	3.16	18	5	26
C124	0.1	0.02	1.07	0.11	1.15	0.1	0.01	52	195	4.8	5.6	5	11
C125	0.08	0.01	3.01	0.17	3.02	0.25	0.01	763	226	5.11	15.1	5	47
C126	0.03	0.01	0.61	0.03	0.99	0.08	0.01	88	232	3.63	5.2	5	7
C127	0.03	0.01	0.73	0.04	1.07	0.09	0.01	138	194	6.37	5.6	5	14
C128	0.06	0.02	0.62	0.05	2.08	0.12	0.01	89	776	3.08	5.5	5	10
C129	0.03	0.01	0.6	0.05	1.43	0.09	0.01	134	511	6.45	5.7	5	9
C130	0.02	0.02	0.68	0.03	1.35	0.14	0.01	133	154	7.08	5.6	5	19
C131	0.04	0.01	0.59	0.03	1.09	0.12	0.01	96	188	4.02	6	5	9
C132	0.03	0.01	0.75	0.03	1.43	0.09	0.01	131	142	5.14	5.1	5	19
C133	0.02	0.02	0.39	0.03	0.69	0.07	0.01	81	134	4.66	2.8	5	6
C134	0.02	0.02	0.38	0.03	0.89	0.09	0.01	56	185	4.62	3	5	5
C135	0.02	0.01	0.52	0.02	1.14	0.08	0.01	61	93	4.1	3.4	10	5
C136	0.02	0.01	0.35	0.03	0.76	0.06	0.01	72	130	3.1	3.5	5	6
C137	0.01	0.01	0.32	0.02	0.66	0.09	0.01	66	107	3.32	2.6	5	8
C138	0.07	0.01	0.72	0.07	1.14	0.13	0.01	137	325	4.73	5.7	11	15
C139	0.06	0.01	0.51	0.04	0.78	0.11	0.01	102	132	1.31	3.4	5	11
C140	0.28	0.03	1.48	0.27	2.85	0.35	0.01	835	723	4.7	13.1	16	28
C141	0.03	0.02	1	0.12	2.76	0.14	0.01	164	235	2.58	9	13	35
C142	0.03	0.02	0.94	0.09	2.54	0.16	0.01	170	678	5.32	8.6	11	30
C143	0.02	0.01	0.66	0.05	1.77	0.11	0.01	148	233	3.72	6.1	12	17
C144	0.04	0.02	0.59	0.06	1.07	0.13	0.01	100	230	4.43	4.2	12	13
C145	0.18	0.04	0.82	0.23	1.47	0.12	0.01	403	338	3.54	9.6	13	17
C146	0.44	0.06	1.76	0.23	2.84	0.44	0.01	114	1471	3.09	26.3	18	43
C147	0.04	0.01	0.63	0.06	1.04	0.06	0.01	75	201	6.83	5.4	5	7
C148	0.03	0.02	0.5	0.05	1.34	0.06	0.01	65	289	3.84	4	12	6
C149	0.08	0.04	0.94	0.1	2.08	0.08	0.01	52	608	3.6	6.3	11	15
C150	0.02	0.01	0.37	0.03	0.87	0.05	0.01	89	111	3.51	3.3	5	6
C151	0.05	0.02	0.55	0.06	1.01	0.12	0.01	125	267	5.19	3.6	13	8
C152	0.03	0.02	0.38	0.05	0.87	0.08	0.01	98	184	6.24	3.1	5	6
C153	0.05	0.02	0.73	0.1	1.94	0.07	0.01	84	659	7.23	7.6	5	13
C154	0.01	0.01	0.34	0.02	0.65	0.07	0.01	57	123	6.4	2.6	5	4
C155	0.01	0.01	0.31	0.02	0.71	0.09	0.01	38	170	4.54	4.5	5	9
C156	0.05	0.02	0.66	0.07	1.48	0.12	0.01	117	207	6.2	6.1	5	16
C157	0.02	0.02	0.48	0.04	1.21	0.1	0.01	100	297	5.6	4	14	8
C158	0.04	0.01	0.67	0.04	1.67	0.11	0.01	202	480	3.42	4.9	5	13
Min.	0.01	0.01	0.31	0.02	0.65	0.05	0.01	38	93	1.31	2.6	5	4
Max.	0.47	0.06	3.01	0.39	3.02	0.44	0.01	835	1471	7.23	26.3	18	47

Table 2: Basic statistical parameters of some trace elements in the study area

Elements	No	Range	Min.	Max.	Mode	Median	Mean	Std.D	Skewness	Kurtosis
Au	38	0.095	0.000	0.095	0.000	0.000	0.003	0.016	5.931	35.646
As	38	1.300	0.200	1.500	0.300	0.300	0.395	0.231	3.191	14.251
Ce	38	439.100	38.640	477.740	0.000	88.390	116.610	89.819	2.660	8.062
La	38	132.700	16.800	149.500	0.000	41.200	51.970	30.566	1.690	2.556
Li	38	11.100	1.000	12.100	2.400	2.500	3.176	2.711	2.379	5.219
Pb	38	30.100	6.400	36.500	8.700	9.800	11.097	5.492	3.030	12.304
Ag	38	0.040	0.010	0.050	0.020	0.020	0.023	0.010	0.753	0.226

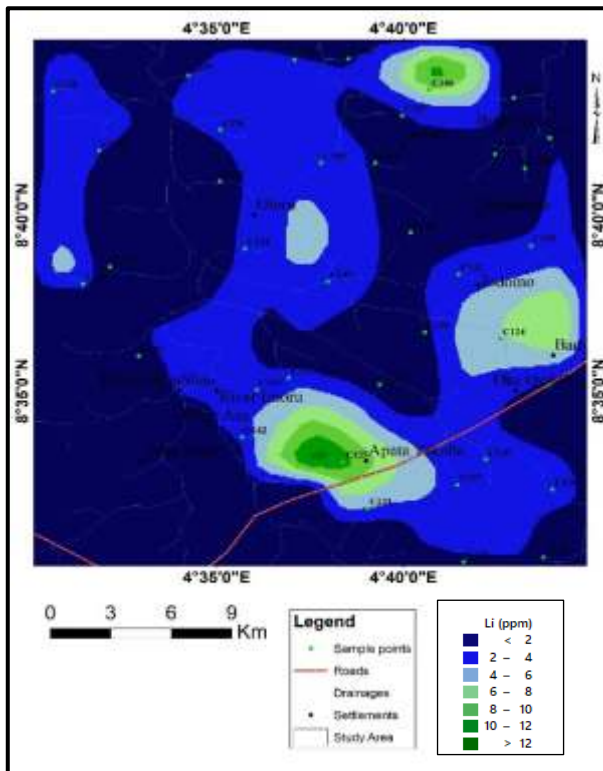


Figure 3: Classified map of Lithium (Li) superimposed on drainage map.

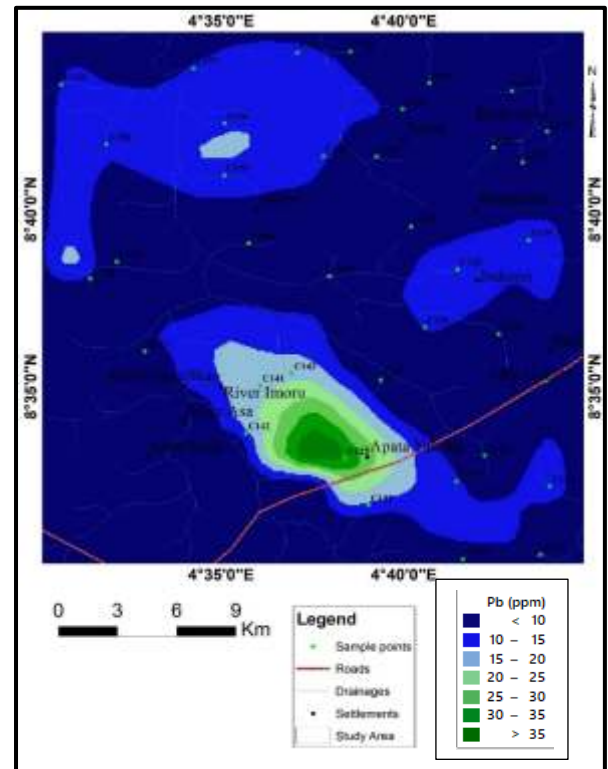


Figure 4: Classified map of Lead (Pb) superimposed on drainage map.

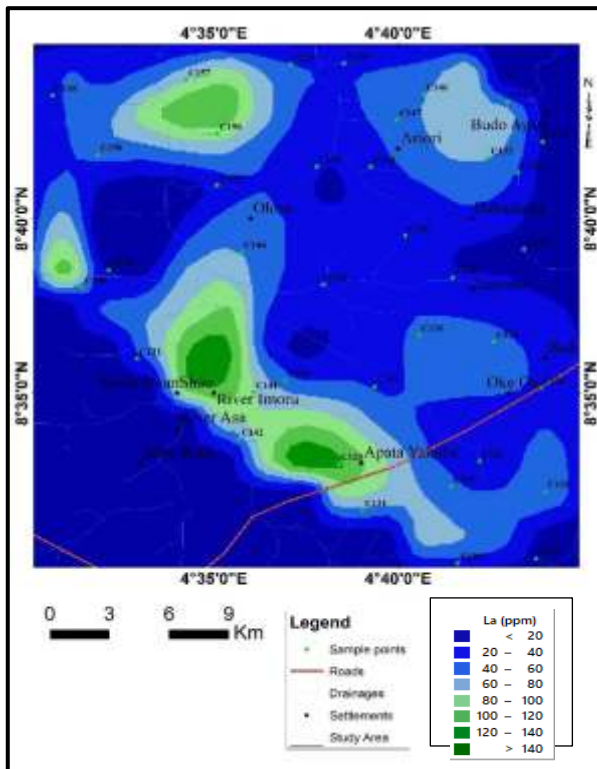


Figure 5: Classified map of Lanthanum (La) superimposed on drainage map.

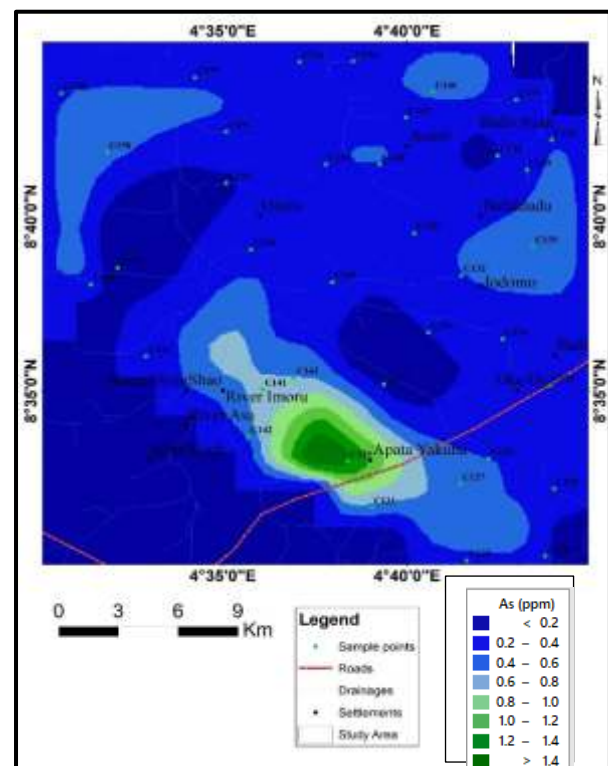


Figure 6: Classified map of Arsenic (As) superimposed on drainage map.

Table 3: Pearson correlation coefficient of some trace element from stream sediments in the study.

	Au	As	Ce	La	Li	Pb	Th
As	0.027						
Ce	0.078	0.748					
La	0.332	0.557	0.895				
Li	0.017	0.518	0.436	0.288			
Pb	0.044	0.783	0.844	0.64	0.453		
Th	-0.002	0.218	0.658	0.709	0.219	0.409	
Ag	0.291	0.104	0.332	0.38	0.223	0.337	0.236

Table 4: Main factors analysis of some elements from stream sediment in the study area

Variable	Factor1	Factor2	Factor3	Factor4	Factor5	Factor6	Factor7	Factor8
Au	0.046	0.607	0.374	-0.553	-0.35	0.506	-0.339	0.847
As	0.192	-0.302	0.3	-0.343	0.236	-0.784	-1.82	-0.343
Ce	0.237	-0.058	-0.145	-0.106	0.128	-0.323	0.953	4.734
La	0.218	0.2	-0.238	-0.229	-0.079	-1.009	1.117	-3.431
Li	0.138	-0.225	0.473	0.442	-0.894	0.013	0.443	-0.251
Pb	0.215	-0.154	0.129	-0.06	0.476	1.695	0.5	-1.553
Th	0.162	0.101	-0.647	0.199	-0.479	0.6	-1.389	0.064
Ag	0.11	0.439	0.215	0.778	0.517	-0.356	-0.445	0.09

(La, Pb, Th), La- (Th, Pb).

5 Conclusion

The statistics of major elements and other trace elements in stream sediments from the study revealed that operational geochemical variables such as Au, As, Ce, La, Li, Pb, Th and Ag have a direct relationship in the stream sediments. Skewness and kurtosis coefficients for Au, As, Ce and Li are considerably higher when compared to element such as Ag. Pearson correlation revealed gold having positive correlation with La and Ag but with negative correlation with Th. The presence of Pb and As in the same factors and the weak correlation between Au- Pb and As suggest that Au is

slightly bonded chemically to sulphides and disseminated freely in the stream sediments as placer gold.

References

- Ali, K., Cheng, Q., Wenchang, L., & Yongqing, C. (2006). Multi-element association analysis of stream sediment geo- chemistry data for predicting gold deposits in south- central Yunnan Province, China. *Geochemistry: Exploration, Environment, Analysis*, 6, 341–348.
- Carranza, E. J. M. (2010). Catchment basin modeling of stream sediment anomalies revisited incorporation of EDA and fractal

- analysis. *Geochemistry: Exploration, Environment, Analysis*, 10(4), 365–381.
- Cheng, Q., Bonham-Carter, G. F., Wang, W., Zhang, S., Li, W., & Xia, Q. (2011). A spatial weighted principal component analysis for multi-element geochemical data for mapping locations of felsic intrusions in the Gejiu mineral district of Yunnan, China. *Computers and Geosciences*, 5, 662–669.
- Embui, V. F., Omang, B. O., Che, V. B., Nforba, M. T., & Suh, E. C. (2013). Gold grade variation and stream sediment geochemistry of the Vaimba-Lidi drainage system, northern Cameroon. *Natural Science*, 5(2A), 282–290.
- Ghadimi, F., Ghomi, M., & Sedigh, M. A. (2016). Identification of Ti-Anomaly in Stream Sediment Geochemistry using Stepwise Factor Analysis and Multifractal Model in Delijan District, Iran. *International Journal of Mining and Geological Engineering*, 50(1), 77–95.
- Grunsky, E. C. (2010). The interpretation of geochemical survey data. *Geochemistry: Exploration, Environment, Analysis*, 10, 27–74.
- Harris, J. R., Wilkinson, L., & Grunsky, E. C. (2000). Effective use and interpretation of lithogeochemical data in regional mineral exploration programs; application of geographic information systems (GIS) technology. *Ore Geology Reviews*, 16, 107–143.
- Johnson, D. E. (1998). *Applied Multivariate Methods for Data Analysis*. California: Duxbury Press, Pacific Grove.
- Mumbfu, E. M., Nforba, M. T., & Suh, C. E. (2014). Geochemical Dispersion of Gold in Stream Sediments in the Paleoproterozoic Nyong Series, Southern Cameroon. *Science Research*, 2(6), 155–165.
- Salminen, R., Kashabano, J., Myumbilwa, Y., Petro, F. N., & Partanen, M. (2008). Indications of deposits of gold and platinum group elements from a regional geochemical stream sediment survey in NW Tanzania. *Geochemistry: Exploration, Environment Analysis*, 8, 313–322.
- Suh, C. E., Lehmann, B., & Mafany, G. T. (2006). Geology and geochemical aspects of lode gold mineralization at Dimako - Mboscorro, SE Cameroon. *Geochemistry: Exploration, Environment, Analysis*, 6, 295–309.
- Xu, Y., & Cheng, Q. (2001). A fractal filtering technique for prospecting regional geochemical maps for mineral exploration. *Geochemistry: Exploration, Environment, Analysis*, 1, 147–156.
- Yilmaz, H. (2007). Stream Sediment Geochemical Exploration for Gold in the Kazdag Dome in the Biga Peninsula, Western Turkey. *Turkish Journal of Earth Sciences*, 16, 33–55.

Evaluation of Some Quarry Dusts Treated Soils

Obaro R. I.¹, Iheme, K. O.², Agbalajobi S. A.¹, Hammed, A.¹, and Obaro, N. T.²

¹Department of Minerals and Petroleum Resources Engineering Technology, Kwara State Polytechnic, Ilorin

²Department of Geology and Mineral Sciences, University of Ilorin Nigeria

Abstract.

Increasing quarry dust by weight on the performance of some lateritic soils from North central Nigeria was examined for effective stabilization. Bulk residual samples of lateritic soil from a single location along Osere road, North-Central Nigeria were stabilized with varying quantity of quarry dust from 0% to 80%. The laboratory analysis such as natural moisture contents, shrinkage limits, Atterberg limits, compaction, unconfined compressive strength and California bearing ratio of the treated soils with quarry dust suggest an improvement in the engineering properties of the soils. This research work also observed that quarry dust is an appropriate stabilizer with optimum amount needed as 60%.

Keywords: Evaluation, quarry dust, lateritic soil

1.0. Introduction

Laterites occur mostly in tropical and sub-tropical regions with hot humid climatic conditions. It is a mixture of clayey iron and Aluminium silicates, silicates formed as a result of the weathering of basalt under humid tropical conditions. Lateritic soils are often used in tropical regions for civil works e.g. roads, buildings etc. Failures of highway pavements have been common on the Nigerian highway system since the colonial period (Jegede, 2000). Failures on Nigeria highways are generally due to poor geotechnical properties of the underlying soils which constitute the base or sub grade material for the entire road configuration. Necessity to improve soil properties for road construction has resulted in the use of various stabilizers (Amu *et al.*, 2010). The application of chemicals such as Portland cement, rock flour, lime, fly ash, saw dust ash, etc. or the combination of them often results in the transformation of soil index properties which may involve the cementation of particles (Amadi, 2010). A variety of ground improvement techniques have been developed and successfully applied in several areas. All these techniques basically involve introduction of different materials in the soil deposit. Quarry dusts are considered as one of the well accepted as well as cost effective ground improvement technique for weak soil deposit. They provide the primary function of reinforcement and drainage, and this improves the strength and deformation characteristics of weak soil deposit

(Thurston, 1996). It is obtained as soil solid wastes during crushing of stones such that the aggregates can be used as a substitute for sand to improve the properties of lateritic soil (Soosan *et al.*, 2001b). Sridharan and Soosan, (2005) also conducted studies on the effect of quarry dust on the geotechnical properties of soil used in highway construction and concluded that the CBR value steadily increased with increase in percentage of quarry dust.

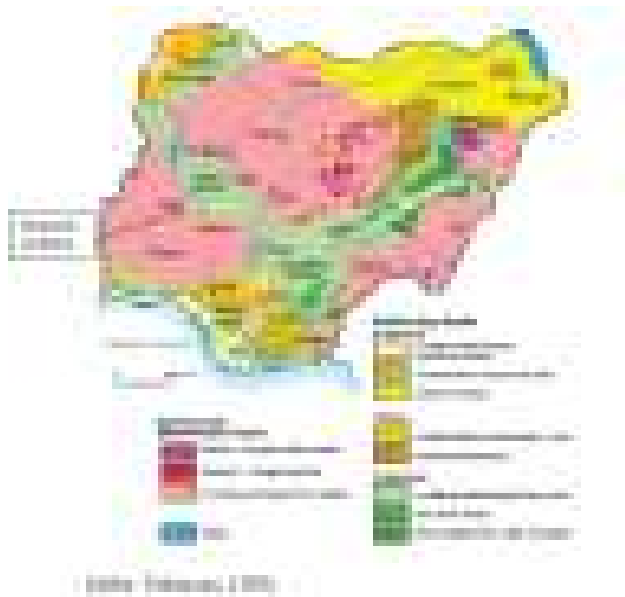
Several authors have worked on the geotechnical properties of lateritic soil using both physical and chemical stabilizers (Obaro and Agbalajobi, 2016; Ogunribido, 2012; Olarenwaju *et al.*, 2011; Rahaman *et al.*, 2010; Okunade, 2010; Okafor and Okonkwo, 2009; and Oloruntola *et al.*, 2008).

This paper examines the results of experimental study carried out on soil sample from the studied location improved with different percentages of quarry dust.

Location of the study area

Nigeria is mostly covered by crystalline rocks and other less than 50% by sedimentary rocks as shown in Figure 1. The study area also lies within the basement complex rocks of North-central Nigeria which comprises of igneous and metamorphic rock units such as biotite granite, migmatite gneiss and granite gneiss. These rocks are often intruded by pegmatite, quartz and quartzo- feldspartic veins with some minerals such as quartz, feldspar, muscovite, and biotite. The study area (Figure 2) is along Osere road,

Ilorin, North-Central Nigeria and lies with an average elevation of about 290 metres above sea level. The co-ordinates of the area is latitude $08^{\circ} 28' 10.0''$ and longitude $04^{\circ} 32' 26.2''$. The climatic condition in the area is influenced by both wet and dry seasons. Due to the alteration in wet and dry seasons, the water table fluctuates in response to the seasonality of the rainfall.



Ilorin, North-Central Nigeria and lies with an average elevation of about 290 metres above sea level. The co-ordinates of the area is latitude $08^{\circ} 28' 10.0''$ and longitude $04^{\circ} 32' 26.2''$. The climatic condition in the area is influenced by both wet and dry seasons. Due to the alteration in wet and dry seasons, the water table fluctuates in response to the seasonality of the rainfall.

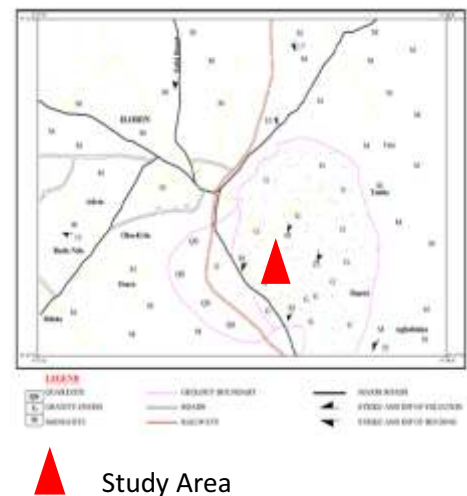


Figure 1: Geological Map of Nigeria (Obaje, 2009): Figure 2: Geological Map of Study

Materials and Methods

Three Bulk samples of lateritic soil was collected from burrow pit at 1.0m, 2.0m and 3.0m at a location with flat relief in Osere area, Ilorin. The natural moisture content was determined immediately at Civil Engineering laboratory, University of Ilorin, Ilorin, Kwara State, Nigeria. Soil samples were air dried for three weeks at room temperature before other analyses was carried out. Natural moisture content, specific gravity, liquid limit, plastic limit, plasticity index, linear shrinkage, unconfined compressive strength, compaction

and California bearing ratio were determined in accordance with acceptable standard procedures of BS 1377 (1990). Quarry dust of 0%, 20%, 40%, 60% and 80% were added to the soil samples for index and engineering analysis.

Results and Discussion

The results obtained from the initial tests are natural moisture content, specific gravity, liquid limit, plastic limit, plasticity index, linear shrinkage as well as engineering property tests (unconfined compressive tests, compaction and California bearing ratio) is shown in Table 1.

Table 1: Summary of the Preliminary Analysis of Soil Sample

Sample Code	Specific Gravity	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Natural Moisture Content (%)	Linear Shrinkage (%)
A	2.59	43.1	23.5	19.6	2.3	8.2
B	2.62	40.0	21.8	18.2	2.8	8.3
C	2.68	37.0	20.6	16.4	2.9	8.6

Table 1 presents the summary of the preliminary analysis of soil samples. The natural moisture content of Sample A, B and C were 3%, 2.8% and 2.9%. These indicate that the soil samples contained very low appreciable amount of moisture which is largely affected by the climatic condition and it is also as a result of void ratio and the specific gravity of the samples. The linear shrinkage values for all the three samples obtained are 8.2%, 8.3% and 8.6% respectively. These values falls within 10% and 8% respectively for sub -grade and sub -base

materials proposed by Madedor (1983) for road construction purpose and hence the soil is expected to perform credibly well. The specific gravity of Sample A, B and C ranges from 2.58g/cm^3 – 2.68g/cm^3 with an average of 2.63g/cm^3 . These values suggest high degree of laterization which agreed with the observation reported in Oyediran and Kalejaiye, (2011). According to Ramamurty and Srditharam, (2005) and Bowles, (1979) these samples can be classified as inorganic clay (Table 2).

Table 2: Typical values of Specific Gravity of Soil Particles (Bowles, 1979)

Soil Type	Specific gravity
Sand	2.65 – 2.68
Gravel	2.65 – 2.66
Clay (Inorganic)	2.52 – 2.66
Clay (Organic)	2.68 – 2.72
Silt	2.65 – 2.66

Results of Engineering Analysis

The results obtained from Atterberg limit, Compaction, Unconfined Compressive and California Bearing Ratio tests with Quarry Dust is shown in Table 3.

Effect of Quarry Dust on Atterberg Limit

The summary of Atterberg tests for all the analysed samples are displayed in Table 3. According to Whitlow, (1995) liquid limit less than 35% indicate low plasticity, between 35% and 50% indicates intermediate plasticity and between 50% and 70% high plasticity, 70% and 90% very high plasticity and greater than 90% is extremely high plasticity. This suggests that all the three samples have an intermediate plasticity. However, increase in the percentage of quarry dust from 0% to 80% reduces the plasticity index and enhance the physical properties of the soil samples (Das, 1994 and Ogunribido, 2012).

Effect of Quarry Dust on Compaction Parameters

Increase in compaction is attributable to the effect of addition of varying quantities of quarry dust by weight on MDD of the studied soil (Table

3). This supports the findings of several authors such as Vinod *et al.*, (2015) and Hussain, (2017). The quarry dust quantities increased in all the samples from 20% to 80% (Figure 3) with a reduction or decrease in the optimum moisture content. Increase in the MDD and decrease in OMC may be credited to quarry dust filling the pores or void of the soil. This however results to more dense packing because of finer particle of quarry dust. In addition to this, higher MDD and lower OMC can also be attributed to the particle size since the soil is better graded with addition of quarry dust producing high dry density. Increase in MDD due to increase in quarry dust can also be attributable to increase in specific gravity of quarry as noted by Eze-Uzomaka and Agbo, (2010). Conversely, decrease in OMC (Figure 4) possibly by increased quarry dust could be as a result of less water for any reaction to occur which tends to increase the strength of the soil as quarry dust fill the soil pore spaces as reported by Oyediran and Idowu, (2017).

Effect of Quarry Dust based on Unconfined Compressive Strength

The unconfined compressive strength (UCS) is

Table 3: Summary of Atterberg, Compaction, Unconfined Compressive and California Bearing Ratio tests with Quarry Dust

Sample Code	Quarry dust Percentage	Liquid Limit LL (%)	Plastic Limit PL (%)	Plasticity Index PI (%)	Maximum Dry Density (Kg/m³)	Optimum Moisture Content (%)	Unconfined Compressive Strength (qu) KN/m²	CBR Unsoaked	CBR Soaked
A	0%	43.1	23.5	19.6	1570	16.0	164.02	55.8	55.8
	20%	41.5	22.3	19.2	1620	15.0	144.01	57.5	56.4
	40%	39.6	20.5	19.1	1750	14.0	144.17	60.6	59.6
	60%	38.2	19.3	18.9	1820	12.0	133.76	65.4	63.7
	80%	36.5	16.9	19.6	1800	13.0	114.10	61.5	60.1
B	0%	40.0	21.8	18.2	1530	17.0	166.05	54.2	54.2
	20%	38.5	19.4	19.1	1580	16.0	158.03	55.4	55.1
	40%	37.5	17.6	19.9	1640	15.0	156.03	57.3	56.4
	60%	35.6	16.6	19.0	1750	15.0	139.13	60.1	59.7
	80%	34.8	16.2	18.6	1710	14.0	125.12	56.2	55.5
C	0%	37.0	20.6	16.4	1620	18.0	162.5	53.5	53.5
	20%	36.9	19.1	17.8	1650	17.0	155.4	54.5	53.6
	40%	35.5	17.2	18.3	1770	16.0	154.3	58.3	57.4
	60%	34.9	17.0	17.9	1790	13.0	135.5	61.4	59.9
	80%	33.7	14.8	18.9	1780	14.0	111.5	57.4	56.3

used to estimate the bearing capacity of highway and subgrade materials (Gidigas, 1980). Das, (2000) reported that consistency of a clayey soil can be determined as follows, 0-25kN/m² indicates very soft, 25-50kN/m² and 100 – 150kN/m² is stiff, 200 – 400kN/m² very stiff and greater than 400kN/m² indicates hard clay. Consistency of all the samples is stiff clayey soil (Table 4). According to Ogbuchukwu and Okeke, (2021) clay soil is mostly stiff when dried and give up their stiffness when saturated. Soil

stabilization generally causes reduction in swelling potentials and degree of expansions of soil materials leading to enhancement in the soil stiffness, permeability, strength and durability. Furthermore, the unconfined compressive strength of the soils (Figure 5) fall above the greater than 103kN/m² specifications for base course materials (FMWH, 1997), thus, the soils are suitable as base course materials for road pavements.

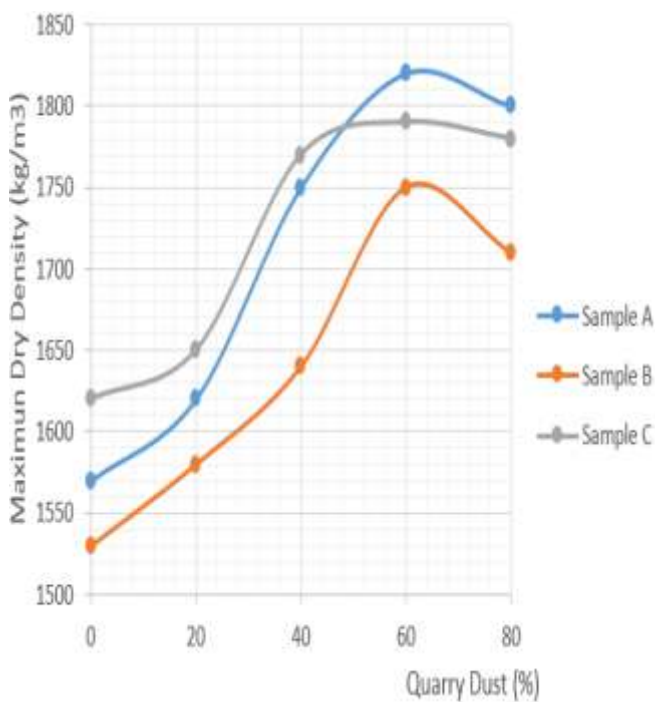


Figure3: MDD variation with Quarry Dust

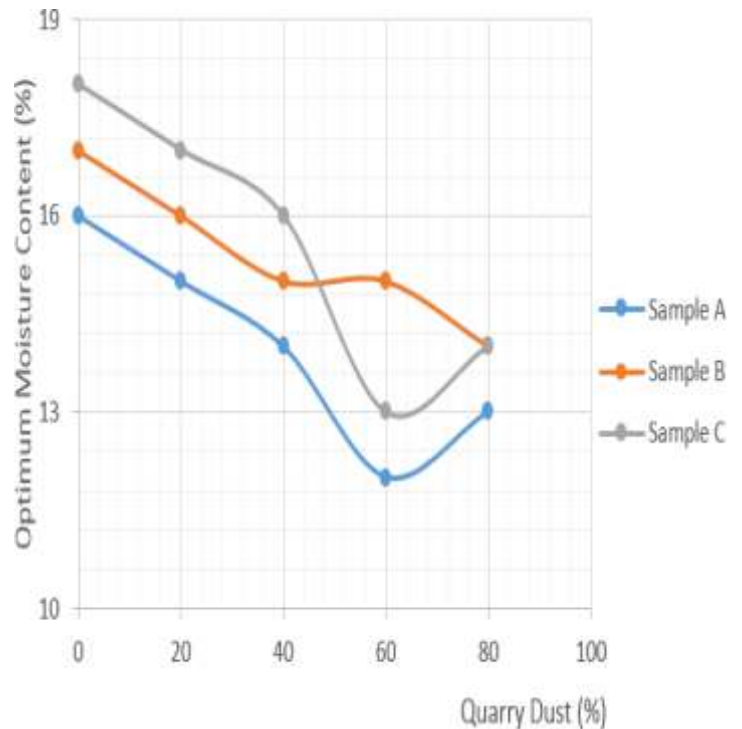


Figure4: OMC variation with Quarry Dust

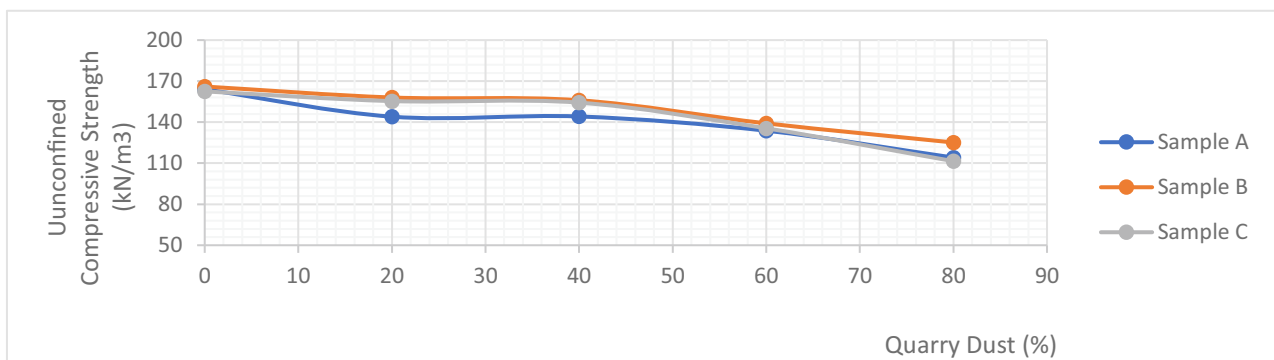


Figure 5: Unconfined Compressive Strength with Quarry Dust

Effect of Quarry Dust based on California Bearing Ratio

California Bearing Ratio is used to establish design parameters for pavement thickness (Wignall *et al.*, 1999). With addition of quarry dust, Sample A CBR value of soil increased from 55.0% at 0% stabilization to 65.0% at 60% stabilization but at 80% stabilization the value decreases to 61% CBR. Sample B CBR value increased from 54.2% at 0% to 60.1% at 60% stabilization but decreases to 56.2% at 80% stabilization while Sample C at 0% stabilization with 53.5% increase to 61.4% at 60% stabilization but decrease to 57.4% at 80% stabilization (Fig. 6). The stabilization at 60% for all the samples suggests that the load bearing capacity of the soil increases with

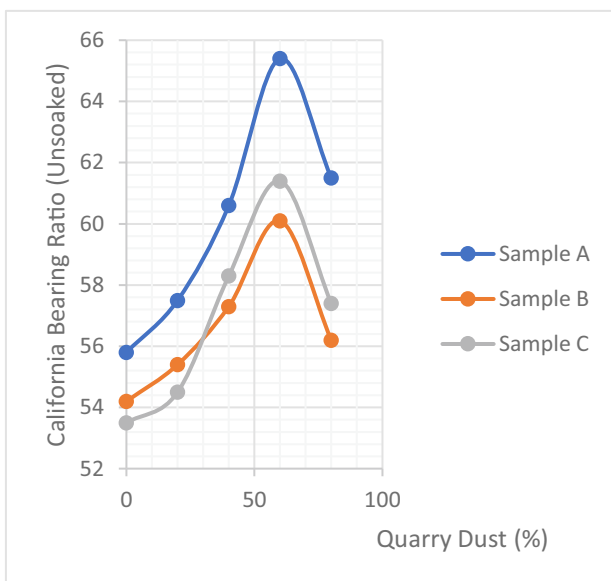


Figure 6: Un-soaked lateritic soil with Quarry Dust

Conclusion

Evaluation of some quarry dusts on the geotechnical properties of some bulk lateritic soils from Osere road, Ilorin, North -central Nigeria has led to the following conclusions;

i. Soil increased with quarry dust using maximum dry density, California bearing ratio, and unconfined compressive strength thus produced denser and hence stronger samples

stabilization mix. On the other hand, the reduction or decrease beyond 60% in the un-soaked CBR values could be related to addition of quarry dust that changes the grading of the soil, leading to reduction in bonding particles of the clay structure, thus decreasing the soil shear strength. The soaked CBR decreases relatively in values to un-soaked CBR. The reduction in the soaked CBR (Figure 7) may be attributable to water during soaking which could have weakened the cohesive forces in the soil structure. This can also be detrimental to sub grades of pavements and foundations. However, the results obtained for both un-soaked and soaked CBR would provide good sub base materials based on general specification for roads and bridges by FWWH (1997).

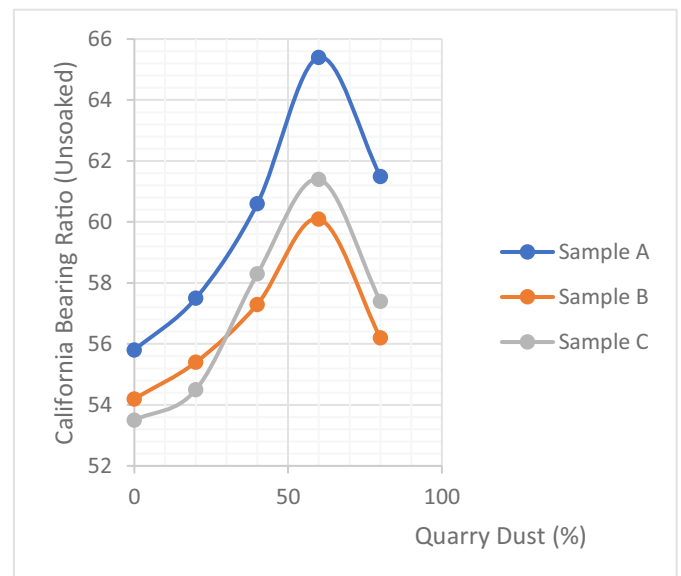


Figure 7. Soaked of lateritic soil with Quarry Dust

while there is a reduction in optimum moisture content as quarry dust was increasingly added.

ii. Addition of more than 60% by weight of quarry dust was observed to cause a decrease in MDD, UCS, and CBR but increase in the OMC. The maximum improvement in MDD, CBR, and UCS with a decrease in OMC was observed in addition to 60% by weight of quarry dust and therefore can be regarded as optimum content

for improvement of the soil. This study has revealed that some quarry dust adequately acts as a cheap stabilizing agent for sub-grade and sub-base purposes in lateritic soil.

References

- Amadi, A. (2010). Evaluation of Changes in Index Properties of Lateritic Soil Stabilized with Fly Ash. *Leonardo Electronic Journal of Practices and Technologies*, Issue 17. pp.69-78.
- Amu, O.O, Origbemide, A.R. and Saseun, E.O. (2010). Effects of Dissolved Alum on Geotechnical Properties of Lateritic Soil for Road Construction. *Research Journal of Applied Sciences, Engineering and Technology*. Vol.2 (6) pp. 543-546.
- BS 1377 (1990). Methods of Testing Soils for Civil Engineering Purposes, *British Standard Institute*, London.
- Bowles, J.E. (1979). Physical and Geotechnical Properties of soil. *Megraw - Hills Incorporation* 2nd Edition.
- Das, B. M. (1994). Principles of Geotechnical Engineering Third Edition, *PWS Publishing, Co.*, Boston, Massachusetts, U.S.A, P.672.
- Das, B.M. (2000). Fundamental of Geotechnical Engineering 4th ed. Thomson Learning USA.
- Frias M, and Cement and Concrete Research Eze - Uzomaka, O. J. and Agbo, D. (2010). Suitability of Quarry Dust as Improvement to Cement Stabilized - Laterite for Road bases. *Electronic Journal of Geotechnical Engineering*, Vol. 15, (K), pp. 1053 – 1066.
- Federal Ministry of Works and Housing (1997). Nigeria General Specifications for Roads and Bridges, *Revised Edision* 2, pp. 137 – 275.
- Gidigas, M. D. (1980). Geotechnical Evaluation of Residual Gravels in Pavement Construction, *Engineering Geology*, 15, 173 – 194.
- Hussain, S. (2017). Effect of Compaction Energy on Engineering Properties of Expansive soils. *Civil Engineering Journal* Vol. 3(8) pp. 610 – 616.
- Jegede, G. (2000). Effect of Soil Properties on Pavement Failures along the F209 Highway at Ado Ekiti, South Western Nigeria. *Construction and Building Materials*. Vol. 14, pp. 311-315. [http://dx.doi.org/10.1016/S0950-0618\(00\)00033-7](http://dx.doi.org/10.1016/S0950-0618(00)00033-7)
- Madedor, A. O. (1983). Pavement Design Guidelines and Practices for Different Geological Areas in Nigeria in Ola, S. A (ed.) *Tropical Soils of Nigeria. In Engineering Practice*, A. A Balkema Publishers, Rotterdam, pp. 291 – 297.
- Obaje N. G. (2009). Geology and Mineral Resources of Nigeria. *Springer, Berlin*, Germany, ISBN 13: 9783540926849 P. 221
- Olarewaju, A. J., Balogun, M. O. and Akinlolu, S. O. (2011). Suitability of Eggshell stabilized Lateritic soil as Subgrade Material for Road Construction. *Electronic Journal of Geotechnical Engineering*, 16. pp. 899 – 908. ISSN 1089-3032.
- Okafor, F.O and Okonkwo U.N (2009). Effect of Rice Husk Ash on some Geotechnical Properties and Soil. *Leonardo Electronics Journal of Practices and Technologies*, Issue 15 pp. 67 – 74.
- Okunade, E.A (2010). Geotechnical Properties of some Coal fly Ash Stabilized in South-western, Nigeria. *Lateritic Soils Modern Applied Science*, Vol. 4 No. 12, pp. 66 – 73.
- Obaro R.I and Agbalajobi S.A (2016). Effect of Rock flour on Lateritic Soil along Asa – Dam Road, Ilorin, Kwara State. Available at: www.nsme.org.ng
- Ogbuchukwu, P. O. and Okeke, O. C. (2021). Effect of Cement and Lime Stabilization on Geotechnical Properties of Expansive Soils in Awka and Environs, South-eastern, Nigeria *Journal of Mining and Geology*, vol. 57 (2), pp. 427–439
- Ogunribido, T.H.T (2012). Effect of Rock flour on Some Engineering Properties of Lateritic Soil. *International Journal on Pure Applied Science Technology* 10 (1). pp. 10 – 16
- Oloruntola M.O, Adeyemi G.O and Oduneye O.C (2008). Comparative Study on the Influence of Cement and Lime Stabilization on geotechnical properties of Lateritic soil derived from pegmatite in Ago-Iwoye Area Southwestern Nigeria. *Journal on Mining and Geology* pp. 95-105.
- Oyediran, I. A. and Kalejaiye, M. (2011). Effect of

Increasing Cement Content on Strength and Compaction Parameters of Some Southwestern Lateritic Soils. *Electronic Journal of Geotechnical Engineering*, 16k, pp. 1501 – 1514.

Oyediran, I. A. and Idowu, O. D. (2017). Performance Analyses of Some Quarry Dust Treated Soil. *Journal of Mining and Geology*, vol. 53 (1), pp. 45 - 53

Ramamurthy, T. N. and Sitharam, T. G. (2005) "Geotechnical Engineering". *S. Chand, New Delhi*. P. 289.

Rahman Z.A, Hamzah, U. and Mohd, R.T (2010). Influence of Oil Contamination on Geotechnical Properties of Balsatic Residual soil, *American Journal of Applied Sciences* 7 (7), pp. 954 – 964.

Soosan T. G., Jose B. T. and Abraham B. M. (2001b). Use of quarry dust in Embankment and Highway Construction. *Proceedings of Indian Geo-technical Conference, December, Indore*. pp. 274-277.

Sridharan A. and Soosan T. G. (2005). Utilization of Quarry Dust to Improve the Geotechnical Properties of Soils in Highway Construction. *Canadian Geotechnical Journal*. 28: pp. 391-400.

Thurston, E (1996). Effect of Replacement of Lateritic soil with Granite Fines on the Compressive Tensile Strength of Laterized Concrete. *Building and environment* 37(5): pp. 491-496.

Vinod, P. P., Sridharan, A. and Sounmya, R. J. (2015). Effect of Compaction Energy on CBR and Compaction Behaviour. *Proceedings of the Institution of Civil Engineers-Ground Improvement*, vol. 168, (2), pp. 116 – 121.

Whitlow (1995). Basic Soil Mechanics, (3rd Edition). *Addison Wesley Longman Limited*.

Wignall, A., Kendrick, P.S., Ancill, R. and Capson, M. (1999). Roadworks; *Theory and Practice*, 4th edn, *Butterworth-Heinem*

Physico-Chemical and Mineralogical Characterization of Dutsen wai cassiterite ore

Oyeladun O. A. W.¹, Agbo A. N.² and Tolu S.³

¹Metallurgical Engineering Technology, Kaduna Polytechnic, Kaduna

²Nigeria Defense Incorporation Company, Kaduna

³Department of Mineral and Petroleum Resources Engineering, Kaduna Polytechnic, Kaduna.

Corresponding Author email: oawoyeladun@gmail.com

Abstract

The physico-chemical and mineralogical characterization of Dutsen wai cassiterite ore was carried out. The physical observation revealed that the ore has metallic lustre, dark bronze in colour and irregular or uneven breakages. The Dutsen wai cassiterite's hardness was found to be 631HB, specific gravity of 4.797 and thermal conductivity was found to be 1.8897 W/mK. The result of chemical analysis of Dutsen wai cassiterite ore using XRF revealed that the ore contains 1.458%Fe, 3.007%Ca, 66.232%Sn, and 1.171%Ti with tin mineral predominant in the matrix of the ore. The mineralogical analysis of Dutsen wai cassiterite ore reveals the presence of cassiterite, phlogopite, loparite and ferrocolumbite. Having carried out the physico-chemical and mineralogical characterization of Dutsen wai cassiterite ore, it was discovered that Dutsen Wai cassiterite ore is economically viable, hence, an engineering process route should be designed for the beneficiation of Dutsen Wai cassiterite ore for economic and commercial purposes.

Keywords: cassiterite, physico - chemical analysis, mineralogical analysis

Introduction

Nigeria a nation adequately blessed with large deposit of ferrous and non-ferrous metallic ores which are yet to be fully harnessed, characterized, and beneficiated due to lack of sufficient studies and technology. Mineral cassiterite has a chemical formula SnO_2 which mainly consisting of tin (Sn) and oxygen (O) (Andriyah et al., 2017). The non-ferrous metallic ores found in Nigeria include lead-zinc ore, tin ore (cassiterite), niobium ore, uranium ore, and precious metals such as (gold and silver) (Abdulfattah et al., 2017).

The principal tin mineral is cassiterite or tinstone, naturally occurring oxide of tin containing about 78.6% Sn. Other tin minerals are stannite ($\text{Cu}_2\text{FeSnS}_4$) and cylindrite ($\text{PbSn}_4\text{FeSb}_2\text{S}_{14}$). The colour is shining black, brownish-black, reddish brown, gray, red, white, and rarely colourless. The crystal system is tetragonal with very common twinning. The fractures are subconchoidal to uneven and brittle. The luster is adamantine to metallic, greasy with white to brownish streak. The average specific gravity is ~ 7.0 . The mineral

hardness is between 6 and 7 in Mohs scale. The cassiterite is formed by hydrothermal process and occurs as veins, alluvial, and placer. The grains are resistant to weathering. Cassiterite remains the primary source of tin metal, used as plates, cans, containers, solders, and polishing compounds and alloys (Halдар, 2020).

Cassiterite is the chief ore of tin (Sn), but it houses other associated minerals such as columbite, wolframite, ilmenite, monazite, and others (Weiss, 1985). When this mineral deposit (cassiterite) is mined from the earth by artisanal miners, it is further processed either locally or industrially (Wills and Napier-Munn, 2006). The top tin producing countries in the world in 2014 are China (125,000 tons), Indonesia (84,000 tons), Peru (23,700 tons), Bolivia (18,000 tons), Brazil (12,000 tons), Myanmar (11,000 tons), Australia (6100 tons), Vietnam (5400 tons), and Malaysia (3500 tons) (Halдар, 2020).

Tin occurs in Nigeria in the form of cassiterite with varying amounts of associated minerals. The major sources of ore bearing cassiterite in Nigeria are the alluvial and eluvial deposits from the biotite granites within the Jurassic alkaline

ring complex of the Jos Plateau. More so, less than 5 % of the total production has been recovered from the pegmatites within the largely Precambrian basement complex consisting of magnesites, gneisses, but with the rapidly depleting reserves. Figure 1 shows the map of Dutsen – Wai, a typical mining area, 20 Km away from Jos. Tin mining in Nigeria is over 100 years old. Prior to 1975, Nigeria was a

major tin exporter of cassiterite concentrates which peaked at about 11,000 tons. There has been a dramatic decline to about 2000 tons. Among the factors accounting for the collapse of this tin industry include the inaccessibility of placer deposits and the current prohibitive cost of mining the ores beneath the basalt flows of Jos (Ogwuegbu, 2011).



Figure 1: The map of Dutsen – Wai

However, the need to carry out the physico-chemical and mineralogical characterization of Dutsen wai cassiterite ore in order to find out the deposit makeup with the cutoff grade is essential in the mining and mineral industries (Thomas et al, 2010). Therefore, there is need to characterize Dutsen Wai cassiterite ore for economic viability. To achieve this, determination of the physical properties (colour, hardness, relative density, electrical and thermal conductivities) of the ore samples, chemical compositions of the ore sample using XRF analytical equipment and mineralogical compositions of the ores sample using XRD/SEM-EDS analytical equipment (Oyeladun, 2015; Oyeladun et al., 2016).

2.0. MATERIALS AND METHODS

2.1. Equipment and Materials

The equipment that was used in the course of this work were: pulverizing machine, gravity bottle (pycnometer), ball milling machine,

weighing machine, X-ray fluorescence spectroscopy (XRF) and X-ray diffractometer (XRD). The materials used include: cassiterite ore and water.

2.2 Methods

2.2.1 Sample collection and preparation of the Cassiterite

50kg of Dutsen wai cassiterite ore was collected from various location at Lere Local Government Area of Kaduna State, Nigeria using grab method and the sample collected was the true representation of the entered ores deposit. In the laboratory, the samples underwent re-sampling using Jones riffle. The sample was pulverized and blended thoroughly so as to achieve homogeneity. The homogenous sample was used for both chemical analysis and mineralogical analysis.

2.2.2 Physical Observation

Method

- i. The sample colour was determined using colour chart.
- ii. The sample was examined by looking at the geometric shape of the mineral
- iii. The sample was checked to determine wherever the breakage was as either irregular or conchoidal.

2.2.3 Determination of the Hardness of the Ores

Hardness measurements on all the specimens will be carried out using Mohr's scale.

2.2.4 Determination of Specific Gravity (Relative Density)

Procedure

- i. The sample was washed thoroughly in order to remove dust and weighed
- ii. Empty specific gravity bottle (pycnometer) was weighed and the weight was recorded
- iii. The ground sample was filled into the specific gravity bottle to about 1/3 of the bottle and weighed the sample and bottle and the weight recorded
- iv. The remaining space in the bottle was filled with water and weighed
- v. The content of the bottle was discarded and filled afresh with water and the weight of bottle filled up with water was determined.

Mass of empty bottle, M_1

Mass of empty bottle + ore, M_2

Mass of empty bottle + ore + water M_3

Mass of empty bottle + water, M_4

Mass of water filling the bottle, $M_4 - M_1$

Mass of water having equal volume as ore

$$= (M_4 - M_1) - (M_3 - M_2)$$

Relative Density of the Ore (S. G.)

$$= \frac{(M_2 - M_1)}{(M_4 - M_1) - (M_3 - M_2)}$$

...Equation 1

2.2.5 Determination of Thermal conductivity

Thermal Conductivity (TC) of the samples with specific heat capacity were measured using radial heat conduction apparatus (Armfield equipment model HT12) with heat transfer service unit (Armfield equipment model HT 10XC). The probe consists of single heater and thermocouple. Constant electrical power was supplied to the heater; the temperature of wire

rose in exponential progression. Temperature rose with time line increased given to TC.

2.2.6. Chemical characterization of the Cassiterite

The head sample collected from the various locations and depths of the Cassiterite was subject to chemical analysis using XRF. The Cassiterite sample was analyzed by determining the percentage of composition of each element in the sample.

2.2.7. Mineralogical characterization of the Cassiterite

The head sample collected from the various locations and depths of the Cassiterite was subject to mineralogical analysis using XRD (X – Ray Diffractometer) Empyrean BV of Netherland Model.

3.0. RESULTS AND DISCUSSIONS

3.1. Physical Properties of Dutsen wai cassiterite

Table 1: Physical Properties of Dutsen wai cassiterite

Property	Value
Physical observation	Light Dark
Hardness	631
Specific Gravity	5.53
Thermal Conductivity	1.8897 W/mK
Heat Transfer	188.9720
Specific Heat	5.0×10^{-3}
Diffusivity	79.5713

Table 1 shows that the physical properties of Dutsen Wai cassiterite; where the physical observation reveal that the ore processes metallic lustre, dark bronze irregular or uneven breakages and Dutsen wai cassiterite the hardness was found to be 631HB, specific gravity of 5.53 and thermal conductivity was found to be 1.8897 W/mK which can be influenced by the present of other element in the ore (Wills and Napier-Munn, 2006; Weiss, 1985).

3.2 Determination of Chemical Property

3.2.1 Chemical Analysis

Table 2: The Result of Chemical Analysis of Head Sample of Dutsen wai Cassiterite Ore

Element	O	Al	Si	P	S	Cl	Ti	K
%	23.381	1.327	0.968	0.000	0.039	0.240	1.171	0.080
Element	Ca	Fe	Sn	Zr	Nb	Ta	Mn	W
%	1.305	1.458	66.232	0.068	0.953	0.510	0.000	0.145

Table 2 shows the result of chemical analysis of Dutsen wai cassiterite ore contains 1.458%Fe, , 3.007%Ca, 66.232%Sn, and 1.171%Ti with tin mineral predominant in the matrix of the ore, while other minerals associated with the ore in minor percentage making the ore deposit

another potential source for tin mineral; with 66.232% tin having meeting up with industrial standard and cut-off grade. The Dutsen wai cassiterite ore is high grade of tin ore (Weiss, 1985).

3.2.2 Determination of Mineralogical Property

Table 3: XRD Analysis Result for the Head Sample of Dutsen wai Cassiterite Ore

Card Number	Score	Mineral Name	Chemical Formula
96-900-7434	66	Cassiterite	$\text{Sn}_{2.00} \text{O}_{4.00}$
96-900-4660	11	Phlogopite	$\text{O}_{22.16} \text{F}_{1.84} \text{Si}_{5.9}$
96-900-4549	22	Loparite-Ce	$\text{Na}_{1.84} \text{La}_{0.36} \text{CeO}$
96-900-3735	6	Ferrocolumbite	$\text{Fe}_{3.16} \text{Nb}_{7.60} \text{MnO}$

From Table 3 and Figure 2, the mineral present is cassiterite. The mineral composition of the ore revealed that the tin is a cassiterite ore deposit (Weiss, 1985). From Table 3, the mineral present are as follows: cassiterite, phlogopite, loparite and ferrocolumbite. The mineral composition of the ore revealed that the cassiterite ore deposit

is associated with other minerals (Weiss, 1985). This reveals that both deposits meet up the cut-off grade for mining, hereby, making the two deposits variable for economy. However, Dutsen wai cassiterite ore sample has more percentage tin mineral assay compare to that of Bishe cassiterite ore sample

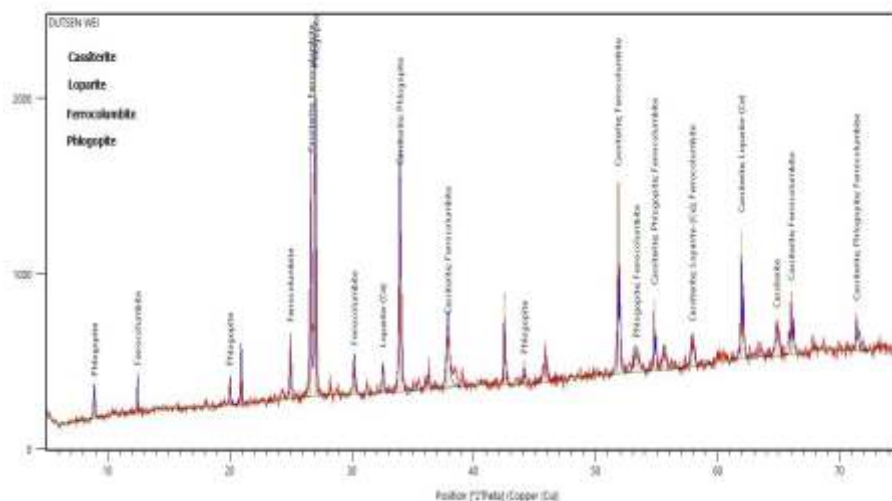


Figure 2: XRD pattern the Head Sample of Dutsen wai Cassiterite Ore

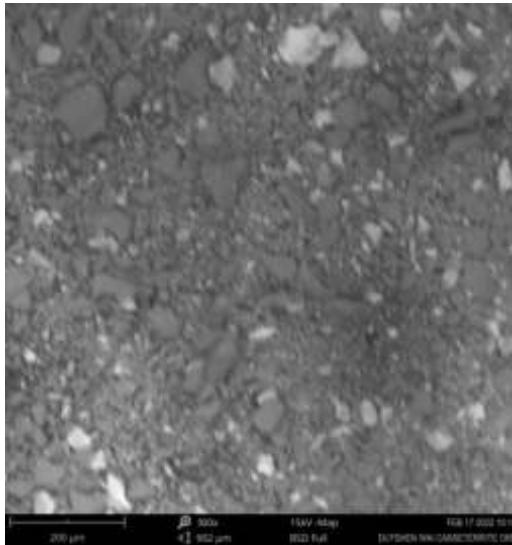


Plate 1: SEM Result of Dutshen Wei Cassiterite Sample ($\times 500$)

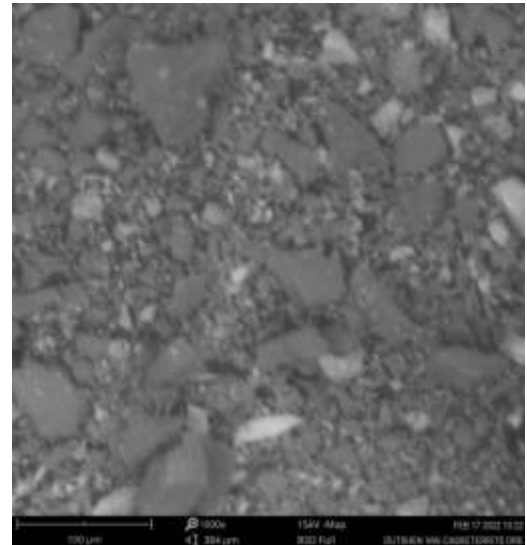


Plate 2: SEM Result of Dutshen Wei Cassiterite Sample ($\times 1000$)

Plates 1 and 2 show the SEM micrographs of the cassiterite ore sample. From the results can be observed that five phases can be recognized: the embedding resin (black background), cassiterite, phlogopite (light grey), loparite (white) and ferrocolumbite (grey particle). Furthermore, it could also be observed that the minerals are separated by grains boundaries, no interlocking of minerals and the mineral particles vary in sizes ranging from 80 to 320 μm . This phenomenon indicates that the minerals can be easily freed from each other during comminution, hence the low requirement in the energy required for the liberation of the tin mineral (Halder, 2020).

4.2.3. Petrological Analysis of the Head Samples



Plate 3: Micrograph of Dutshen Wei Cassiterite ore Sample under plane polarized light ($\times 1000$)

Plate 3 shows micrographs of the cassiterite ore sample under plane polarized light at 1000x. From the results can be observed that five phases can be recognized: the embedding resin (black background), cassiterite, phlogopite (light grey), loparite (white) and ferrocolumbite (grey particle).

4.0. CONCLUSION AND RECOMMENDATION

4.1. Conclusion

The physico-chemical and mineralogical characterization of Dutsen wai cassiterite ore was carried out and following conclusions were drawn:

- The physical observation reveals that the ore processes metallic luster, dark bronze irregular or uneven breakages and the hardness was found to be 631HB, specific gravity of 5.53 and thermal conductivity was found to be 1.8897 W/mK;
- the result of chemical analysis of Dutsen wai cassiterite ore contains 1.458%Fe, 3.007%Ca, 66.232%Sn, and 1.171%Ti with tin mineral predominant in the matrix of the ore;
- The mineralogical analyses of Dutsen wai cassiterite ore reveals the presence of cassiterite, phlogopite, loparite and ferrocolumbite.

4.2. Recommendation

Having carried out the physico-chemical and mineralogical characterization of Dutsen wai

cassiterite ore, it was discovered that Dutsen wai cassiterite ore is economically viable, hence, an engineering process route should be designed for the beneficiation of Dutsen Wai cassiterite ore for economic and commercial purposes.

References

- Abdulfattah, F. Rafukka, I. A. and Manladan S. (2017) Trends in Characterization and Beneficiation of Non-ferrous Metallic Ores in Nigeria Materials Science, Geology
- Andriyah L., Lalasari L. H. and Manaf A. (2017) The Formation of Sodium Stannate from Mineral Cassiterite by the Alkaline Decomposition Process with Sodium Carbonate (Na_2CO_3), IOP Conference Series: Materials Science and Engineering 176.
- Ebikemefa, C. E. (2020) Benefits of cassiterite mining by artisanal miners in Jos Plateau, Nigeria, Bulletin of the National Research Centre 44:113.
- Haldar, S. K. (2020) Minerals and rocks in Introduction to Mineralogy and Petrology (Second Edition), Elsevier Inc. pp 1-51
- Ogwuegbu M., Onyedika G., Hwang J., Ayuk A., Peng Z., Li B., Ejike, E.N.O. and Andriese M. (2011): Mineralogical Characterization of Kuru Cassiterite Ore by SEM-EDS, XRD and ICP Techniques, Journal of Minerals & Materials Characterization & Engineering, Vol. 10, No.9, pp.855-863,
- Oyeladun, O. A. W. (2015): Characterization of Azara Copper Ore Deposit, Nasarawa State (M. Sc. Thesis) A. B. U., Zaria, (Unpublished).
- Oyeladun, O. A. W. Thomas D. G. and Yaro S. A. (2016): Physico - chemical and Mineralogical Analysis of Azara Complex Ore, Nigerian Mining Journal Vol. 14 No. 2
- Thomas, D.G., Yaro S.A. and Oloche O.B. (2001): Chemical and Mineralogical Characteristics of Toto Muro Iron Ore, Journal of Engineering and Industrial Application (J.E.T.I.A) Vol.1, Pp 76-79.
- Weiss, N. L., (1985): Mineral Processing Handbook by American Institute of Mining Metallurgical and Petroleum Engineering Incorporated in the United States of America by Kings Port Press.
- Wills, B. A. and Napier-Munn, T. (2006): Mineral Processing Technology-An Introduction to the Practical Aspects of Ore Treatment and Mineral Recovery, Seventh Edition, Amsterdam: Elsevier Science and Technology Books, P450

Geochemical Studies and Industrial Features of Talcose Rock in Alla Area, North - central Nigeria

Obaro R. I.¹, Agbalajobi S. A.¹, Odediran, O.A.¹, Hammed, A.¹, and Obaro, N. T.²

¹Department of Minerals and Petroleum Resources Engineering Technology, Kwara State Polytechnic, Ilorin

²Department of Geology and Mineral Sciences, University of Ilorin Nigeria

Abstract

Talc bearing rocks has been identified in several location in Nigeria and it is used in industries with little emphasize on its industrial applications. Three talc bodies have been identified in the Alla area within the Schist belt of North-Central, Nigeria. Two talc bodies were examined through X-ray diffraction, while three talc bodies were assessed for X-ray fluorescence to ascertain their suitability for industrial applications. The results of X - ray diffraction studies of the talc bodies further revealed the presence of substantial talc, chlorite, quartz, anthophyllite, hornblende, and dolomite with strong peaks and percentage weight composition. The chemical analysis from X - ray fluorescence of the talc bodies suggests that the SiO₂ (mean of 57.10%) with of enrichment in the talc bodies is a result of chemical weathering while the magnesium content suggests hydrothermal alteration accompanied by serpentization of the tholeiitic protoliths which is comparable to similar talc bodies within the schist belts of South - western Nigeria. These are very significant in determining its end use for industrial purposes. However, the SiO₂ of all the samples in the study area based on standard specification can be used for ceramics/refractories, while the Al₂O₃ (mean of 2.24%) contents can be useful in paints, electrical insulators, and ceramics/refractories. The magnetite contents (MgO) of talc bodies can be used as fertilizers and can also be useful in paper, textile fillers, and pharmaceutical industries.

Keywords: Talcose, composition, mineral, chemical, industries

Introduction

Industrial or non-metallic minerals are largely consumed raw materials in the manufacture of several products, including ceramics, cements, ceilings, chemicals, cosmetics, drugs, glass, insecticides, and refractories. These comprise calcite, clays, feldspar, gypsum, magnetite, phosphate, quartz, and zircon, which are known for their occurrence in various localities in Nigeria (Elueze and Awonaiya, 1989). Industrial or non-metallic minerals also constitute a huge and emergent class of mineral industry. The value and quantity of production exceed the metallic minerals but are less than the energy resources. Assessments of the Nigerian mineral resources suggest that past efforts have been concentrated on exploration and exploitation of crude oil, most importantly, hydrocarbons, and to some extent metallic minerals such as Pb, Zn, Sn, and Fe. Nonetheless, the recent pursuit of diversification particularly industrialization has led to the provision of the relevant raw materials (Elueze and Ogunniyi, 1985). Significant among

these are refractory, ceramic, glass, and metallurgical components, including talc. Elueze (1981) reported that meta-ultramafite is widely distributed within the schist belt of Nigeria and it hosts talc bearing rocks which constitute the predominant type, and the unit may contain a basic or minor quantity of tremolite, actinolite, serpentine, chlorite, and magnesite. Talc is a hydrous magnesium silicate and a versatile industrial mineral with a very wide range of applications (Okunlola *et al.*, 2002). Talc bearing rocks are found within the Precambrian Schist belts, which are largely restricted to the south-western and north-central parts of the Nigerian basement (Oyawoye, 1972; Mccurry, 1976). In the Southwest, they occur in notable areas around Iseyin district (Elueze, 1982), Apomu area (Ige, 1985), Obaloru Araromi (Ife Ilesha group) (Akin - Ojo, 1992), Baba-Ode (Okunlola *et al.*, 2002). In the north-central, they can be found in Odogbe, Isanlu Makutu (Ayoade, 1983), Egbe-Isanlu Schist belt (Olobaniyi, 1997), Oro district

(Adekeye, 2001), Kagara (Ojo *et al.*, 2017) However, several authors has worked on the occurrence of talc bodies but there has been little published work on the mineral constituents and their potential in industrial applications. In north central Nigeria, some of the known occurrences are found in the Alla area. Representative samples of talc bearing bodies were therefore selected for further studies so as to assess their suitability for industrial applications.

Geological Settings

The geology of the study area falls within the Precambrian basement complex of north-central Nigeria (Figure 1). The study area is Alla, Isin Local Government Area in Kwara State (Figure 2). It falls within the Precambrian of North-Central, Nigeria, which is a part of the Nigeria basement complex. It has a coordinate of latitude $N08^{\circ} 16' 928''$ and Longitude $E004^{\circ} 57' 187''$. The oldest rocks in the area comprise

a gneiss complex whose principal member is biotite-hornblende gneiss with intercalated amphibolites. Talcs within Nigerian Schist belts are usually associated with amphibolites from which they thought it had been derived (Kehinde – Phillips, and Tietz, 1995). They are conformable lenses within the meta-sediments, and they occur as small low-lying hills within the meta-sedimentary sequence (Adekeye, 2001). Other rock types are older granite, mainly porphyritic granite, gneiss and granite-gneiss, and quartz schist. The minerals that could be identified, particularly in the study area, include talc, feldspar, quartz, mica, etc. The climatic conditions of the area during the dry season last from October to February, while the rainy season in the area begins towards the end of March and ends in October. The humid tropical climate of Ilorin has particularly encouraged comparatively deep weathering of surface rocks.

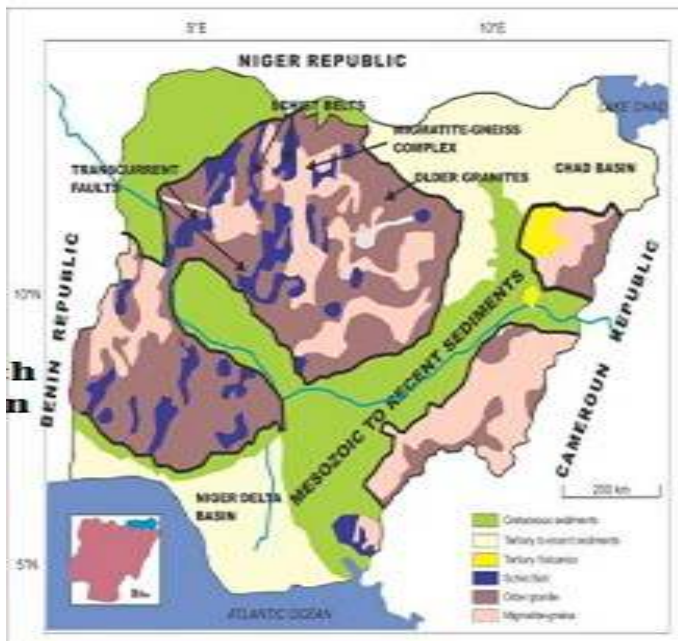


Figure 1: Geological map of Nigeria (After Obaje, 2009)

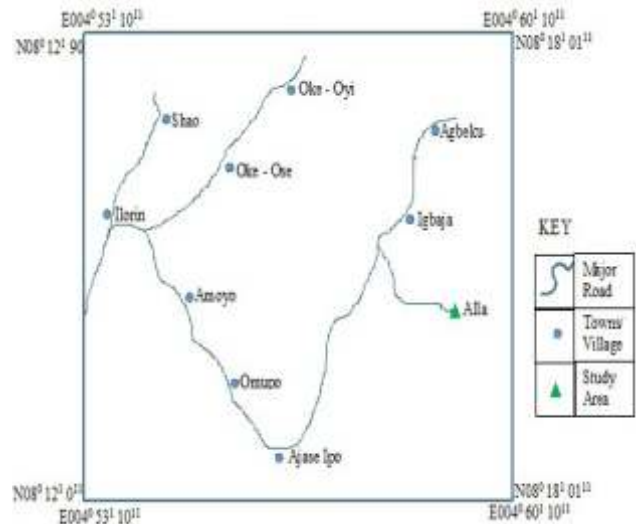


Figure 2: Location map of the study area

Materials and Methods

The research was carried out in two major stages: fieldwork and laboratory analyses. The fieldwork entails the collection of three fresh representative samples of talc using equipment such as a hammer, shovel, sample bags, and

global positioning system, among others. The samples were tagged as sample A, sample B and sample C and they were separated in different sample bags before transported to Afe Babalola University, Ado – Ekiti, Ekiti State for detailed analysis. In the laboratory, the rock samples

were pulverized in preparation for the geochemical analysis. The geochemical analysis carried out include X – Ray diffraction and X – Ray Fluorescence analysis. Based on laboratory analysis, mineral constituents were dissolved based on analytical procedures which involve the addition of 5 ml each of per chloric acid (HClO_4) and trioxonitrate (V) HNO_3 acid and 15 ml Hydrofluoric acid (HF) to 0.5 g of sample. The solution was stirred and allowed to evaporate to dryness after it was warmed at a low temperature for some hours. Four (4) ml of Hydrochloric Acid (HCL) was added to the cooled solution and warmed to dissolve the salts. The solution was cooled and later diluted to 50 ml with distilled water. Light emitted by the ions was converted to an electrical signal by a photo multiplier in the spectrometer. The intensity of the electrical signal produced by emitted light from the ions were compared to a standard and the concentration were then computed. Analytical precisions vary from 0.1 % to 0.04 % for the major elements.

Results and Discussion

X – Ray Diffraction

The result of X-ray diffraction analysis is shown in Table 1 below. X-ray diffraction studies in samples A and B revealed the presence of talc, anthophyllite, and a substantial quantity of chlorite and hornblende with strong peaks (Figure 3 and Figure 4). Strong peaks of quartz and dolomite are close to those of talc and anthophyllite. Talc was identified at (8.71, 26.48, 28.0, 336.70, and 45.53) 2θ values for sample A, while sample B was also identified at (21.06, 26.11, 33.98, and 60.74) 2θ values (Figure 3 and

Figure 4). Peaks of chlorite occur closely with those of talc and are higher than hornblende and quartz at (18.98, 22.00, 55.27) 2θ values, while for Sample B it is at (16.40, 35.52, 40.98 and 68.98) 2θ values. Hornblende and quartz peaks are recorded for Sample A at values of 2θ (21.00, 30.51) for hornblende and of 2θ values for quartz is (34.02 and 40.38). The sample B at its peak for hornblende of 2θ values (25.62 and 30.97) and of 2θ values for quartz (39.47 and 42.70). Dolomite, anthophyllite and muscovite peaks are recorded at values of 2θ (42.26, 50.21 and 68.20). Sample B for dolomite, anthophyllite and muscovite peaks at 2θ values of (57.53, 64.70 and 74.62).

However, the percentage weight composition of talc in samples A and B is 66.95% and 55.97%, respectively (Table 1). The chlorite is 8.55% for sample A and 20.72% for sample B. The Hornblende for both samples is 8.10% and 9.35%, respectively. The quartz for sample A weight percentage composition is 5.35%, while for sample B it is 6.03%. The anthophyllite also has 3.56% (sample A) and 3.49% (sample B). The muscovite also has 5.20% (sample A) and 1.71% (sample B), while the dolomite has 2.29% (sample A) and 2.56% (sample B). The percentage of X-ray diffraction studies for both samples indicate that it has a significant amount of talc and it is made up of talc-chlorite schist. This is as a result of substantial quantities of talc and chlorite, which are found in both samples but are economically viable. Other minor mineral composition include mainly hornblende, quartz, muscovite, anthophyllite and dolomite.

Table 1: Results of X – ray Diffraction for Sample A and Sample B

S/N	Mineral Present	X – ray Diffraction of Percentage Weight Composition (Sample A)	X – ray Diffraction of Percentage Weight Composition (Sample B)
1.	Talc	66.95	55.97
2.	Chlorite	8.55	20.72
3.	Hornblende	8.10	9.35
4.	Quartz	5.35	6.03
5.	Muscovite	5.20	3.49
6.	Anthophyllite	3.56	2.56
7.	Dolomite	2.29	1.71
TOTAL		100%	99.83%

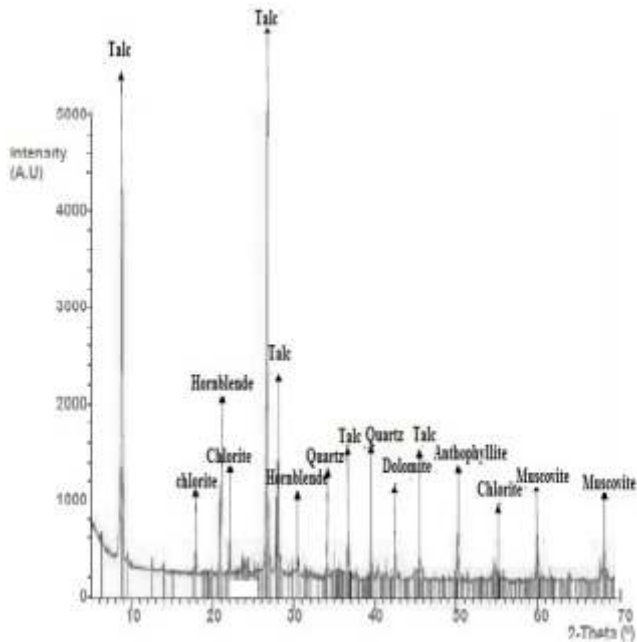


Figure 3: X – Ray Diffractogram of Talc for Sample A

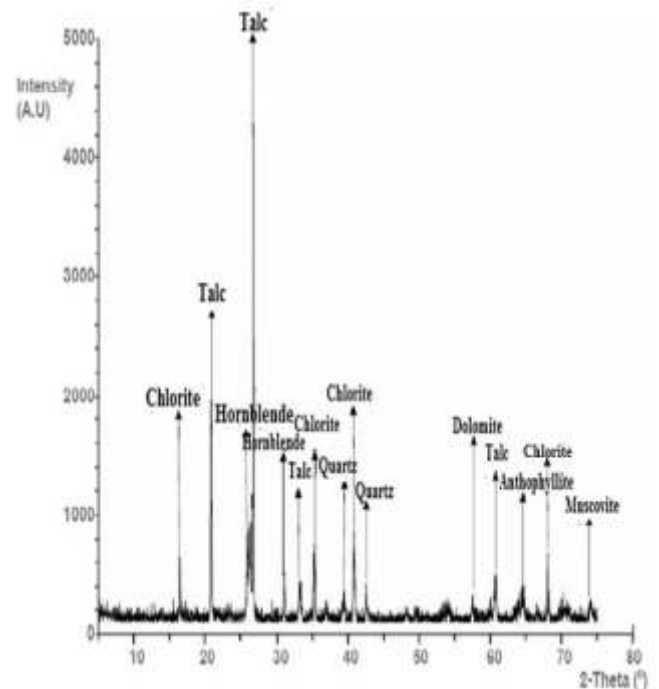


Figure 4: X – Ray Diffractogram of Talc for Sample B

X – Ray Fluorescence

The X – Ray Fluorescence presents major elemental data in Table 2. It reveals that both talcose rock samples have a variable proportion of SiO_2 , which is 57.42% for Sample A, 57.34% for Sample B, and Sample C is 56.55% with an average of 57.10%. This value is similar to Ijero talcose rock (Okunlola, 2011) and Wonu-Apomu talcose rock (Bolarinwa and Adeleye, 2015), but lower than the talcose rock in Agbamu in Oro District (Adekeye, 2001). However, the talcose rock contains a slightly higher mean value when compared to Ilesa talc bodies (Okunlola and Anikulapo, 2006). Al_2O_3 content of Alla area for Sample A is 2.39%, Sample B is 2.09%, and Sample C is 2.25% with an average of 2.24%. This is comparable with those of Ijero talc but with higher differences from Ilesa talc and the talcose rock in Agbamu in Oro district. The Fe_2O_3 content for Samples A, B, and C is 6.18%, 6.33%, and 6.21%, respectively, with an average of 6.24%, which is less than Ijero, Wonu-Aponu, and Ilesa talc but higher than the value in Agbamu in Oro district. The magnesium content (MgO) suggests that Sample A is 25.92%, Sample B is 26.64%, and

Sample C is 28.23% with an average of 26.93%. This suggests that it is lower than Ijero and Wonu-Apomu but has a corresponding value with Ilesa and Agbamu in Oro district talc bodies. However, samples with higher oxide have silica (>57%) and magnesia contents (>28%) but with correspondingly low Al_2O_3 (<2.25%), Fe_2O_3 (<6.33%), CaO (<1.52%), and K_2O (<0.05). The significance of SiO_2 , MgO, Al_2O_3 , Fe_2O_3 , CaO , and K_2O (Table 3) indicates that the oxides significantly reflect subtle mineralogical differences between the samples. The SiO_2 enrichment in the talcose rock is a result of chemical weathering, while the magnesium content suggests hydrothermal alteration accompanied by serpentization of the tholeiitic protoliths. The loss of ignition for sample A is 4.72%, sample B is 4.94% and sample C is 4.88% with an average of 4.85%. The result from the study area is close to that of Wonu Apomu and Agbamu talc but higher than that of Ijero and Ilesa, respectively. According to Durotoye and Ige (1991), the results are comparable to similar talc bodies within the schist belts of southwestern and north-central Nigeria (Table 4). These are very significant in determining its end use for industrial purposes.

Table 2: Chemical Composition of Talcose Rock for Samples A, B and Sample C

S/N	Parameters	Formulae	Percentage weight Composition (Sample A)	Percentage weight Composition (Sample B)	Percentage weight Composition (Sample C)
1.	Silicon Oxide	SiO ₂	57.42	57.42	56.55
2.	Aluminum Oxide	Al ₂ O ₃	2.39	2.09	2.25
3.	Ferric Oxide	Fe ₂ O ₃	6.18	6.33	6.21
4.	Calcium Oxide	CaO	1.41	1.43	1.52
5.	Magnesium Oxide	MgO	25.92	26.64	28.23
6.	Manganese Oxide	MnO	0.04	0.04	0.03
7.	Titanium Oxide	TiO ₂	0.06	0.06	0.05
8.	Copper Oxide	CuO	0.01	0.01	0.01
9.	Potassium Oxide	K ₂ O	0.05	0.05	0.04
10.	Sodium Oxide	Na ₂ O	0.03	0.03	0.03
11.	Sulphide	SO ₃	0.01	0.01	0.01
12.	Lead Oxide	Pb ₂ O ₅	0.01	0.01	0.01
13.	Nickel Oxide	NiO	<0.01	<0.01	<0.01
14.	Zinc Oxide	ZnO	0.01	0.01	0.01
15.	Chromium Oxide	Cr ₂ O ₃	0.02	0.02	0.15
16.	Loss on Ignition	LOI	4.72	4.94	4.88

Table 3: Chemical composition of Talcose Rock from Alla area compared with some Commercial Talcs in other Locations.

S/No	Author/Location	Oxides Composition					
		SiO ₂	Al ₂ O ₃	Fe ₂ O _{3T}	CaO	MgO	L.O.I
1.	Okunlola <i>et al.</i> (2011) Talcose rock in Ijero – Ekiti	56.42	2.25	7.11	2.61	27.74	3.64
2.	Bolarinwa and Adeleye, (2015) Talcose rock in Wonu – Apomu	56.42	2.74	6.43	1.71	29.15	4.58
3.	Bolarinwa and Adeleye, (2015) Talcose rock in Ilesa	52.35	5.17	9.39	1.36	26.34	0.05
4.	Durotoye and Ige, (1991) Talcose rock in Nigeria	53.19	-	1.83	-	31.73	5.23
	Adekeye (2001) Oro District (Agbamu)	58.80	1.42	1.65	2.25	25.72	4.05
5.	Alla Talc (Sample A)	57.42	2.39	6.18	1.41	25.92	4.72
6.	Alla Talc (Sample B)	57.34	2.09	6.33	1.43	26.64	4.94
7.	Alla Talc (Sample C)	56.55	2.25	6.21	1.52	28.23	4.88

Economic Potentials

The geological material of interest in the study area is essentially talcose rock. The unit value of crude talc was estimated to be 26 dollars per metric tons (Barsotti and Morse, 2000). The content of talc, chlorite, hornblende, and a host

of others with SiO₂, Al₂O₃, MgO, and Loss on ignition of talc is are very important in determining its end uses. The SiO₂ of all the samples in the study area, based on the standard specification in Table 4, indicates that it can be used for ceramics/refractories, while

the Al_2O_3 contents can be useful in paints, electrical insulators, and ceramics/refractories. The magnesite contents (MgO) of talcose rock can be used as fertilizers but can also be useful in paper, textiles, fillers, and pharmaceutical industries. Other possible uses of talc after comminution includes insecticides and rubber. According to

Ogunbanjo and Amoka (2005), Talcose rocks attaining industrial specification in this research work can be used for cosmetics, paper, and paints. The low abrasion indicates that talc can also be useful in rubber industries, while the electrical resistivity suggests that it can be used in ceramics, plastics, automotives, and rubber.

Table 4: Summary of Industrial specifications for Talc (Source: Mondo, 2008)

Industry	$\text{SiO}_2\%$	$\text{MgO}\%$	$\text{CaO}\%$	$\text{Al}_2\text{O}_3\%$	$\text{Fe}_2\text{O}_3\%$
Ceramics/Refractories	>56	>28	<1	<4	<1.5
Paint/Plastic	>40	>20	<1	<2.5	<1.5
Paper/Textile	>60	31-33	0.19-3.90	0.93-2.37	0.3
Cosmetic/Pharmacy	>60	<30	<1.5	0.3	<0.75
Fertilizer/Pesticide	>25	-	-	-	<1.5
Electronic Insulators	>60	<30	<1	<2.5	<1.5

Conclusion

Geochemical analysis of talcose rock has been carried out in Alla. The Talcose rock has high SiO_2 , MgO , Fe_2O_3 , L.O.I. contents and low CaO , K_2O contents with variable proportions of Al_2O_3 . On the basis of the mineralogical and geochemical characteristics of the talcose rock, the other major findings of this study are as follows:

- (i). The chemical and mineralogical properties of the talcose rocks were compared to many existing commercial talc, and are suitable for several low- to medium-grade industrial applications such as refractories, paints, paper, electrical insulators, textile filler, and rubber
- (ii). The coexistence of chlorite with talc is not detrimental to talc for many applications because they have similar mineralogical compositions
- (iii). The chemical compositions are important criteria for most of the industrial applications, such as refractories; paints, ceramics, and textiles, which can be extracted or mined in the area.

The data from the present work provide a valid basis tool for choosing the beneficiation methods for specific applications.

References

- Adekeye, J.I.D (2001). Appraisal of Talc Bodies of Oro District, Southwestern Nigeria and their Potential for Industrial Applications. *Bagale Journal of Pure & Applied Sciences*. Vol. 1, pp. 59 – 64.

- Akin-Ojo, O. A. (1992): Compositional and Industrial Studies of Talc Bodies in the Precambrian Domain of southwestern Nigeria. *Unpublished Ph.D. Thesis University of Ibadan*. 215p.
- Ayoade, E. A. O. (1983): The Industrial mineralogical assessment of a Nigerian Talc deposit at Odogbe, Isanlu Makutu. *Unpublished M.Sc Thesis, University of Hull, United Kingdom*. 85p.
- Barsotti, A. F. and Morse, D. E. (2000). Industrial Minerals, Society of Mining, Metallurgy and Exploration. Vol. 53, pp. 17 - 21
- Durotoye, M.A and Ige, O.A. (1991). An Inventory of Talc Deposit in Nigeria and Industrial Application Potentials *Journal of Mining and Geology*. 27 (2), 27-31
- Elueze, A. A. (1982). Mineralogy and Chemical Nature of Meta-ultramafics in Nigerian Schist belts, Nigeria. *Journal of Mining and Geology*, 19, 23-25.
- Elueze, A. A. and Ogunniyi, S.O. (1985). Appraisal of Talc Bodies of the Ilesha District, Southwestern Nigeria and their Potentials for Industrial Application. *Natural Resources Development* 2221, 26-34.
- Elueze, A .A. and Awonaiya, F.A. (1989).

- Investigation of talc bodies in Iseyin area, Southwestern Nigeria in Relation to their Applications as Industrial Materials. *Journal of Mining and Geology*. 25(2), pp. 217-225.
- Kehinde – Phillips, O. O. and Tietz, G. F. (1995). The Mineralogy and Geochemistry of the Weathering Profiles over Amphibolites Anthophyllite and Talc Schists in the Ilesha Schist Belt, Southwestern Nigeria. *Journal on Mining and Geology*. Vol. 31 (1). pp.53 – 62.
- Ige, O. A. (1985): Mineralogical and industrial properties of some Wonu-Apomutalcs, western Nigeria. *Nigerian Journal of Science*. 19, 121-130.
- Mc Curry, P. (1976). The Geology of the Pre-Cambrian to Lower Paleozoic Rocks in Northern Nigeria-a review in Kogbe.
- Mondo (2008). Talc. Global Trends of Talc for Industrial Applications, London, *Mondo Minerals*, 7, pp.57–66.
- Obaje N. G. (2009). Geology and Mineral Resources of Nigeria. *Springer, Berlin, Germany*, ISBN 13:9783540926849 P.221
- Olobaniyi, S. B. (1997). Geological and Geochemical Studies of the Basement rocks and Associated Iron – Formation of Isanlu Schist Belt, Southwestern, Nigeria. Unpublished Ph.D. Thesis, University of Ilorin. P.240
- Ogunbanjo, M.I. and Amoka, I.S. (2005). Froth Floatation Studies on Kagara Talc. *Journal of Engineering, Technology and Industrial Applications*. 1, pp.66-71.
- Ojo, A. A., Tavershima, N. and Ismail, Y. A. (2017) Geochemistry and Origin of Talc Mineralization in Kagara Area (Sheet 142 SE and Part of Sheet 142 SW) North Central, Nigeria, *International Journal of Innovative Research and Development*, Vol. 6 Issue 12
- Okunlola, O.A. and Anikulapo, F.A. (2006). Compositional Characteristics and Industrial Qualities of Talcose Rock to Erin Omu Area, South Western Nigeria. *Journal of Mining and Geology*. 42(2), 113-126
- Okunlola, O. A., Ogedengbe, O. and Ojutalayo, A. (2002). Compositional features and Industrial Appraisal of the Baba-Ode talc occurrence, South Western Nigeria. *Global Journ. Of Geol. Sci*. 1(1), 63-72
- Okunlola, O.A., and Anikulapo, F.A. (2006). Compositional characteristics and Industrial Qualities of Talcose rocks in Erin-Omu area, South Western Nigeria. *Journal of Mining and Geology* 42(2), 113-126.
- Okunlola, O. A., Ogedengbe, O. and Ojutalayo, A. (2002). Compositional Features and Industrial Appraisal of the Baba-Ode Talc Occurrence, South Western Nigeria. *Global Journ. Of Geol. Sci*. 1(1), 63-72
- Okunlola, A.O., Akinola, O.O. and Olorunfemi, A.O. (2011). Petrochemical Characteristics and Industrial Features of Talcose Rock in Ijero-Ekiti Area, Southwestern Nigeria. *Ife Journal of Science* vol. 13, no.2 pp.317 – 326.

Economic Potential of Stream Sediments in Share Sheet 202SW, Northcentral Nigeria

¹Agunleti, Y. S. and ²Adeleke, J. O.

¹Department of Geology, University of Abuja, Federal Capital Territory*

²Department of Geology, Ibrahim Badamasi Babangida University, Lapai, Niger State

Corresponding author: *asylong@yahoo.com

Abstract

The focus on how to locate and develop metalliferous deposits in the country has taken a centre stage. Modern methods of using the peculiar lithological settings as well as geochemical analysis cannot be over emphasized. Stream sediments sample points were pre-determined on relevant topographic maps to make ways to designated locations with the aid of hand-held Geographic Positioning System (GPS) receiver and Compass. The sample points were designed to represent drainage catchment size in the range of 10-30km² each, with even spatial distribution across the area. The choice of the best location for sampling on the field is upstream and far away from any obvious contamination to the natural system such as human and animal tracks; roads and spots where animals assemble in the stream to drink, dumped refuse, bank-fall or soil material in the stream etc. Gold was detected in all samples and showed relatively wide concentrations which ranges from (0.00025 - 0.09480 ppm, Arsenic, which is commonly known as one of the pathfinder elements for gold occurs frequently in the samples. Arsenic was detected in all the samples analyzed and showed concentrations which range between 0.2 ppm and 1.5 ppm, Cerium is one of the REEs and was also detected in all the samples analyzed. It showed concentrations which range between 38.64 ppm and 477.74 ppm. Lanthanum is widely distributed in the study area and the values range from 16.8 ppm –145.9 ppm, Lithium was detected in all the samples analyzed and showed concentrations which range between 1.0 ppm and 12.1 ppm. The study revealed that Ce, La and Pb are enriched in the stream sediments and may justify further economic search for minerals hosting these elements.

Keywords: Gold, Cerium, Lanthanum, Pathfinder, Economic, Stream Sediment.

1 Introduction

Geology and mapping for mineral deposits is an ancient technique. With the recent priority attention given to the diversification of the Nigerian economy, the development of the solid mineral sector has become very active. The focus on how to locate and develop metalliferous deposits in the country has taken a centre stage. Modern methods of using the peculiar lithological settings as well as geochemical analysis cannot be over emphasized. Most applications of geochemistry in mineral exploration focus on detecting and mapping patterns in the chemical composition of the lithosphere or biosphere that can be linked to the effects of mineralization. These may include relative enrichment or depletion of elements, or

changes to element speciation or mineralogical associations. To follow up some geochemical anomalies discovered in a regional stream sediment survey in parts of Northcentral Nigeria, a medium density geochemical sediments survey was carried out around Share Sheet 202 SW, located in Ifelodun L.G.A, Kwara State, North central Nigeria.

2 Literature Review

Stream sediments and other drainage materials are commonly used in regional reconnaissance geochemical mapping for weathered materials (minerals) dispersing mechanically and hydromorphically in catchment area (Hale and Plant, 1994; Hawkes, 1976).

Further dispersion may ensue in stream

sediments when soil or weathering debris that has anomalous metal content becomes incorporated through erosion in stream sediment. Analysis of the fine sand and silt of stream sediment can be a particularly effective method for detection of mineralized bodies within the area drained by the stream (Howarth and Govett, 1983). Geochemical mobility in the secondary environment depends on certain inherent properties of the elements and the main features of the landscape (Smith, 2009).

Understanding the characteristics of basement complex terrain with varied geological history will be the first step towards knowledge of the distribution of mineralization in the stream sediments. Mineral deposits represent anomalous concentrations of specific elements, usually within a relatively confined volume of the Earth's crust (Shannon, 1976; Sharp, 1978). Such an element referred to as a pathfinder, is of value in prospecting because its halo is broader than that of the element of primary interest or because it may be detected more readily by conventional analytical procedures.

Govett (1973) used geo chemical patterns around mineralized systems to identify fertile provinces for mineral deposits especially in the early stages of exploration. This approach is corroborated by measuring regional geochemical features that reflect processes leading to formation of ore deposits (Cohen *et al.*, 2012).

Gold is usually one of the most important elements targeted during stream sediments studies and it is more effective to analyze for the spatial distribution of a suite of elements than the gold alone (Ali *et al.*, 2006; Embui *et al.*, 2013; Suh *et al.*, 2006). Stream sediments have been successfully used in many prospecting projects during recent years in Africa (Salminen *et al.*, 2008). Carranza 2009, 2010) successfully used multifractal models to analyze stream sediment geochemical data to identify threshold values

3 Methodology

3.1 Stream Sediment Sampling

After a detailed desktop study from the drainage pattern of the study area, selections of first and

second order stream were focused on and in carrying this out, samples were collected from both the active channels and the curvatures upstream (Figure 1). Collapsed bank materials were avoided. Samples were taken after scraping off surface materials. Representative composite samples from the sites in the stream bed (over a length of about 50 m) were collected using the shovel. Care was taken to avoid digging into the bedrock. Stream sediments were collected upstream. Enough coarse-grained materials were collected into a plastic pan, enough to yield a minimum of 0.5kg <0.150mm material (dry weight).

3.2 Analytical Methods

All the samples collected after sampling exercise were conveyed to NGSA National Geosciences Research Laboratory (NGRL) at Kaduna, for proper sun drying, packaging and pulverization. A total of thirty-eight (38) selected representative samples of stream sediments were analyzed for major and trace element contents. The samples were thereafter packaged and shipped to MS Analytical, Langley Township, Canada. The analytical techniques for the whole rock geochemical and mineral analysis were performed on the powdered samples by inductively coupled Plasma- Mass Spectrometry (ICP - MS).

4 Results and Discussion

The study area is underlain by migmatitic gneiss, granitic gneiss, quartzitic schist, medium-coarse grained biotite granites, fine grained granites and porphyritic granites (Figure 2). Table 1 shows Pearson correlation coefficient of some trace elements while Table 2 shows geochemical variables of trace elements such as Au, As, Ce, La, Li, Pb, Th and Ag in the stream sediments.

4.1 Trace elements in the study area

Trace elements considered for this study are gold, arsenic, cerium, Lanthanum, lithium, lead, thorium and silver.

Gold (Au)

Gold was detected in all samples and showed relatively wide concentrations which range between 0.00025 ppm and 0.0948 ppm. Within the study area, the high concentration of gold

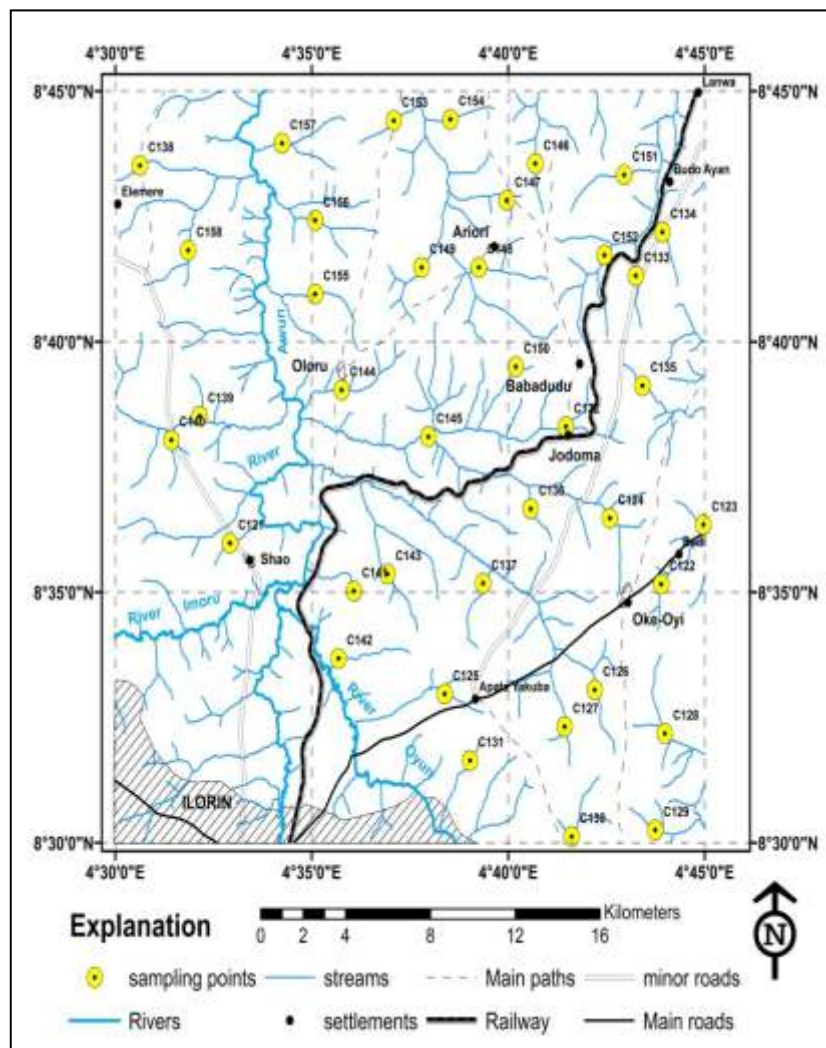


Figure 1: Drainage pattern and sample points of stream sediment within the study area



Figure 2: Sample collection and wet sieving in the field

was observed in the northwestern axis and precisely on a second order stream which is an indication of proximity from the source area. The underlying rock is migmatite gneiss with a contact with the granites. In comparing the background value of Gold (Au) in the stream

sediment samples of the study area (0.00025 ppm) with the average abundance of Au in the earth's crust (0.004 ppm), it is observed that the abundance of Gold (Au) in this area is relatively high.

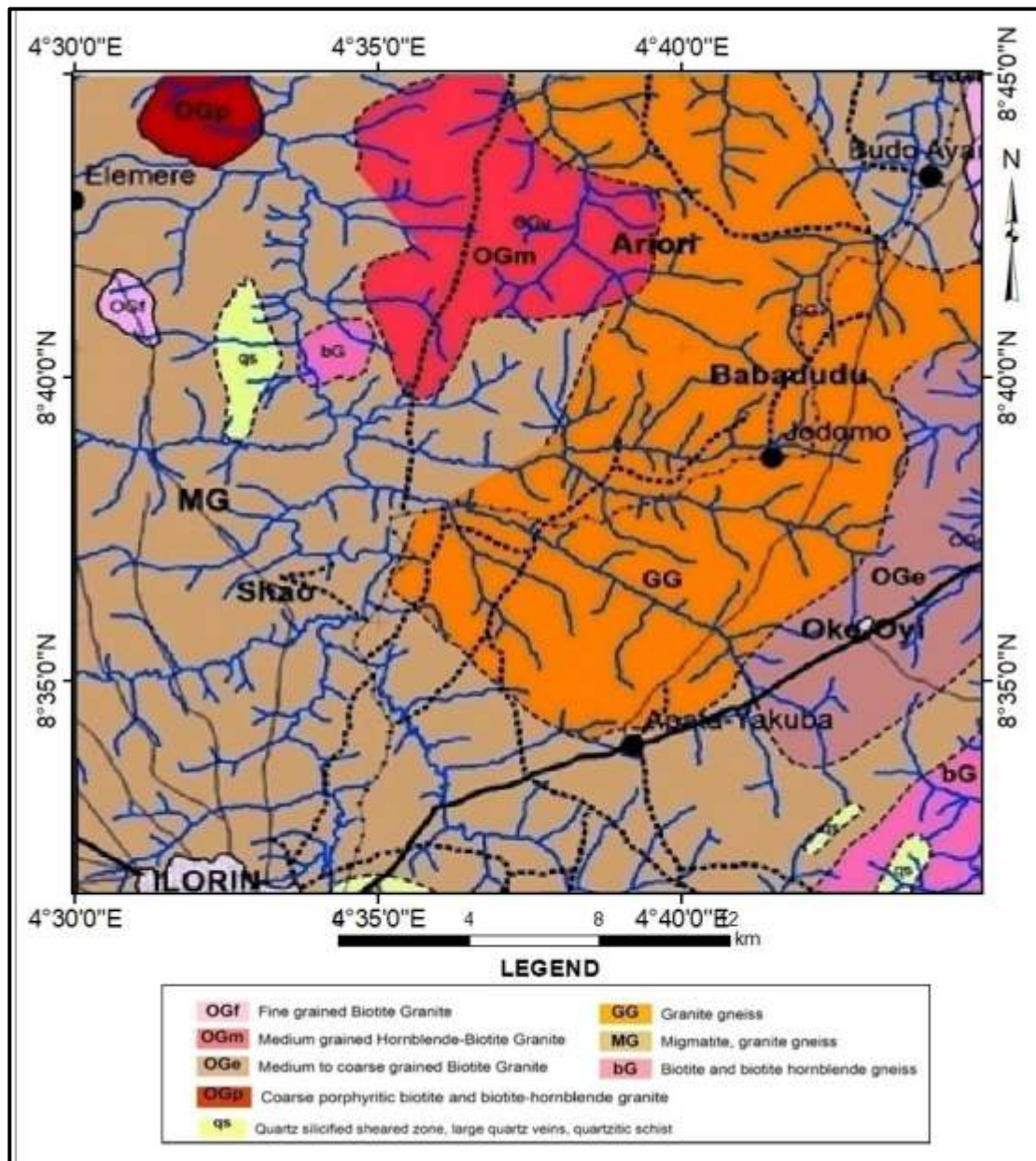


Figure 2: Geological map of the study area (Share Sheet 202SW)

Table 1: Pearson correlation coefficient of some trace element in stream sediments from the study.

	Au	As	Ce	La	Li	Pb	Th
As	0.027						
Ce	0.078	0.748					
La	0.332	0.557	0.895				
Li	0.017	0.518	0.436	0.288			
Pb	0.044	0.783	0.844	0.64	0.453		
Th	-0.002	0.218	0.658	0.709	0.219	0.409	
Ag	0.291	0.104	0.332	0.38	0.223	0.337	0.236

Table 2: Trace elements contents of stream sediments in the study area

Sample I. D	Au	As	Ce	La	Li	Pb	Th	Ag
C121	0.001	0.2	85.3	39.8	2.1	10.0	14.7	0.04
C122	0.000	0.3	70.0	37.3	1.9	8.5	11.6	0.02
C123	0.000	0.2	78.4	29.4	12.1	10.5	10.8	0.03
C124	0.000	0.3	76.9	43.1	5.8	8.7	12.9	0.01
C125	0.001	1.5	477.7	128.5	11.2	36.5	21.1	0.03
C126	0.000	0.4	59.0	29.1	3.3	8.4	8.2	0.02
C127	0.000	0.5	89.5	47.5	3.6	10.8	8.2	0.02
C128	0.000	0.3	164.1	55.1	3.0	11.3	16.0	0.01
C129	0.000	0.6	69.5	30.3	3.1	11.3	8.4	0.01
C130	0.001	0.6	184.2	89.1	2.6	11.4	13.4	0.03
C131	0.000	0.3	109.8	51.6	2.4	9.8	13.6	0.02
C132	0.001	0.4	56.2	21.6	2.4	11.5	6.3	0.02
C133	0.000	0.3	88.4	47.4	1.6	6.9	13.1	0.02
C134	0.000	0.4	51.8	25.5	1.3	6.5	8.7	0.01
C135	0.000	0.5	54.5	16.8	2.0	10.2	5.3	0.01
C136	0.003	0.2	76.1	41.2	1.5	10.1	14.9	0.02
C137	0.000	0.2	89.0	38.9	1.0	7.4	9.5	0.02
C138	0.000	0.3	89.0	40.9	3.3	9.6	14.3	0.02
C139	0.000	0.2	88.4	39.0	1.8	7.7	11.5	0.04
C140	0.000	0.6	383.7	149.5	6.1	20.6	71.5	0.04
C141	0.000	0.6	209.4	102.0	2.8	16.8	10.7	0.03
C142	0.000	0.4	192.6	64.0	3.0	14.7	12.3	0.03
C143	0.000	0.6	193.8	55.0	2.4	17.6	9.5	0.03
C144	0.000	0.3	115.6	56.5	1.8	6.6	5.7	0.02
C145	0.000	0.3	52.6	24.9	3.7	7.6	7.2	0.02
C146	0.012	0.6	102.1	51.8	10.7	6.5	9.5	0.03
C147	0.002	0.3	76.2	49.2	2.8	9.5	8.3	0.05
C148	0.000	0.4	53.8	29.8	1.8	8.4	7.3	0.02
C149	0.000	0.3	52.8	25.9	3.2	11.8	11.5	0.02
C150	0.000	0.3	38.6	27.0	1.3	6.4	4.8	0.01
C151	0.000	0.4	185.1	95.3	1.7	8.7	29.7	0.01
C152	0.000	0.2	123.3	65.7	1.2	7.6	16.3	0.01
C153	0.000	0.2	84.9	47.9	2.7	16.2	14.7	0.02
C154	0.000	0.2	63.8	37.4	1.1	6.8	10.9	0.02
C155	0.000	0.2	94.2	37.1	1.0	14.4	11.6	0.04
C156	0.095	0.4	159.2	111.8	2.5	13.0	13.5	0.04
C157	0.000	0.3	79.0	38.7	1.3	8.2	9.0	0.02
C158	0.001	0.5	81.2	41.1	2.5	12.1	13.1	0.02
Min.	0.000	0.2	38.6	16.8	1.0	6.4	4.8	0.01
Max.	0.095	1.5	477.7	149.5	12.1	36.5	71.5	0.05

Arsenic (As)

Arsenic, which is commonly known as one of the pathfinder elements for gold occurs frequently in place of some of the sulfur in the sulfides that are principal ores of many of the heavy metals. Arsenic was detected in all the samples analyzed and showed concentrations which range between 0.2 ppm and 1.5 ppm. The highest concentration value of arsenic within the study area falls around the southern portion but in comparing the background value of arsenic which is 0.3 ppm with the average abundance of element in the earth's crust which is 1.8 ppm, the abundance of arsenic is also relatively low.

Cerium (Ce)

Cerium is one of the REEs and was also detected in all the samples analyzed. It showed concentrations which range between 38.64 ppm and 477.74 ppm. The concentration trend of cerium takes a NW/SE orientation. These areas have an underlying geology which includes granite gneiss and migmatite gneiss and when comparing its background value (85.33 ppm) with its average crustal abundance of element which is 66.5 ppm, the abundance of cerium is relatively high.

Lanthanum (La)

Lanthanum is widely distributed in the study area and the values range from 16.8 ppm –145.9 ppm. Also, as one of the REEs, it shows a similar pattern of concentration with that of cerium and extends to the northeastern part of the study area. The areas showing high values has their underlying geology to include granite gneiss, migmatite gneiss and porphyritic granite. In comparing its background value (41.1 ppm) with its earth's average crustal abundance, which is 39 ppm, the abundance of lanthanum is relatively high.

Lithium (Li)

Lithium was detected in all the samples analyzed and showed concentrations which range between 1.0 ppm and 12.1 ppm. Though being highly sought for, the concentration of lithium isn't high within the study area and moreover the underlying geology around the highest value is granite gneiss and not pegmatite which is the host rock for lithium mineralization. When the

background value of lithium (2.4 ppm) within the study area is compared with its average crustal abundance which is 20ppm, the abundance of lithium is very low.

Lead (Pb)

Lead concentrations range between 6.4 ppm and 36.5 ppm. Areas showing the highest concentration occurs towards the southern part with the underlying rocks being migmatite gneiss. The area having the highest value is underlain by the migmatite gneiss, occurring towards the southern. The abundance of lead is relatively moderate when comparing the background value (10 ppm) within the study area with the average crustal abundance which is 14 ppm.

Thorium (Th)

Thorium shows range of concentrations between 4.8 ppm and 71.5 ppm. Areas showing high values of thorium are mostly underlain by the migmatite gneiss and tends to take a concentration trend of NW/SE. A comparison of the background value (11.5 ppm) for thorium in the study area with its average abundance in earth's crust (9.6 ppm) shows that thorium is relatively high. These anomalous and relatively high Th concentrations are significant and may be related to suspected tin mineralization.

Silver (Ag)

Silver was detected in all the samples analyzed and showed concentrations which range between 0.01 ppm and 0.05 ppm. Areas showing high values of silver are mostly underlain by the migmatite gneiss and a comparison of the background value (0.02 ppm) for silver in the study area with its average abundance in earth's crust (0.075 ppm) shows that silver is relatively very low.

5. Conclusion

5.1 Economic potential in the area

The average crustal abundance of elements in the earth and their distribution within the study area for some selected trace elements in stream sediments justify their economic potential. Gold was detected in all samples and showed relatively wide concentrations which ranges from 0.00025 - 0.0948 ppm. Arsenic, which is

commonly known as one of the pathfinder elements for gold occurs frequently in the samples. Arsenic was detected in all the samples analyzed and showed concentrations which range between 0.2 ppm and 1.5 ppm Cerium is one of the REEs and was also detected in all the samples analyzed. It showed concentrations which range between 38.64 ppm and 477.74. Lanthanum is widely distributed in the study area and the values range from 16.8 ppm –145.9 ppm. Lithium was detected in all the samples analyzed and showed concentrations which range between 1.0 ppm and 12.1 ppm. Though being highly sought for, the concentration of lithium is not high within the study area and moreover the underlying geology around the highest value is granite gneiss and not pegmatite

which is the host rock for lithium mineralization. Lead concentrations range between 6.4 ppm and 36.5 ppm. Thorium shows range of concentrations between 4.8 ppm and 71.5 ppm. Silver was detected in all the samples analyzed and showed concentrations which range between 0.01 ppm and 0.05 ppm.

Table 3 revealed that Ce, La and Pb are enriched in stream sediments sampled in the study area and may justify further economic search for minerals hosting these elements. The correlation of Ce vs La and Ce vs Pb are 0.895 and 0.844 respectively revealed that these elements are not just elevated in the streams sediments but are co-genetic in relationship.

Table 3: Average crustal abundance and enrichment of some trace element content in stream sediments from the study.

Average Crustal Abundance (Wedepohl, 1995)		Average Crustal Abundance (This Study) N=38	Enrichment Factor	Remarks
Elements	ppm			
Ce	60	115.79	55.79	Enriched
La	30	51.65	21.65	Enriched
Y	24	15.15	-8.85	Not Enriched
Zn	79	14.21	-64.79	Not Enriched
Pb	10	11.07	1.07	Enriched
Cu	68	6.4	-61.6	Not Enriched
Co	30	5.29	-24.71	Not Enriched
Ni	90	4.55	-85.45	Not Enriched
Sc	16	2.18	-13.82	Not Enriched
Sn	2.2	0.63	-1.57	Not Enriched
Ag	0.08	0.02	-0.06	Not Enriched
Au	0.0031	0.001	-0.0021	Not Enriched

References

- Ali, K., Cheng, Q., Wenchang, L., and Yongqing, C. (2006). Multi-element association analysis of stream sediment geochemistry data for predicting gold deposits in south- central Yunnan Province, China. *Geochemistry: Exploration, Environment, Analysis*, 6, p.341– 348.
- Carranza, E. J. M. (2009). Mapping of anomalies in continuous and discrete fields of Stream sediment geochemical landscapes. *Geochemistry: Exploration, Environment, Analysis*, 10(2), p.171–187.

- Carranza, E. J. M. (2010). Catchment basin modeling of stream sediment anomalies revisited incorporation of EDA and fractal analysis. *Geochemistry: Exploration, Environment, Analysis*, 10(4), p.365–381.
- [Cohen, D. R., Rutherford, N. F., Morisseau, E. and Zissimos, A \(2012\) Geochemical patterns in the soils of Cyprus. *Science of the Total Environment* 420, p.250262.](#)
- Embui, V. F., Omang, B. O., Che, V. B., Nforba, M. T., and Suh, E. C. (2013). Gold grade variation and stream sediment geochemistry of the the Vaimba-Lidi drainage system, northern Cameroon. *Natural Science*, 5 (2 A) , p.282–290.
- [Govett, G. J. S. \(1973\). Differential secondary dispersion in transported soils and post-mineralization rocks: An electrochemical interpretation. In: Jones MJ \(ed.\) –Geochemical Exploration 1972, p.8191. London: Institution of Mining and Metallurgy.](#)
- [Hale, M. and Plant, J. A. \(1994\) Handbook of Exploration Geochemistry. Vol. 6: Drainage Geochemistry. Amsterdam: Elsevier.](#)
- [Hawkes, H. E. \(1976\). The downstream dilution of stream sediment anomalies. *Journal of –Geochemical Exploration* 6, p.345358.](#)
- Howarth, R. J. and Govett, G. J. S. (1983). “Handbook of Exploration Geochemistry, Vol.2: Statistics and Data Analysis in Geochemical Prospecting,” Elsevier, Amsterdam
- Salminen, R., Kashabano, J., Myumbilwa, Y., Petro, F. N., and Partanen, M. (2008). Indications of deposits of gold and platinum group elements from a regional geochemical stream sediment survey in NW Tanzania. *Geochemistry: Exploration, Environment Analysis*, 8 , p.313–322.
- Shannon, S. S. (1978). Uranium hydrogeochemical and stream sediment reconnaissance of the Pueblo NTMS quadrangle, Colorado, including concentrations of forty-three additional elements, GJBX-14 (79), 14pp.
- Sharp, R. R. (1978). Results of elemental analyses of water and waterborne sediment samples from areas of Alaska proposed for the Chukchi Imuruk National Reserve, Sela-wik National Wildlife Refuge, and Cape Krusenstern National Monument, GJBX-26 (79)
- [Smith, D. B. \(2009\). Geochemical studies of North American soils: Results from the pilot study phase of the North American Soil Geochemical Landscapes Project. *Applied –Geochemistry* 24, p.13551356.](#)
- Suh, C. E., Lehmann, B., and Mafany, G. T. (2006). Geology and geochemical aspects of lode gold mineralization at Dimako - Mboscorno, SE Cameroon. *Geochemistry: Exploration, Environment, Analysis*, 6, p.295– 309.
- Wedepohl, K. H., (1995). The composition of the continental crust. *Geochimica et Cosmochimica Acta*, 59, p.1717-1232

