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Mine Geo-environment Assessment: Carbonate Rock Mine Waste as Construction Material Addictive and Coupled with Pollution Index Model

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Abstract

Overburden material is typically removed in surface mining operations to expose the primary ore deposit. Because of the presence of trace minerals, environmental pollution and acid drainage are caused when the overburdened materials are removed from the mine site and transported to another location. In order to promote the economic and environmental sustainability of dolomite mining, the waste materials must therefore be evaluated for their environmental impact and potential industrial application. Akoko Edo Nigeria is known for its large production of dolomite and carbonate rock with large tonnage waste. The hydrogeochemical and geotechnical analysis of selected mine in this area is performed by randomly collecting and analyzing soil and water samples from four exploration drill holes using an atomic absorption spectrophotometer. The geotechnical analysis results show that dolomite waste soil is suitable for constriction material addictive such as road subgrade, dam design, highway, and other construction work. According to the study's findings, the mine water is slightly polluted, as measured by both the Overall Index of Pollution (OIP) and the Pollution Load Index (PLI). The chemical analysis of the mine pit water also reveal that the mean value of electrical conductivity, TDS, iron, manganese, copper, and lead all exceed the WHO and SON standards for a safe drinking water. A new pollution assessment model with suitable prediction correlation accuracy (R2= 0.76, mean average error = 0.27) is also developed in this work.

1. Introduction

Mining waste is overburdened or barren rock stripped during the extraction and processing of mineral resources. Such waste includes topsoil overburden (that is removed to gain access to mineral resources) as well as waste rock and tailings [1]. Industrial mineral extraction is the process of removing valuable minerals from the earth's crust, which is most commonly accomplished through blasting. Ikpeshi, Nigeria's mines have the greatest carbonate processing capacity in Edo State, with the ability to crush 175,000 tons of ore every day [2]. According to [2], the geological area of Ikpeshi is home to a wide variety of mineralized rocks, many of which have a high concentration of calcite and metal. The quantity and mobility of metals present in the rocks of the catchment area typically determine the concentrations of trace metals in rivers and the rate of underground water contamination. During surface mining, a large amount of material is excavated to enable direct access to the main deposit [3]. The volume of waste produced thus

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depends on the mine's size, the geological, and geotechnical contrasts between the orebody and its host rock, and the mine's technical maturity. These waste materials are usually abandoned, and considered worthless due to the need for specific ore during the mining period. Mining activities contribute to environmental pollution if not properly managed with a good waste control management system. At present, the assessment of dolomite mine waste as construction materials addictive is still not very clear and well-understood. According to Idris *et al*., the sources of pollution in Ikpeshi's mining terrain are open pits, waste disposal areas, haulage roads, processing plant mills, waste rock pile areas, and tailing [4]. They noted that the flow of contaminated drainage from a surface mine can directly degrade the groundwater situation downhill from the mine. This mine drainage can originate from pits, ponds or the infiltration and flow of rainwater and groundwater during mining and frequently during reclamation [5]. Similarly, the impact of carbonate minerals on the hydrogeochemical properties of the surface and underground water is still unrevealed to explain the classification and applicability. How to get the best road-filling earth materials is one of the important issues studied in the fields of civil and structural engineering both at home and abroad [6]. During construction work, landfilling materials are often gotten from borrowed pits for leveling and land grading; such borrowed materials sometimes contribute to the quick failure of roads due to the low strength and clay content effect [7]. According to Mukiza *et al*., road base materials support the stiffness and load-bearing capacity of the road and explained the reliability of the road [8]. The heterogeneous nature of waste material is a result of the stone fragment present and the weathered materials making them a good road-filling material that can contribute to the load-bearing capacity [8]. Research work had focused on various materials and their suitability for civil construction works [9-11]. The assessment of dolomite waste had yet to be considered. Dolomite as carbonate rock has a high potential to support the cementing rate and stiffness of road base [12]. Understanding soil geotechnical properties are critical to the practice of construction and structural engineering because the design and construction work such as road infrastructures, port facilities, and waste disposal plants necessitates the consideration of critical environmental issues to ensure sustainability and public acceptance [13]. The first step in any engineering structure site investigation is to identify the geological conditions and properties of the materials that can have a significant impact on the construction [14]. The failure of building structures has increased inexorably in the recent years throughout Nigeria, becoming a source of serious concern for building engineers [15]. Investigating soil and other building addictive materials like mine waste is thus critical for improving engineering structural design. When buildings impose very heavy loads and the zone of influence is very deep, Roy and Bhalla observed that it would be preferable to invest some money in sub-surface exploration rather than overdesigning the building and increasing its cost [16]. Understanding the applicability of other materials such as mine waste gives support to construction works, and improves building and other construction work stability. According to Roy and Bhalla, building soil properties such as plasticity, compressibility or strength always affect design stability, status after loading, and ground response over time [16]. A lack of knowledge of soil properties before application in building any engineering structure, according to Douglas and Ransom, can result in construction errors [17]. The plasticity index and liquid limit are two of these properties that can help an engineer understand the consistency or plasticity of clay [4].

To determine the applicability of dolomite soil waste, its engineering suitability has been considered in this study. Most construction company selects construction material based on apparent similarity to other well known soils, as soil load-bearing capacity is dependent on soil type and other conditions such as groundwater and environmental factors. The impact of soil property on construction work had received numerous considerations from several authors [18].Work shows the influence of soil structure on it engineering property. Fine-grained characteristics reduce the load-bearing capacity as compared to coarse-grained soils [18]. In 2009, Oke *et al*. studied the geotechnical characteristics of the sub-soil at a collapsed building site in Ebute-metta, Lagos [19]. Through field observations and laboratory analysis of collected soil samples, the soil properties were evaluated, and found to contribute to the failure. The findings revealed that the presence of unfavorable soil conditions contributed to the collapse of the four-story building structure in Ebute-Metta on July 26, 2006. They discovered two unfavorable soil conditions: the presence of reddish-brown, lateritic, stiff, silty clay with a thickness of 10.50 m, on which a shallow foundation was built, and the presence of highly compressible materials such as wood, plastic, and nylon at the foundation level. Instead of wasting mine overburden materials, these materials can be considered usable for engineering work. This paper focused on engineering application of dolomite soil waste and dolomite small scale mining impact in the Akoko Edo region of Nigeria.

The applicability of soil for construction work depends on it engineering properties, which depend on the soil's various features, characteristics, and the chemical properties. To consider Akoko Edo dolomite overburden material suitability for construction material addictive, the first section of this paper examined the geotechnical properties of mine soil to determine the suitability as a construction material. The other part of this paper focused on assessing the mine activities effect on surface and underground water using various evaluation indices, hydrogeochemical analysis with world health organization standard. To minimize the mine advance effect on water, a new prediction model was also proposed for the prediction of pollution index using the origin of chemical ions in the case study area.

2. Materials and methods

This section explains the methodology used in achieving the purpose of this study, and also gives brief information about the mine's geological properties and mine site state of art condition.

2.1. Sample collection

The case study mine, Golden girl dolomite quarry, is located at Akoko Edo, Edo state Nigeria depicted in Figure 1. Purposeful samples were collected from the mine waste dump area (see Figure 2) following Etikan and Bala with the coring machine [20]. A lithologic sample was obtained from four drilled holes using a Dutch Cone penetrometer test machine. The tests were distributed throughout the case study area to provide an accurate representation of the subsoil condition directly beneath the area. The penetrometer test required 2.5 tons of testing equipment. When the anchor of the testing equipment began to pull, the tests were called off. Drilling was done with an auger borehole machine and a light cable percussion drilling rig equipped with a shell and auger tools. The drilling was completed to a depth of 30m below the existing ground level. Standard Penetration Tests (SPTs) and soil sampling were performed in-situ during the drilling operations at appropriate depth intervals of 0.75 to 1.50 m. Section 2.1 contains information on the sub-soil strata types encountered in the borehole as well as the results of the in-situ Penetration Tests. The borehole log was created after physically logging soil samples extracted from boreholes and taking laboratory test results into account. The depths of the four drill holes are shown in Table 1. The flow sheet/specific objectives of this research work are presented in Figure 3.

Table 1. Characteristics of the sampling drill holes.

Drill hole ID	Drill depth
DH1	4.5
DH2	5.0
DH3	4.0
DH4	5.0

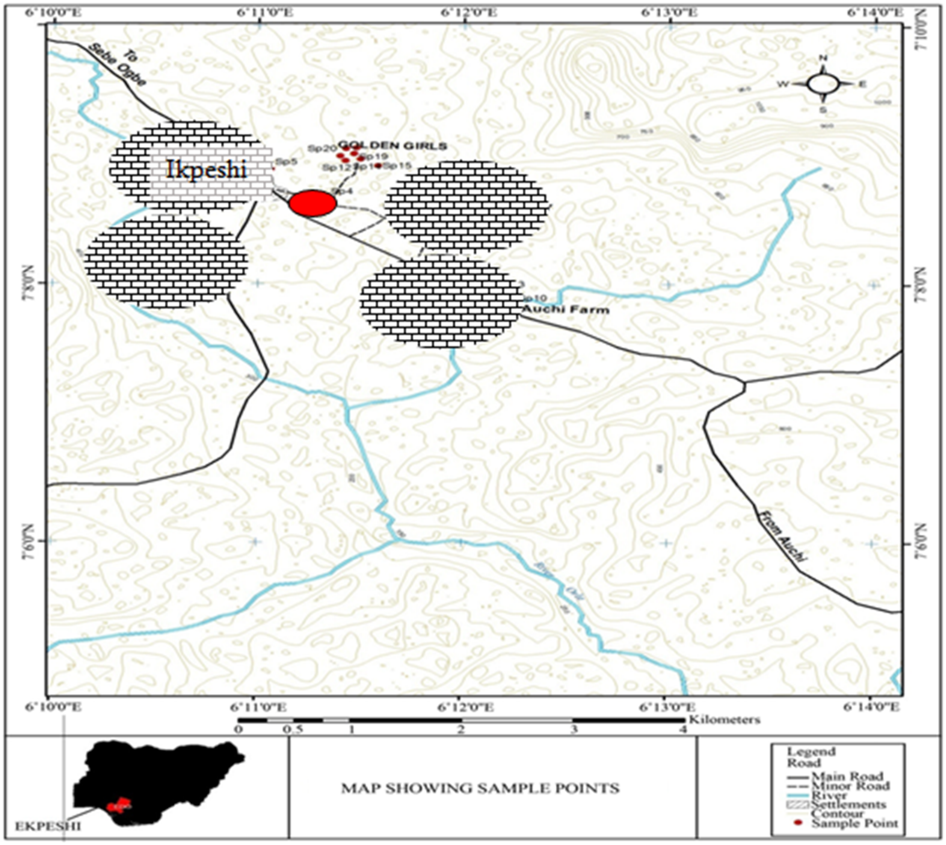


Figure 1. Topographic map showing the case study area after Idris *et al.* [4].

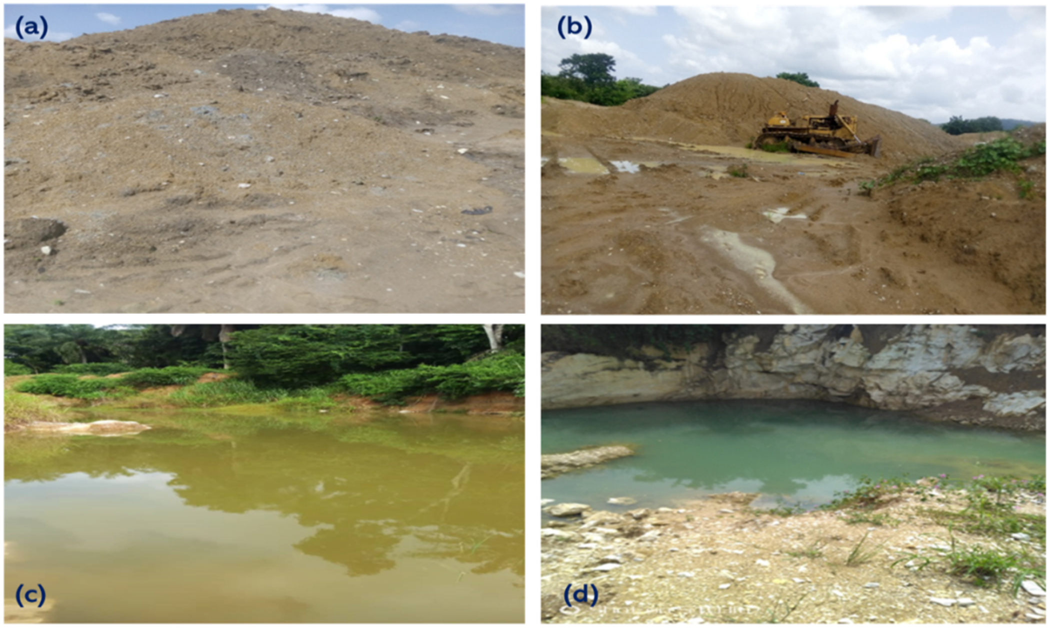
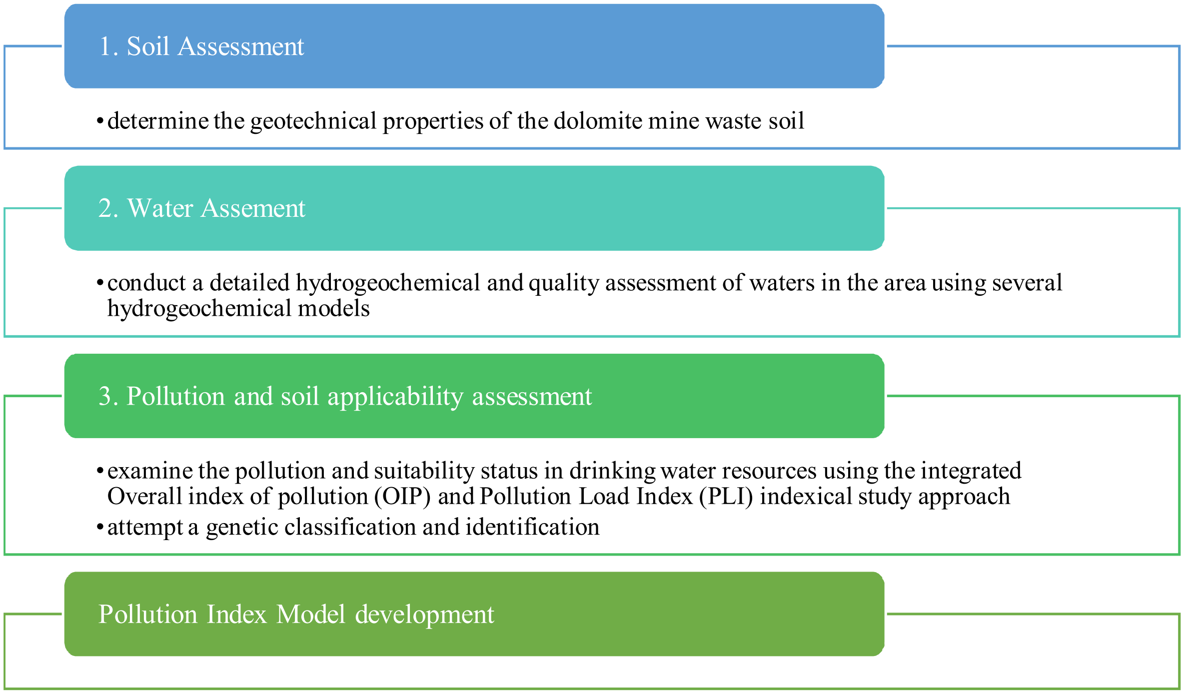


Figure 2.Shows waste soil dump (a&b), and surface water (c&d) of Ikpeshi dolomite mining site.



1. Soil Assessment

- determine the geotechnical properties of the dolomite mine waste soil

2. Water Assement

- conduct a detailed hydrogeochemical and quality assessment of waters in the area using several hydrogeochemical models

3. Pollution and soil applicability assessment

- examine the pollution and suitability status in drinking water resources using the integrated Overall index of pollution (OIP) and Pollution Load Index (PLI) indexical study approach
- attempt a genetic classification and identification

Pollution Index Model development

Figure 3. Study objectives summary

2.2 Mine waste soil geotechnical property test

In general, geotechnical tests involve determining specific gravity, soil shear strength, sieve analysis, cohesion, angle of internal friction, and other strength parameters and index properties. These tests were carried out on both the undisturbed cohesive soil samples and the remolded coring samples. The testing samples came from borehole drilling operations. The undisturbed recovered tube was subjected to an undrained triaxial compression test, and an Oedometer Consolidation test per relevant sections of the British Standard Institution Code of Practice as specified in B.S. 1377 of 1990-Methods of Test for Soils for Civil Engineering Purposes. The test results are presented in tabular and graphical formats in the following section. According to [16], the water content of fine-grained soil has a significant impact on its consistency. The water content of a fine-grained soil slurry gradually decreases, causing it to change from a liquid to a plastic state, then to a semi-solid state, and finally to a solid state. Depending on the soil, the water content at these transitions varies. Roy and Bhalla explained how the mine soil waste consistency limits were determined [16]. The water content at the boundary between the liquid and plastic states of consistency of the soil, expressed as a percentage of the weight of the oven-dried soil, was defined as the liquid limit of the soil [16]. Although sandy soil does not have a plastic stage, very fine sand does, as mentioned by [21]. The plastic limit of soil is an important property that shows its suitability as a construction material. Atterberg classified mine soil wastes based on the plasticity index, demonstrating correlations between the plasticity index, soil type, degree of plasticity, and degree of cohesiveness (Table 2) [22].

Table 2.Type of soil based on plasticity index [16].

Plasticity index (%)	Soil type	Degree of plasticity	Degree of
0	Sand	Non-Plastic	Non-cohesive
<7	Silt	Low plastic	Partly cohesive
7-17	Silt clay	Medium plastic	Cohesive
>17	clay	Highly plastic	Cohesive

Soil specific gravity is the mass of soil solids divided by the mass of an equal volume of water. The soil property revealed the impact of soil mineralogy [23] as well as the history of weathering on the soil [24]. According to Raj, soil-specific gravity is relatively important in terms of the qualitative behavior of the soil [25] and useful in soil mineral classification, with iron minerals having a higher specific gravity value than silicas [26]. The soil property index indicates the suitability of the soil as a construction material; a higher specific gravity value indicates a greater strength for roads and foundations.

2.3. Mine surface and groundwater hydrogeochemical analysis

Ten water samples total were taken from the studied area including surface water (pit and stream) used for domestic purposes. In November and December of 2019, the sampling was done during the transition period (i.e. the end of the rainy season). The pH and TDS of in-situ physical variables were measured using a pH-meter. The samples were taken in 2-L sterilized plastic bottles, properly labeled, and stored in ice-filled coolers. Sample of water for the 10 field-collected water samples, laboratory work was done using Atomic Absorption Spectrophotometer (AAS) analysis. The composition and traces of elements in the Ikpeshi samples were determined with the help of AAS analysis. There were a total of 18 water quality parameters that were examined. These were further divided into three categories: heavy metals, major chemical ions, and physical parameters (properties). The major chemical ions include Mg^{2+}, K^+, Na^+, Ca^{2+}, Cl^-, SO_4, and HCO_3, while the heavy metals include Mn, Ni, Pb, Zn, Fe, and Cu. According to the American Public Health Association, the American Water Works Association, and the Water Environment Federation [27-28], the water sample was tested for its hydrogeochemical properties. The results of the element analysis of groundwater and surface (pit and stream) water samples from the studied area were compared with the maximum acceptable limits for drinking water quality set by the World Health Organization (WHO) [29] and the Standard Organization of Nigeria [30]. To find out where the chemical ions in the waters came from, the chloro-alkaline index values of the major chemical ions were calculated (Equations (1, 2)). Li *et al.* were able to figure out where and how often ion exchange processes happened in water by using these indices, knowing how the main ion exchange processes in water work can help control how contaminants and pollutants move through water and soil [31]. When the chloro-alkaline index (CAI) is negative, the forward ion-exchange process is more likely to be going on. However, a positive CAI signifies the reverse ion exchange process [32]. In the present work, the CAI values were determined for each sample using Equation (1).

$$\text{Chloro-alkaline index (CAI)} = \frac{Cl^- - Na^+ + k^+}{SO_4^{2-} + HCO_3^-} \qquad (1)$$

To further establish a clearer understanding of the origin of chemical ions in the case study waters, it was necessary to determine the rock water equilibrium. This was done by calculating the Gibbs ratios represented in Equation (2).

$$\text{Gibbs Ratio (GR)} = \frac{Na^+ + K^+}{Na^+ + K^+ + Ca^{2+}} \qquad (2)$$

In this study, the overall index of pollution (OIP) was calculated using the same method that Sargaonkar and Deshpande used to figure out how polluted drinking water sources are [29]. In this study, the OIP for 18 parameters (including pH, TDS, EC, TDS, HCO_3, K^+, Mg^{2+}, SO_4, Fe, Mn, Zn, Cu, and Pb) was evaluated. Equations (3, 4) were used to compute the OIP as an average index value.

$$\text{OIP} = \sum_{i=1}^{n} \frac{PI_i}{n} \qquad (3)$$

$$\text{PI} = \frac{Vn}{Vs} \qquad (4)$$

where i = 1, 2…*n*,*n* = the number of parameters, PI is the pollution index for the ith parameter, Vn is the observed value of each parameter, and Vs is the standard value of a particular parameter given by the Standard Organization of Nigeria (SON) andthe world health organization (WHO) [29, 30].Following the classification scheme of [31], OIP $\leq$ 1 signifies that excellent water quality is under class C1, OIP of 1 $\geq$ 2 is of acceptable quality and classified under Class C2, and OIP of 4 $\geq$ 8 indicates slightly polluted water and is categorized under the class C3. However, OIP 8 $\geq$ 15.9 signifies polluted water (class C4), and OIP > 16 indicates heavily polluted water (class C5). The pollution load index (PLI) was also used to determine the degree to which the concentration of a particular heavy metal in water exceeds its background value (concentration). Additionally, the PLI was used to determine the summary indication of the overall extent of trace metal pollution among the water samples. The PLI was determined using the functions expressed in Equation (5) [32-34].

$$\text{PLI} = \sum(PI_1 \times PI_2 \times PI_3 \times PI_4 \ldots\ldots \times PI_n) \qquad (5)$$

where PI represents the pollution index described in Equation (4). The classification scheme by Tomlinson *et al*. [34] was employed in this present study: PLI: 1 ≥ 2; PLI 2 ≥ 3: unpolluted-to-moderately polluted; PLI < 1 = unpolluted; PLI 3 ≥ 4: moderately-to-highly polluted; PLI 4 ≥ 5: highly polluted; PLI > 5: very highly polluted. According to the Bhutiani *et al*. [35] classification scheme, PLI < 1 indicates no pollution, 1 < PLI < 2 represents moderate pollution, and2 < PLI < 3 signifies heavy pollution, whereas PLI > 3 is an indication of extremely heavily polluted water source. A new proposed pollution index model was developed using the origin of chemical ions in the case study. The pollution index result was used as the target variable with the Gibbs Ratio (GR) to developed an exponential model using Microsoft© Excel functions. To accurately evaluate the developed model prediction error, four model error assessment indices were used to assess the model predicted values. The proposed model prediction accuracy checkers used were correlation coefficient, root mean square error (RMSE), and mean absolute error (MAE).

RMSE shows the fitted standard deviation of the variation between the actual values and the predicted values from a model; it is computed using Equation (6).

$$\text{RMSE}=\sqrt{\frac{\sum_{i=1}^{N}(Ai-Pi)^2}{N}} \tag{6}$$

MAE expresses the mean absolute error of model predicted values, giving close reflection of the exact predictive value relationship with the actual value. MAE is calculated using Equation (7).

$$\text{MAE}=\frac{1}{N}\sum_{i=1}^{N}|Ai-Pi| \tag{7}$$

where P_i indicates the predicted value, and A_i indicates the actual value.

3. Results and Discussion

This first section presents the results of the field investigation and data collection. The second section presents the laboratory test results, interpretation, and discussion using generally acceptable standards.

3.1. Mine soil waste profile

As seen in the borehole, the soil stratigraphy at this site is made up of dark brown to grayish lateritic sandy clay. The top layer is less than 1 m and 2.25 m thick. The main things that were used to divide the deposits into different strata were the general condition of the overburden, their engineering properties, and other physical and index properties. Tables 3-6 have information about the stratigraphic profile of the mine soil that was found by drilling a hole at the site.

Table 3. DH 1 stratigraphic profile.

Stratum	Thickness of stratum(m)	Descriptions of stratum
0.00 –2.25	2.25	Dark brownish to greyish lateritic sandy clay with gravel in-situ
3.00–8.25	5.25	reddish brown very stiff lateritic clay.
9.00–12.75	3.75	Brown to yellowish very stiff sandy Clay.
13.50–30.00	16.50	Brownish medium to dense clayey Sand. SPT values range from 22 to 37

Table 4. DH 2 stratigraphic profile.

Stratum	Thickness of stratum(m)	Descriptions of stratum
0.00–2.25	2.25	Dark brown to greyish stiff lateritic sandy clay with gravel
3.00–8.25	5.25	Reddish brown very stiff clay.
9.00–21.00	12.00	Brownish very stiff sandy clay.
21.75–30.00	8.25	Dark brownish dense clayey sand. SPT value of 33.

Table 5. DH 3stratigraphic profile.

Stratum	Thickness of stratum (m)	Descriptions of stratum
0.00–1.50	1.50	Grey to yellowish lateritic clay with gravel
2.25–17.25	15.00	Brownish to yellowish/reddish very stiff to hard clay.
18.00–19.50	1.50	Brownish to yellowish very stiff sandy clay.
20.25–30.00	9.75	Light brownish medium silty sand with gravel in place.

Table 6. DH 4stratigraphic profile.

Stratum	Thickness of stratum(m)	Descriptions of stratum
0.00–0.25	Less than 1m	Light grey silty sand with root plant
0.75–8.00	7.25	Dark grey medium sandy clay.
3.75–17.25	13.50	Reddish-brown to greyish very stiff to hard clay.
18.00–19.50	1.50	Brownish to yellowish very stiff sandy clay.
20.25–30.00	9.75	Light brownish medium silty sand.

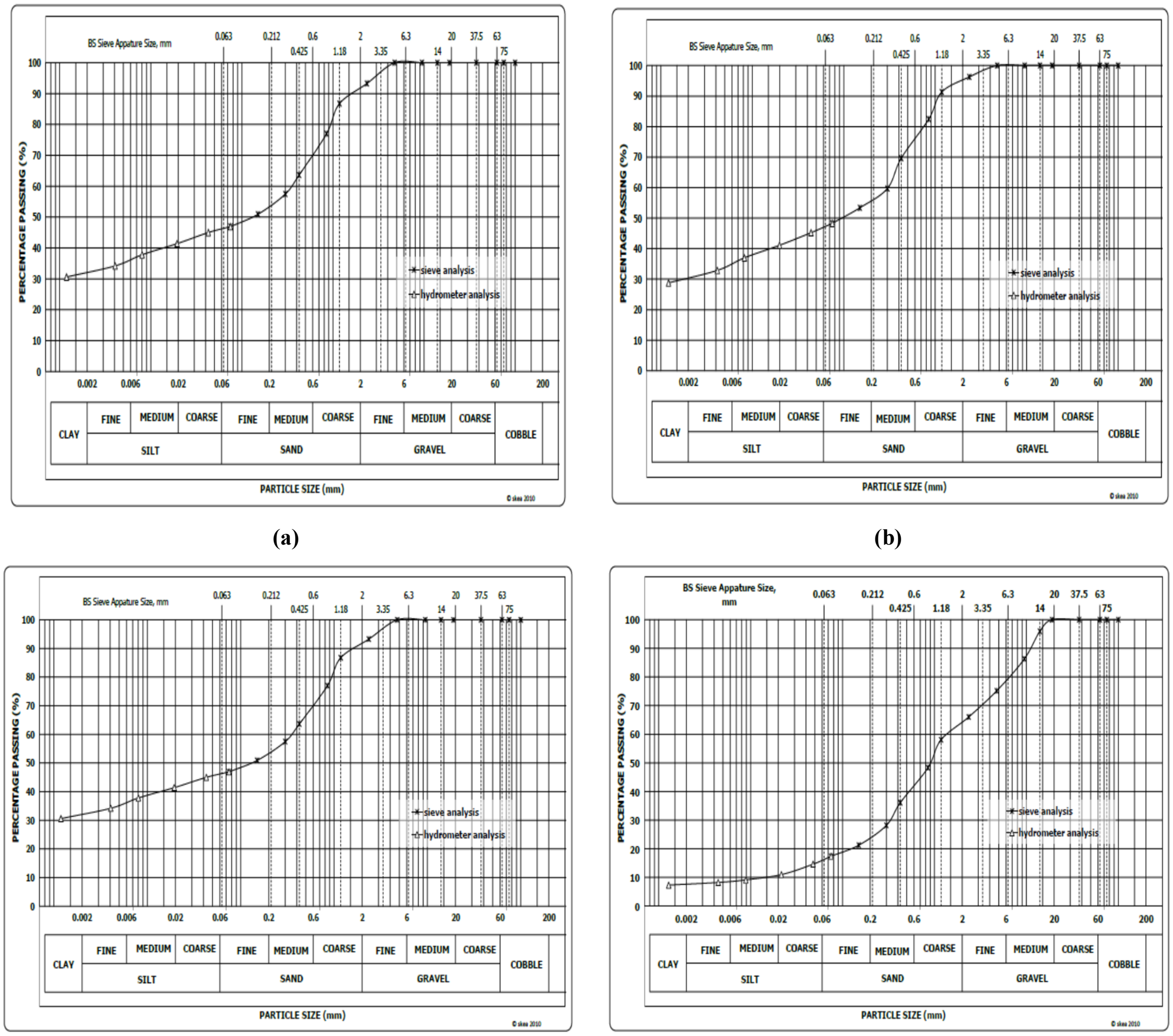
3.2. Mine soil waste geotechnical analysis result

Table 7 shows the geotechnical results of mine soil waste. The moisture content, dry density, cohesion, angle of internal friction, and coefficient of consolidation were calculated to be 24%, 1.66 kg/m^3, 82KN/m^2, and 80, respectively. The liquid limit, plastic limit and plastic index Atterberg limit test results were 65, 23, and 42, respectively. The soil's plastic index (PI) increased due to the high percentage of clay-sized fraction in the sample, as indicated by the stratigraphic profile in section 3.1[36]. The high PI value revealed the mine soil waste's low sand content [37]. Because the measured water content falls between the liquid and plastic limits, the mine waste soil is in the plastic range [16]. Using the plasticity index in Table 2, the soils were classified as clay soil, high plasticity, and cohesive soil [21]. Due to the high clay content, the soil is not suitable for building foundation filling according to soil consistency limits [38]. The soil's specific gravity was 2.6, revealing the mine waste soil to be silt sand [26]. According to the Roy study, the high specific gravity of the soil suggested its suitability for subgrade materials used in road construction [39]. Soil shear resistance is caused by friction and particle interlocking, as well as possible cementation or bonding at particle contacts [40, 41]. The shear strength of waste soil reveals its suitability to support structural load, maintain an equilibrium slope, and is used for dam design, highway, and airfield design, and slopes and cuts [25, 42, 43].

Table 7. Geotechnical properties of the soil samples.

Sample ID	Description	Moisture content %	Specific gravity	Dry Density	Shear strength		Atterberg limits		
					CohesionKN/m^2	Friction angle (^{o})	LL	PL	PI
1	Reddish Brown withish stiff Clay	24	2.6	1.66	82	8	65	23	42
2	Reddish Brown withish stiff Clay	24	2.6	1.66	83	8	64	24	45
3	Reddish Brown withish stiff Clay	24	2.6	1.66	83	8	64	24	45
4	Brownish reddish stiff Clay	24	2.6	1.66	83	8	64	24	45

The particle size distribution of the soil was determined using the American Society for Testing and Materials [44]. Particle size distribution curves were plotted for the four drill hole samples based on the particle size analysis. The particle size distribution curve depicts the distribution of different particle sizes in soil mass [45-7]. Figure 4 depicts the results of the soil sieve analysis. According to the particle size distribution curve, the mine waste soil is coarse fine medium sand with grain particle sizes ranging from 0.06 to 5mm. The mine waste soil is useful in the design of filters because it provides more interlock and increased shear resistance [25].



(a) (b)

(c) (d)

Figure 4.Particle size distribution curve for the four samples retrieved from the field; a. DH1, b. DH 2, c. DH3, d. DH4.

3.3. Mine groundwater condition and quality

During the borehole drilling operations, groundwater seepage was encountered at average depths of about -15m below the existing ground level. Seasonal variations should however be expected.

3.3.1. General characteristics of mine water quality

Table 8 shows the results of the hydrogeochemical analysis for the case study mine. The major element variations are shown in Figure 5 when compared to the world standard [29] and the Nigeria Standard [30]. The results revealed that some of the parameters (60%) had a low standard deviation variation from the standard. This variation, according to Rahman *et al.*, indicates that the water has been affected by a variety of hydrogeochemical processes [48]. In general, the physical properties and major ion concentrations of the mine's surface waters exceeded the SON [30] and WHO [29] limits. Even though 70.0% of surface water samples (7 of the total location sample points) had pH concentrations above the SON [30] recommended limit (6.5-8.5), the waters were described as moderately basic (high pH). Some samples had low pH (high acidic) values due to rock-water interaction and oxidation of exposed intruded sulfide ore minerals such as Galena and sphalerite (PbS and ZnS) [49]. These sulfide minerals (intruders) may have leached into the groundwater system as a result of their interaction with rainwater, lowering the pH. The acidity of the water tends to increase as the TDS increase (Fig. 5b). Although Rose and Cravotta proposed that when the pH of mine water is 3.5 [50], the relatively high pH values observed could be due to buffering by carbonate rocks, particularly shale (overburden material) that hosted carbonate and barite mineralization [51].

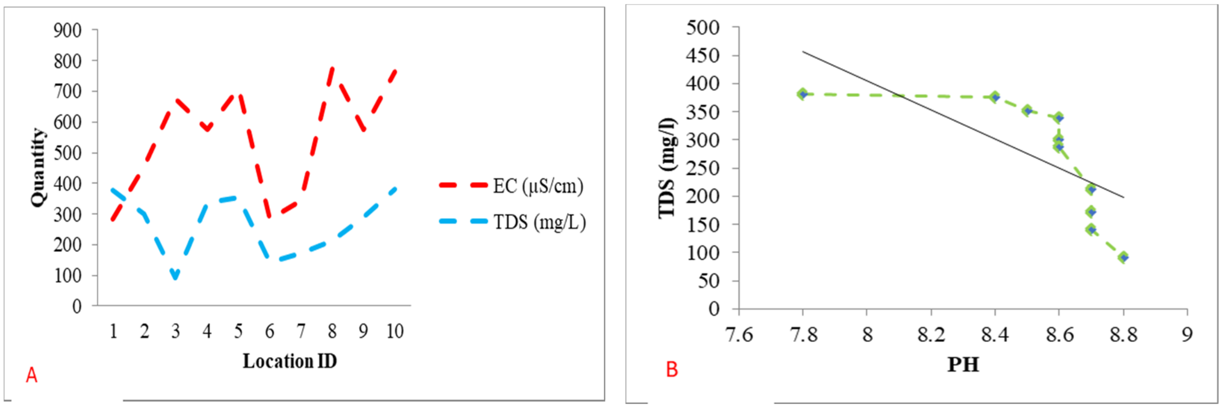


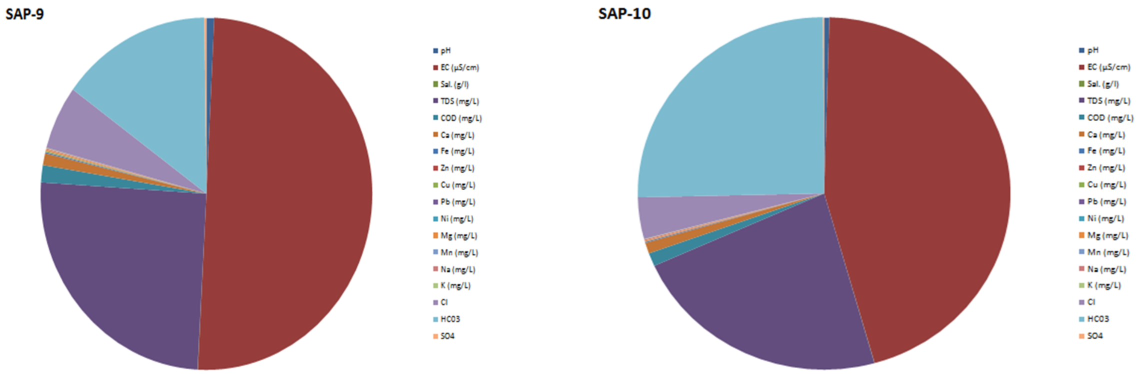
Figure 5. Relationship between total dissolve substance and (A) the water electric conductivity and (B) Ph.

The conductivity of a specific water sample is an indirect measure of its dissolved ion concentration [52]. Water with a total dissolve substance (TDS) of 1000 mg/L is considered unfit for drinking by the World Health Organization [29]. The TDS values of the analyzed results are less than 400 mg/L (Figure 5 and Table 8), with a mean concentration of 265.59 mg/L, indicating that some of the groundwater samples meet the WHO and SON [30] recommended standards for domestic water quality. This proportional relationship between electric conductivity (EC) and TDS (see Figure4) could be associated with weathering and dissolution of dolomite and calcite minerals, notably Ca^{2+}, HCO$_3^-$, and Mg^{2+} whose source is from the mine. Moreover, marble played host to mineralization of barite mineralization as noted from field observation. Moreover, low pH will increase the dissolution of minerals thus increasing the TDS. Based on the SON [30] and WHO [29] limits, all the water samples are considered unfit for drinking and domestic use. Additionally, high HCO$_3$ content as shown in all samples (see Figure 6 and Table 8) may have been sourced from weathering and dissolution of siliciclastic-rich carbonate rocks from the dominant lithology of the studied area [53].

3.3.2. Heavy metal concentration

Six trace metals (Mn, Ni, Pb, Zn, Fe, and Cu) were examined in the water samples to determine their suitability for drinking. Figure 7 depicts a visual representation of the trace-element concentrations in the water samples. Except for Fe and Pb, all other heavy metals had values that were lower than the WHO [29] and SON [30] maximum permissible limits. The increased Mn concentration in water has been linked to low water pH ATSDR [54]. Mn^{2+} concentrations are higher in waters with a pH of 4-7 [54]. Simmonds and Ghasemi observed that, while Mn and Fe appear to behave similarly, Mn may be more mobile than Fe in sedimentary environments. Similarly, Fe tends to precipitate faster than Mn [55]. Furthermore, the high Mn concentrations found in the water samples could be attributed to the dissolution of manganese-bearing calcite ((Ca, Mn) CO$_3$) from the location of carbonate rock [56]. The presence of low-quality Zn and high-concentration Pb suggests anthropogenic sources such as mining activities in the studied area. Furthermore, field observations revealed that carbonate mineralization occurred in the studied area in conjunction with sulfide minerals such as PbS (galena) and ZnS (sphalerite) [49]. Their dissolution could have been caused by oxidation reactions (with rainwater). Furthermore, the moderate pH of the waters may have caused weathering and subsequent dissolution of the deposit in the case study location. As illustrated in Figure 6, Zn, Cu, and Pb have the highest values among the ten samples. Table 8 presents the complete hydrochemical analysis result for the 10 samples gotten from the mine with the threshold limit of each chemical composition according to WHO and SON respectively.

Figure 6. Major chemical compositional analysis result from the 10 water sample.



Continues of Figure 6. Major chemical compositional analysis result from the 10 water sample.

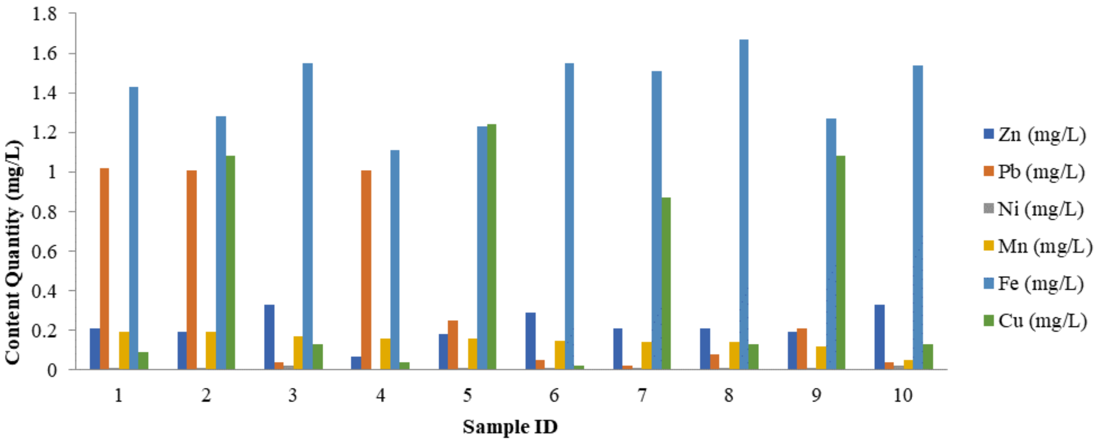


Figure 7.Relationship between the trace metal in the case study water sample.

Table 8. Result of the water sample hydrogeochemical analysis.

Sample ID	pH	EC (µS/cm)	Sal. (g/L)	TDS (mg/L)	COD (mg/L)	Ca (mg/L)	Fe (mg/L)	Zn (mg/L)	Cu (mg/L)	Pb (mg/L)	Ni (mg/L)	Mg (mg/L)	Mn (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)
Loc.1	8.6	284	0.19	376.8	22.3	14.8	1.43	0.21	0.09	0.02	0.01	1.47	0.19	2.37	1.12	40.5
Loc.2	8.5	456	0.13	300.3	23.5	25.1	1.28	0.19	1.08	0.01	0.01	2.3	0.19	2.49	1.15	46.7
Loc.3	8.7	675	0.15	90.7	24.1	25.42	1.55	0.33	0.13	0.04	0.02	1.23	0.17	0.86	0.43	48.3
Loc.4	8.6	574	0.31	338.8	28	24.95	1.11	0.07	0.04	0.01	0	3.01	0.16	3.72	1.34	52.4
Loc.5	8.7	711	0.32	352.7	25.2	12.42	1.23	0.18	1.24	0.01	0.01	1.5	0.16	2.87	1.32	58.6
Loc.6	8.4	284	0.13	141.7	8.1	16.83	1.55	0.29	0.023	0.03	0.01	2.74	0.15	1.92	0.51	68.4
Loc.7	8.7	344	0.15	171.7	21.7	12.56	1.51	0.21	0.87	0.02	0.01	1.4	0.14	2.14	0.85	60.2
Loc.8	8.8	775	0.31	212.3	12.2	26.56	1.67	0.21	0.13	0.02	0.01	1.44	0.14	1.35	0.68	65.6
Loc.9	8.6	574	0.26	288.6	18.2	12.34	1.27	0.19	1.08	0.01	0.01	1.53	0.12	1.09	0.52	67.5
Loc.10	7.8	765	0.31	382.3	20.6	16.85	1.54	0.33	0.13	0.04	0.02	1.72	0.05	1.79	0.78	64.6
Max	8.8	775	0.32	382.3	28	26.56	1.67	0.33	1.24	0.04	0.02	3.01	0.19	3.72	1.34	68.4
Min	7.8	284	0.13	90.7	8.1	12.34	1.11	0.07	0.023	0.01	0	1.01	0.05	0.86	0.43	40.5
SD	0.28	192.06	0.083	104.48	6.08	6.02	0.18	0.078	0.51	0.012	0.005	0.51	0.041	0.86	0.3423	9.7703
Mean	8.54	544.2	0.226	265.59	20.39	18.783	1.414	0.221	0.4813	0.021	0.011	1.634	0.147	2.06	0.87	57.28
SON	6.5-8.5	1000		500		5	0.3	-	1	0.01	-	20	-	-	10	100
WHO	6.5-8.5	1000		500		5	1	-	0.5	0.01	-	20	-	-	10	100

3.3.3. Chloro-alkaline index and Gibbs ratio result

The presence of the forward ion-exchange process is indicated by a negative chloro-alkaline index (CAI), according to Mgbenu and Egbueri [32]. A positive CAI, on the other hand, denotes the reverse ion exchange process. CAI (Table 9) identified and confirmed that the predominant ion exchange responsible for the release of alkali metals (Ca, Mg, and K) in the water system was a reversed ion exchange in the current study. According to the Gibbs values, 76.0% of the water samples fall within the rock-weathering dominance value, as shown in Table 9. This confirms that weathering and mineral dissolution including silicates and carbonates appear to be the primary processes governing the hydro geochemistry of the studied area [49]. The Gibbs values also indicate that the waters in the area have had a long-term interaction with the surrounding rocks or soils. This assumption is consistent with relatively high hydrochemical values such as EC and TDS (Table 9).

3.2.4. Overall index of pollution (OIP) and pollution load Index (PLI)

The result revealed that the water in the case study area indicated slightly polluted water, and was categorized under class C3 (OIP= 4.88-5.71, see Table 10).

The pollution load index (PLI) similar to the OIP results (PLI= 0.165-2.48), the PLI results showed an unpolluted-to-moderately polluted in all the samples, with all the water samples falling within the "moderately polluted" category.

Table 9. Chloro-alkaline index and Gibbs ratio result.

Sample ID	CAI	GR
SAP-1	0.223659	0.190815
SAP-2	0.110834	0.126653
SAP-3	0.287992	0.048297
SAP-4	0.145716	0.16861
SAP-5	0.253713	0.252258
SAP-6	0.275169	0.126168
SAP-7	0.232066	0.192283
SAP-8	0.176124	0.071004
SAP-9	0.392022	0.115412
SAP-10	0.148146	0.132338
Max	0.392022	0.252258
Min	0.1108342	0.0482965
SD	0.0835801	0.0604446
Mean	0.2245443	0.1423837

Table 10. Overall index of pollution (OIP) and pollution load index (PLI).

Content	Mean	WHO (Standard)	WHO PI	SON Standard	SON PI
pH	8.54	8.5	1.004706	8.5	1.004706
EC	544.2	1000	0.5442	1000	0.5442
TDS	265.59	500	0.53118	500	0.53118
HCO_3	275.86	100	2.7586	100	2.7586
K	0.87	10	0.087	10	0.087
Mg	1.634	20	0.0817	0.2	8.17
SO_4	2.643	10	0.2643	100	0.02643
Fe	1.414	1	1.414	0.3	4.713333
Mn	0.147	0.1	1.47	0.05	2.94
Zn	0.221	0.01	22.1	5	0.0442
Cu	0.4813	0.5	0.9626	1	0.4813
Pb	0.373	0.01	37.3	0.01	37.3
OIP			5.709857		4.883412
PLI			2.482448		0.165497

3.3. Proposed Pollution index model

The model was developed using the result of the ten samples collected from the case study area. Figure 8 presents the correlation relationship between the origin of chemical ions in the case study area and the case responding pollution rate. The result shows that the pollution index has a positive correlation with the Gibb's ratio value. To improved water pollution assessment, a new proposed model was developed to predict the pollution index of water samples based on the supply ions in waters which can influence the hydrogeochemical signatures of waters samples.

The proposed model is presents in Equation (9) with 1.036 exponential constant.

$$PI = 1.036e^{4.913GR} \quad (9)$$

The prediction accuracy of the model was validated with three dataset using coefficient of correlation (R^2), root mean square error (RMSE), and mean absolute error (MAE).

The result of the model prediction checkers shows that the model R^2, RSME, and MAE are 0.763, 0.315 and 0.27, respectively. The model low value of the model error analysis indices show that the new model giving close reflection of the exact predictive value relationship with the actual value with low variation between the actual values and the predicted values.

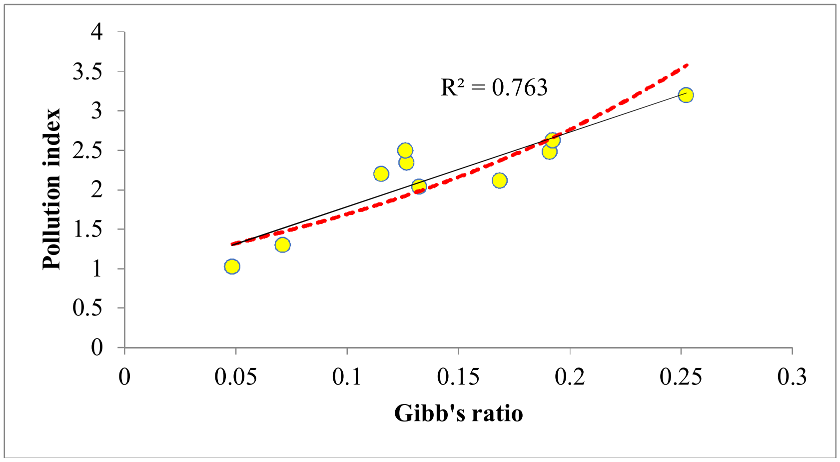


Figure 8. Relationship between the Gibb's ratio and pollution index.

4. Conclusions

Carbon mineralization is the transformation of carbon dioxide into a solid mineral such as carbonate which may be significant to understand the behavior of carbonate rocks within the context of the research work. In addition, the majority of carbonate rocks derive from sedimentary deposits in marine settings, and their water-yielding qualities vary greatly based on the parameters such as porosity and permeability. Carbonate rock treatment for acid mine drainage has been recognized as an effective method for pollution management and is commonly used in mines. Overall, these results suggest that the research could examine the possible use of carbonate rocks to control pollution and provide water for building and residential use, taking into consideration their specific features and behavior in different environments.

The present study has successfully been carried out an overall suitability assessment of mine soil waste and waters for construction applicability and domestic purposes in the dolomite quarry located in southwest Nigeria using an integrated approach.

The following conclusions can be drawn from the study findings:

1. It was discovered that the mine soil waste in the studied area is rich in silt clay sand content, with high specific gravity, consistency limits, and shear strength property. The bore hole profile revealed that the soil stratigraphy was made up of dark brown to greyish lateritic sandy clay.
2. The moisture content, dry density, cohesion, angle of internal friction, and coefficient of consolidation were calculated to be 24%, 1.66 kg/m^3, 82KN/m^2, and 80, respectively. The liquid limit, plastic limit, and plastic index Atterberg limit test results were 65, 23, and 42, respectively. The soil's plastic index (PI) increased due to the high percentage of clay-sized fraction in the sample.
3. According to the particle size distribution curve, the mine waste soil is coarse fine medium sand with grain particle sizes ranging from 0.06 to 5mm. The mine waste soil is useful in the design of filters. The geotechnical analysis results show that dolomite waste soil is suitable for road subgrade, dam design, highway, and airfield design, and slopes and cuts, as well as soil filters as addictive, to provide more interlock and increased shear resistance, to support structural load, and to sustain a slope in equilibrium.
4. The studied area's water quality was found to be degraded due to elevated levels of heavy metals (such as Fe and Pb); thus these metals are regarded as the primary influencers of the case study mine surface and underground water quality.
5. The study's findings revealed that the mine water was slightly polluted according to the result of both the overall index of pollution (OIP) and pollution load index (PLI).
6. The chemical analysis of the dolomite mine water also revealed that the mean value of electrical conductivity, TDS, iron, manganese, copper, and lead all exceeded the WHO and SON considered acceptable drinking water levels. A higher proportion of the analyzed waters are unfit for drinking or domestic use.
7. The result of the proposed pollution assessment model has good performance with high goodness of fit and low mean absolute error value (R^2=0.763, RSME=0.315, and

MAE=0.27). The model can be used as a supporting tool for practical assessment of water pollution rate.

As a result, it is strongly recommended that frequent monitoring and assessment of overall water resources be encouraged in dolomite mines. Waste disposal, land use, and agricultural practices that help to preserve the quality of water resources should also be implemented in dolomite abandoned mines. Based on this study, we also recommend that the case study mine pits should be reclaimed immediately after the mining operation to prevent acid generation from high sulphate content, the rock piles, dumped sites, tailing, and mine pits should be neutralized with alkaline materials.

The authors' future work will focus on applying numerical modelling techniques to simulate the effect of spatial chemical composition change due to water contamination on slope stability Moreover, the authors also plan to get more dataset on water pollution to apply machine learning in predicting pollution index using the chemical composition origin index and key hydrogeochemical properties as the input variables.

Disclosure statement

The authors report there are no competing interests to declare.

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ارزیابی ژئومحیط معدن: زباله های معدن سنگ کربنات به عنوان مواد ساختمانی اعتیادآور و همراه با مدل شاخص آلودگی

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چکیده:

مواد روباره معمولاً در عملیات معدنکاری سطحی حذف می‌شوند تا ذخایر اولیه سنگ معدن نمایان شود. به دلیل وجود مواد معدنی کمیاب، زمانی که مواد اضافه بار از محل معدن خارج شده و به مکان دیگری منتقل می‌شوند، آلودگی محیطی و زهکشی اسیدی ایجاد می‌شود. به منظور ارتقای پایداری اقتصادی و زیست محیطی معدن دولومیت، مواد زائد باید از نظر اثرات زیست محیطی و کاربرد صنعتی بالقوه آنها ارزیابی شوند. آکوکو ادو نیجریه به دلیل تولید زیاد دولومیت و سنگ کربنات با ضایعات با تناژ زیاد شناخته شده است. تجزیه و تحلیل هیدروژئوشیمیایی و ژئوتکنیکی معدن منتخب در این منطقه با جمع‌آوری و آنالیز تصادفی نمونه‌های خاک و آب از چهار چال حفاری اکتشافی با استفاده از دستگاه اسپکتروفتومتر جذب اتمی انجام شد. نتایج تجزیه و تحلیل ژئوتکنیکی نشان می‌دهد که خاک پسماند دولومیت برای مواد اعتیادآور انقباضی مانند بستر جاده، طراحی سد، بزرگراه و سایر کارهای ساختمانی مناسب است. بر اساس یافته‌های این مطالعه، آب معدن کمی آلوده است، همانطور با شاخص کلی آلودگی (OIP) و شاخص بار آلودگی (PLI) اندازه گیری شد. تجزیه و تحلیل شیمیایی آب گودال معدن همچنین نشان می‌دهد که میانگین رسانایی الکتریکی، TDS، آهن، منگنز، مس و سرب همگی فراتر از استانداردهای WHO و SON برای آب آشامیدنی سالم است. یک مدل ارزیابی آلودگی جدید با دقت همبستگی پیش‌بینی مناسب (R2 = 0.76، میانگین خطای = ۰,۲۷) نیز در این کار توسعه داده شده است.

کلمات کلیدی: ضایعات معدن، خواص ژئوتکنیکی خاک، ارزیابی کیفیت آب معدن، زمین شناسی خاک، کارهای ساختمانی.