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INVESTIGATION OF ELEMENTAL CONSTITUENTS OF EROSION-PRONE SOILS OF ENUGU STATE AND THEIR CONSEQUENT CHEMICAL STABILIZATION

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ABSTRACT

Soil erosion is one of the most serious environmental problems facing the South-Eastern part of Nigeria, including Enugu State. This research, therefore, investigates the elemental constituents of erosion-prone soils to address the erosion problem through chemical stabilization at erosion sites in Enugu State. The chemical/elemental constituents of soil samples from three non-erosion-prone areas (NEPA) used as control, and three erosion-prone areas (EPA) were determined. The elemental components of the soil were determined using an Atomic Absorption Spectrophotometer (AAS). The particle size distribution and the unconfined compressive strength (UCS) of EPA were determined using standard laboratory methods and a Pocket penetrometer, respectively. Solutions of $CaCl_2$, $CaCO_3$, $AlCl_3$, $Ca(OH)_2$, and $Ca(NO_3)_2$ were prepared and applied to each of the two erodible soil samples for chemical stabilization. Stabilization was confirmed by using the penetrometer. Results of the chemical analysis showed that cation concentrations (ppm) were relatively higher in non-erosion-prone soils than in erosive soils. Results of the particle distribution analysis showed that each soil sample contained a higher percentage of sand, followed by clay and then silt. The results of the chemical stabilization showed that, of the five chemicals used, $Ca(NO_3)_2$, $AlCl_3$, and $CaCl_2$ provided the best stabilization, while $CaCO_3$ and $Ca(OH)_2$ yielded poor stabilization. The erosion problem in Okunino and Obinagu can be mitigated by applying chemical stabilizing agents in appropriate proportions.

Key words: Chemical stabilization, Erosion, Erosion-Prone; Non-Erosion Prone; Soil; Unconfined Compressive Strength.

1.0. Introduction

Soil erosion occurs when topsoil is washed away by agents of denudation, such as rain, wind, and glacial ice (Ojo et al., 2023). The soil erosion process comprises a complex mechanism that includes the separation of surface soil particles, their transport, and deposition (Husein et al., 2024). Erosion is widely recognized as one of soil's major threats (Asuoha et al., 2019), and it is reported that each year, over 75 billion tons of soil are lost due to erosion (Khallouf et al., 2021). In Nigeria, about eighty percent of land degradation is a result of soil erosion (Ojo et al., 2023), and the soil erosion menace, which is facing most Nigerian states, is becoming a leading ecological challenge (Obiahu & Elias, 2020). Soil erosion leads to the loss of fertile topsoil, which is necessary

for food security (Eekhout & de Vente, 2022). An urgent concern is that soil erosion continually reduces the amount of land available for increasing agricultural production (Yaseen et al., 2025). From Wright (1998), soil erosion by water is among the main obstacles to the efficiency of agriculture, and therefore to economic development, in most of the developing countries (Wright, 1998). Soil erosion also leads to organic matter loss, which then lowers the soil's capacity for water holding and nutrient holding. Soil erosion also impacts habitats, including coral reefs, coastal habitats, and fluvial habitats. Also, transported sediments from soil erosion affect human activities, such as damage to infrastructure and housing, reservoir sedimentation for drinking water and irrigation, and river delta activities (Eekhout & de Vente, 2022).

Many soil conservation strategies have been employed to mitigate soil erosion. According to Blanco-Canqui and Lal (2010), some biological measures include reduced tillage, no-till, crop rotations, agroforestry, cover crops, canopy and residue cover management, and riparian buffers. According to Balasubramanian (2017), vegetation planting, silt fences, and matting are erosion-control methods, with vegetation planting being the most effective and natural erosion-prevention method.

Many researchers, both globally and locally, have conducted research on soil and soil erosion across different scopes. In Enugu State, research on soil erosion has also been conducted by researchers such as Okwu-Delunzu (2015), Okolotu et al. (2016), and Ekwueme et al. (2021). Some of these various researchers have written on methods of soil erosion prevention and/or control. Despite several plausible approaches to preventing soil erosion, the problem has persisted to date, necessitating this research. This study then proposes the use of inorganic chemicals to stabilize certain erosion-prone areas in Enugu State.

2.0. Materials and Methods

2.1. The Study Area: Enugu State

The study area is located in three local government areas in Enugu State, Nigeria. The erosion sites used in this study were Okunino, Obinagu, and Abor (Figure 1), identified by the Enugu State Ecological Department. Enugu urban lies approximately between latitudes 6° 2'N and 6° 30'N and between longitude 70° 26'E and 70° 37'E. The total area coverage is approximately 72.8 square kilometers. Enugu urban comprises three council areas: Enugu North, Enugu East, and Enugu South Local Government Areas (LGA). It is bounded in the east by Nkanu LGA, in the West by Udi LGA, in the North by Igbo-Etiti and Isiuzor, and in the south by Nkanu West LGA (Egbokhare et al., 2002).

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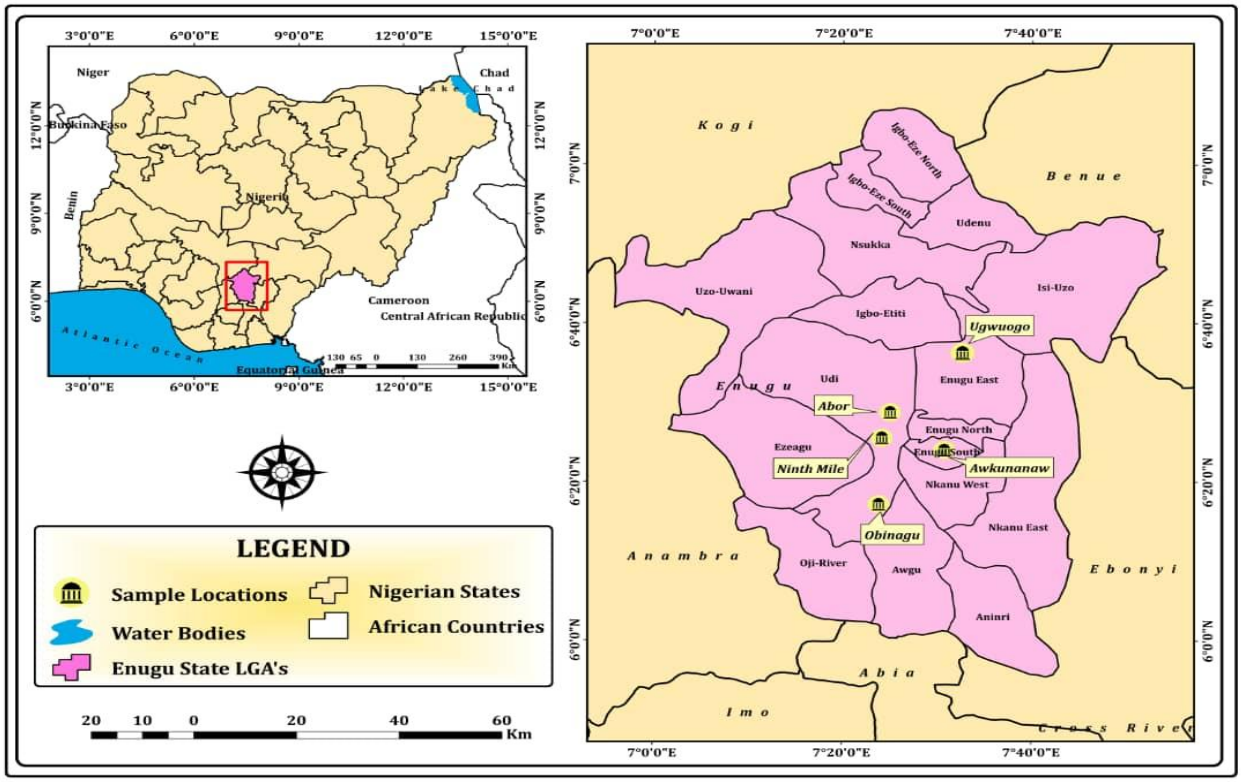

Figure 1: Map of Enugu State showing the sample location. Source: Department of Geology and Meteorology, Nnamdi Azikiwe University, Awka, Nigeria.

2.2. Soil Sample Collection

For the analysis, six soil samples were collected: three from erosion-prone areas of Okunino, Obinagu, and Abor, and three from non–erosive areas of Ninth Mile, Ugwuogo, and Obinagu. The soil samples were collected with a shovel at a depth of 11 cm below the soil surface in polyethylene bags, labelled as non-erosion-prone area NEPA 1 - 3, while the erosion-prone area was labelled as EPA 1 - 3, and taken for laboratory analysis.

2.3. Determination of Cations

Heavy metal ion analysis was conducted using a Varian AA240 Atomic Absorption Spectrophotometer according to the method of the American Public Health Association (APHA, 1995). The sample (2 g) was weighed into a crucible and placed in a muffle furnace to be ashed at 450 °C for 2 hours. Then removed from the furnace and allowed to cool at ambient temperature. The dry ash was emptied into a 250 mL beaker. 20 mL of 20% H_2SO_4 was added, heated in a water bath for 20 minutes, filtered, made up to 50 mL with de-ionized water, and stored in a sample bottle for AAS elemental analysis.

2.4. Determination of Particle Size of Soil (ASTM D422, 2017)

The soil sample (30 g) was weighed into a 250 mL beaker, and the beaker was filled with distilled water to the 200 mL mark. The soil was washed four times with distilled water. 20 mL of 25% sodium hexametaphosphate solution was added, followed by 200 mL of distilled water. The mixture was allowed to stand for 16 hours (i.e., overnight) after which it was transferred into a 0.2 mm sieve. The sample on the sieve is sand, while the sample that passes through is silt. Each was dried to a constant weight and was calculated as shown below.

$$\% \text{ Sand} = \frac{\text{Residue x } 100}{Sample} \quad (1)$$

$$\% \text{ Silt} = \frac{\text{Residue x } 100}{Sample} \quad (2)$$

$$\%Clay = 100 - (\%Silt + \%Sand) \quad (3)$$

2.5. Chemical Stabilization Procedures

2.5.1. Preparation of soil particles

The soil samples from erosion–prone areas were sun-dried for six hours to remove moisture.

2.5.2. Preparation of stabilizing chemicals

Solutions of the soil-stabilizing chemicals: calcium chloride ($CaCl_2$), aluminum chloride ($AlCl_3$), calcium trioxocarbonate (IV) ($CaCO_3$), calcium hydroxide ($Ca(OH)_2$), and calcium trioxonitrate (V) ($Ca(NO_3)_2$) were used for the stabilization process. The solutions were prepared by adding 25 g of each salt to 250 cm^3 of water.

2.5.3. Procedure for Soil Stabilization

Soil samples were stabilized following the procedure by Okoye et al. (2022) with modifications. A sample (15 g) was weighed into fabricated metallic pipes (27 mm diameter and 62 mm length), which were used to hold the soil sample. 5 mL of each stabilizing chemical was poured into the fabricated pipe, and the samples were allowed to adsorb the chemicals. The soil chemical mixture was placed on an electric heater for 30 minutes to evaporate water, leaving behind the solute particles that bind the soil particles together. The unconfined compressive strength (UCS in kg/cm^3) was determined using a pocket penetrometer.

2.5.4. Confirmation of soil particle compaction test

The confirmatory test was performed using a 16–T 171 Pocket penetrometer, which measures the soil's resistance to penetration. The soil's resistance to penetration is related to its strength. The tip of the penetrometer was placed on the soil surface at a right angle. Then the penetrometer handle was slowly pushed to drive the needle tip into the soil. As pressure on the penetrometer handle is released, the handle returns smoothly to its initial position, leaving the plastic ring on the needle (i.e., the steel rod) behind. The needle is calibrated. This test was carried out on 15 g of each of the five soil samples using the five chemical stabilizers, and the unconfined compressive strength (UCS) readings were recorded in kg/cm^2 (ASTM D2166, 2017).

2.5.5. Method of Data Analysis

The results were analyzed using one-way analysis of Variance (ANOVA). Tukey's HSD test was used as the post hoc test to make pairwise comparisons between groups. Statistical decisions and conclusions were made at 5% level of significance; hence, a significant difference existed if the p-value (p) is less than .05 ($p < .05$); otherwise, the difference was not significant ($p > .05$). These tests were done using the Statistical Package for Social Science (SPSS) version 21.

3.0. Results and Discussion

3.1. Chemical Analysis of Soil Samples

Table 1 below shows the concentrations of cations in the different soil samples studied, comprising three non-erosion-prone areas (NEPA) used as controls and two erosion-prone areas (EPA).

Table 1: Concentration of Cations of the different Soil Samples in ppm

Cation	NEPA 1 (Ninth Mile)	NEPA 2 (Ugwuogo)	NEPA 3 (Obinagu)	EPA 1 (Okunino)	EPA 2 (Obinagu)	EPA 3 (Abor)
Zn	3.777	2.361	5.554	4.172	4.543	4.094
Mg	15.131	18.266	13.034	15.411	15.298	17.263
Na	0.000	0.000	14.911	39.159	6.053	65.859
Ca	18.477	21.556	21.314	6.666	6.261	47.492
Al	58.195	80.891	53.864	6.448	6.447	37.112
Fe	1295.0	1347.0	1333.0	21.259	21.147	1329.0
Mn	1.705	2.923	3.363	3.287	2.867	3.228
Si	23.829	26.637	28.526	12.832	15.849	14.373

NEPA: Non-erosion-prone, EPA: Erosion-prone

3.1.1. Calcium Concentration (Ca)

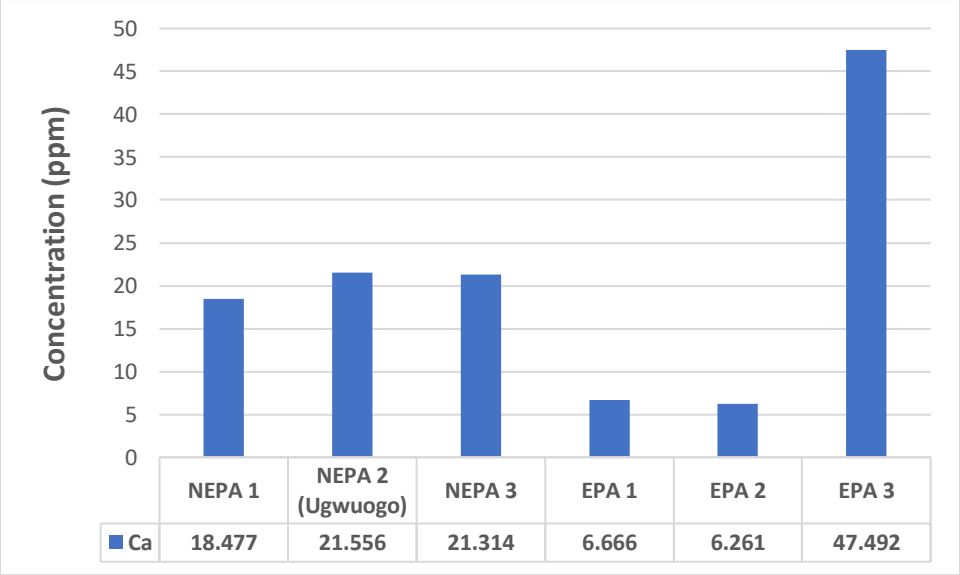

Figure 2: Calcium concentration across the NEPA and EPA

From the results of the analysis, Table 1 and Figure 2, the concentrations of calcium in NEPA 1, 2, and 3 were 18.477, 21.556, and 21.314 ppm, respectively, whereas those of EPA 1, 2, and 3 of Okunino, Obinagu, and Abor were 6.666, 6.261, and 47.492 ppm, respectively.

The calcium concentration in NEPAs is relatively the same, except in NEPA 1, where a slightly lower concentration was

discovered. Also, EPA 1 and 2 have relatively similar calcium concentrations, except for EPA 3 (Abor), which shows a much higher value than the other erosion-prone areas.

The exact geological parent material at these sites requires further investigation, but the higher Ca2+ suggests it may have contributed to the stability of NEPAs' soil particles. Calcium is a good soil binder. The flocculation of Ca^{2+} forms bridges between the clays and the organic matter in the soil. This agrees with the findings in the research carried out by Wuddivira et al. (2006); Cody (2024), and Kachhadiya et al. (2025) on the effects of calcium on soil structural stability, in which they stated that the cationic bridging effect of the calcium ion (Ca^{2+}) is crucial in the formation and stability of soil aggregates. Hence, applying calcium salt solutions at an appropriate concentration may bind the soil particles in erosion-prone soils.

Generally, calcium concentrations are higher in all NEPAs than in EPAs, which may explain why they are not erodible. Also, NEPA 1 and 2 have no sodium, which aids in soil particle dispersion.

3.1.2. Silicon Concentration (Si)

The silicon concentrations across the NEPAs and EPAs are shown in Figure 3.

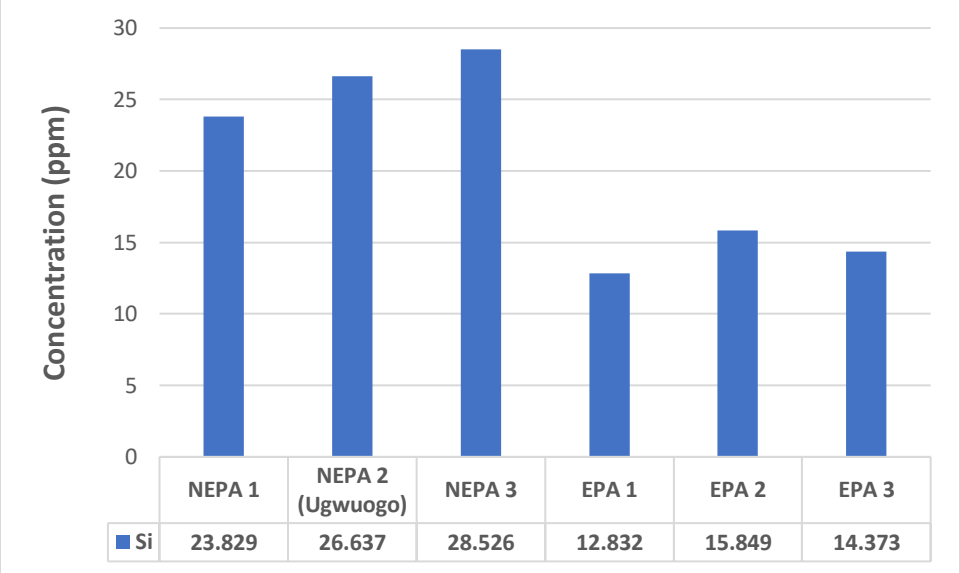

Figure 3: Silicon concentration across the NEPAs and EPAs

From Figure 3, the concentration of silicon in NEPA 1, NEPA 2, and NEPA 3 was 23.829, 26.637, and 28.526 ppm, respectively, while those of EPA 1, EPA 2, and EPA were 12.832, 15.859, and 14.373 ppm, respectively.

High concentrations of silicon significantly improve soil stability against erosion by enhancing soil structure, increasing particle cohesion, and reducing permeability. Silicon, often applied as amorphous silica or soluble silicates (e.g., potassium/sodium silicates), forms cementitious complexes that bind soil particles, particularly in degraded or sandy soils (Barbosa et al., 2024; Yang et al., 2026; Bagheri, 2024). The values obtained for silicon in all non-erosion-prone area soils were higher compared to those obtained in erosion-prone soils. These low concentrations of silicon in erosion-prone soils might result from leaching by water

erosion. This is consistent with the findings of Ojiako (2017), who found that non-erodible soils have the highest percentage of silicate material and that silicon or silicate material is a good soil binder.

But research (More et al., 2019; Omar and Usman, 2017) carried out on the evaluation of silica-supplying power of soils for growing rice showed that the silica content of the dry-season crop was higher than that of the wet-season crop, which may be because of more favourable climatic conditions, which enhanced silicon adsorption during the dry season. Since silicon concentration in the soil varies with the season, maximum desired stabilization may not be achieved with silicon salts for soil stabilization to curb the menace of erosion.

3.1.3. Sodium Concentration (Na)

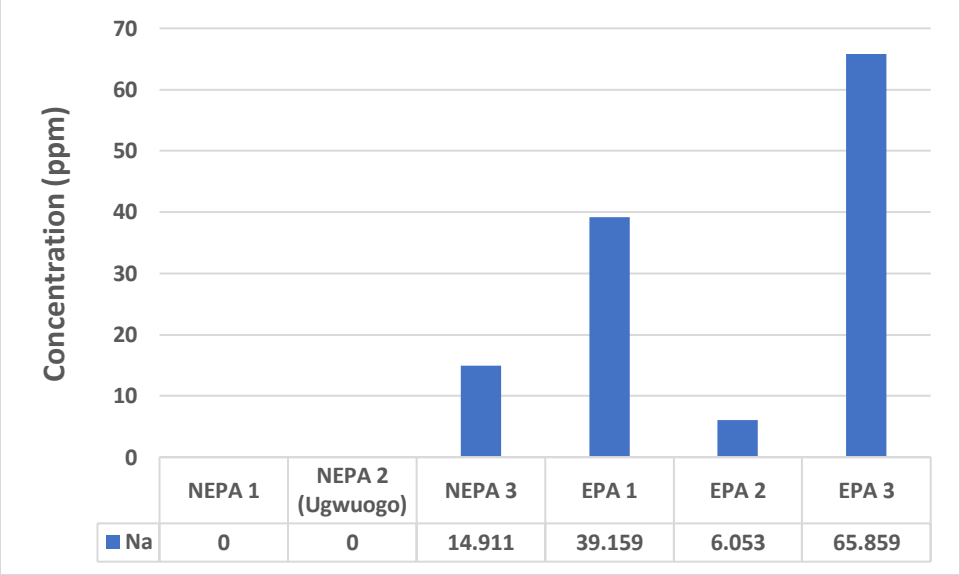

Figure 4: Sodium concentration across the NEPAs and EPAs

The sodium concentrations in the non-erosion-prone areas of Ninth Mile, Ugwuogo, and Okunino were 0.00, 0.00, and 14.911 ppm, respectively, whereas those in EPAs 1, 2, and 3 were 39.159, 6.053, and 65.859 ppm, as shown in Figure 4 below.

Research undertaken by Wayne and Chris (2005) showed that this cation (Na^+) causes instability mainly because of its ability to attract water molecules around it when the soil is wet. Sodium is a highly hydrated cation surrounded by a shell of water, which increases the distance between the cation and negatively charged soil colloid and reduces the attraction between the cation and the colloid. This increases the relative diameter of the cations until they can no longer remain attached to the soil clay colloid (Warrence et al., 2002). The clay particle floats off into the soil, with water blocking soil pores and causing poor soil structure, which in turn makes the soil erodible. Therefore, soil dispersion is the physical process associated with high sodium.

The findings by Wayne and Chris (2005) are consistent with the results in Table 1. NEPA 1 and 2 contain no sodium, which may explain why they are not erodible, and have a higher calcium content than the erosion–prone areas. All the EPAs contained sodium, with EPA 3 having the highest Na concentration (65.859 ppm). Na in EPA 2 is relatively low, which could be attributed to the soil structure and topography of this area.

This trend of soil dispersion by sodium (Na^+) can be reversed by adding stronger cations such as calcium, from $Ca(NO_3)_2$ and $CaCl_2$. This results in cation exchange, which enhances the stability of the soil aggregate

3.1.4. Aluminum Concentration (Al)

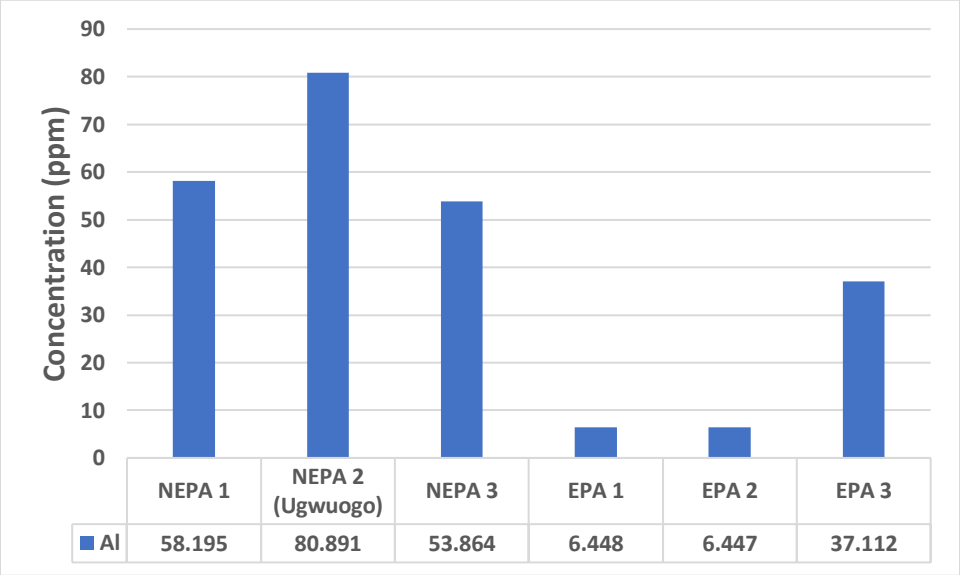

Figure 6: Aluminum concentration across the NEPAs and EPAs

The concentration in ppm of aluminum in NEPAs 1, 2, and 3 were 58.195, 80.891, and 53.864 ppm, respectively, while those of EPA 1, 2, and 3 were 6.448, 6.447, and 37.112 ppm, respectively, as indicated in Figure 6. All the EPAs have a lower aluminum content than NEPA 1, based on the results obtained (Table 1).

Hence, the non-erodibility of NEPA 1–3 may be attributed to the high aluminum concentration in their soil matrices. This finding is consistent with Ndzana et al. (2021), who found that Al and Fe act as cementing agents affecting soil aggregate stability in Latosols. Those for EPA 1–3 were very low, especially for EPA 1 and 2. The low aluminum concentration can be attributed to natural factors like high rainfall leaching, acidic soil pH dissolving aluminum, or highly weathered tropical soils. Aluminum salt promises to be a good soil particle binder, holding the soil particles of the three erosion-prone soils. This will be proven by the actual chemical stabilization.

3.1.5. Iron Concentration (Fe)

The concentration of iron in all soil samples is shown in Figure 7 below, which shows the Fe concentration across the NEPAs 1 – 3 to be 1295, 1347, and 1333 ppm, respectively, while those of EPAs 1 – 3 were 21.259, 21.147, and 1329 ppm, respectively.

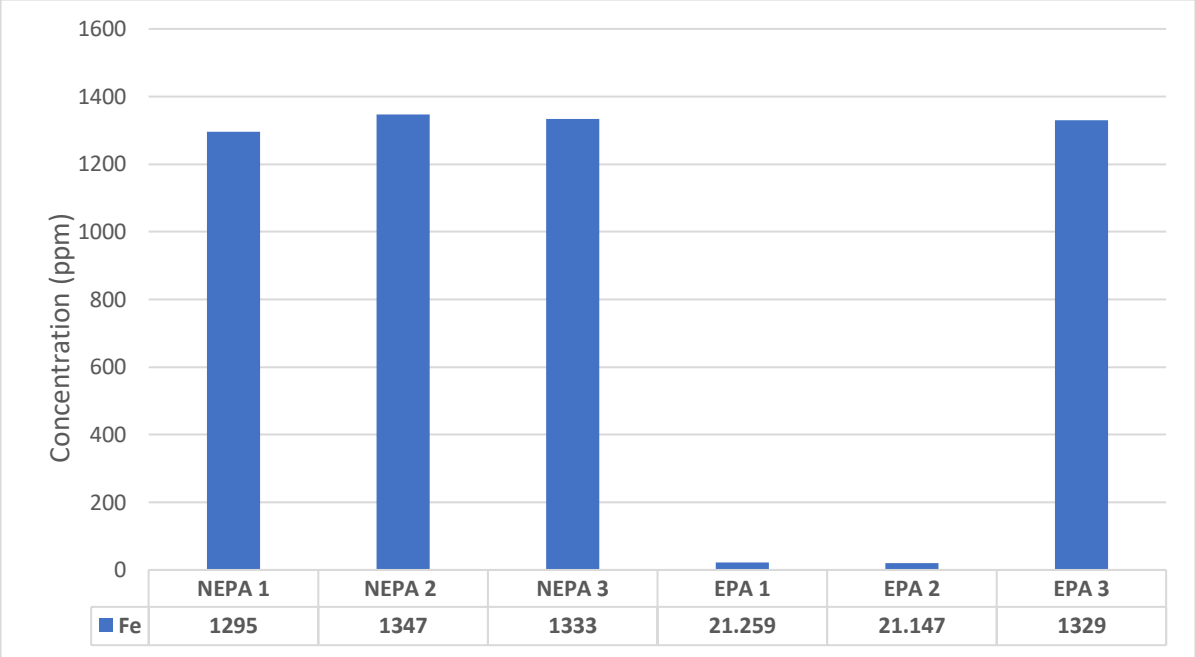

Figure 7: Iron concentration across the NEPAs and EPAs

Iron concentration across the NEPAs 1 – 3 were 1295, 1347, and 1333 ppm, respectively, while those of EPAs 1 – 3 were 21.259, 21.147, and 1329 ppm, respectively. The results showed that all iron concentrations in the NEPAs were very high compared to those in the EPAs, except in EPA 3 (Abor), where a very high Fe concentration, comparable to those of NEPAs 1–3, was observed. Other environmental factors, such as topography, in addition to low clay content, may have made the soil particles at this site erodible.

The study by Oyetola (2017) on aggregate stability and organic carbon as affected by different land uses showed that the concentration of iron oxide (Fe_2O_3) in the soil can increase aggregate stability. This is because iron oxide acts as a binding agent in arid and tropical soils and affects the edge charge and variable surface charge of clays and minerals. This is consistent with the results obtained in this research, as shown in Table 1 and Figure 7 above. This could be another plausible reason why the soil particles in non-erosion-prone areas 1 to 3 are stable, apart from their high calcium content. Therefore, application of the salt solution of this iron may, to a large extent, solve the erosion problem in Okunino and Obinagu, and not in Abor, as it is already reaching in iron in a concentration (1329 ppm) comparable to 1295, 1347, and 1333 ppm of NEPAs 1, 2, and 3, respectively.

However, iron toxicity can pose another problem. Iron toxicity occurs when there is a deficiency of zinc. Excess iron can result in dark green foliage, stunted growth of tops and roots, dark brown to purple leaves on some plants (Montás Ramirez et al., 2002).

Based on the results obtained, the zinc concentration is relatively low in all erodible and non-erodible soil samples studied, thereby increasing the potential toxicity of iron in these samples. This is consistent with the findings of Okoye et al. (2022) on the chemical stabilization of erosion-prone soils in Anambra State. It is, therefore, not advisable to apply solutions of salts of Fe to the erosion-prone soils for the sake of stabilizing them. This is to avoid the toxic effects of iron due to the low concentration of Zn^{2+} in these areas.

3.1.6. Magnesium Concentration (Mg)

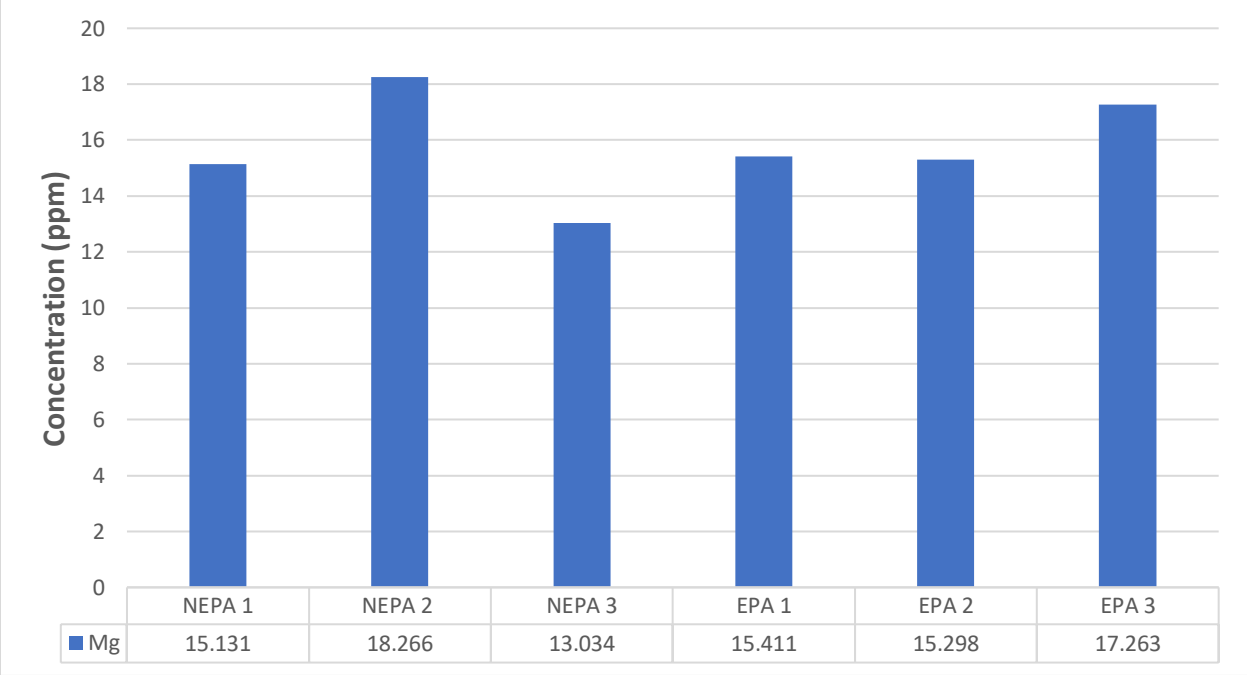

Figure 8: Magnesium concentration across the NEPAs and EPAs

Figure 8 shows that the magnesium concentrations across the NEPAs 1–3 were 15.131, 18.266, and 13.034 ppm, respectively, while those of the EPAs 1–3 were 15.411, 15.298, and 17.263 ppm, respectively.

Mg has a flocculating property which binds soil particles together and confers a strong ability of soils to resist erosion. However, based on the results, there is no significant difference in magnesium concentration between NEPAs and EPAs, indicating that magnesium is not the primary metal responsible for soil erosion susceptibility.

3.2. Particle Size of Erosion–Prone and Non–Erosion–Prone Soils

Table 2 shows the results from laboratory analysis of six (6) soil samples: two from erosion-prone areas and three from non–erosion–prone areas. It shows the values obtained for particle size distribution.

Table 2: Particle Size Distribution in Non-Erosion Prone and Erosion–Prone Soils of Enugu State

Particle size distribution	NEPA 1 (Ninth Mile)	NEPA 2 (Ugwuogo)	NEPA 3 (Obinagu)	EPA 1 (Okunino)	EPA 2 (Obinagu)	EPA 3 (Abor)
% Sand	63.8	47.1	65.7	75.3	75.7	72.1
% Silt	14.35	28.70	19.40	10.7	15.6	16.4
% Clay	21.85	24.20	14.9	7.2	8.7	11.5

Soil particle size is determined by the percentage of sand, silt, and clay particles in a soil sample (Ingmar et al., 2024). Generally speaking, clay-rich soils have more than 40% clay particles, sandy soils have more than 55% sand particles, and loamy soils have percentages of sand, silt, and clay in the right proportions so that the influence of all particles is equal (Abdulkadir, 2016). It is clear from the values in Table 2 above that none of the soil samples analyzed are clay-rich, as the clay content determined for each is below 40%. This implied that they cannot be depended upon for a clay supply. However, comparing the erosion-prone areas (EPAs) with the non-erosion-prone areas (NEPAs) showed that the percentage of clay (21.85%, 24.20%, and 14.90%) was high in all non–erosion–prone areas (NEPAs) of Ninth Mile, Ugwuogo, and Obinagu, respectively. The values for EPA 1, 2, and 3 were 7.2%, 8.7%, and 11.5%, which are clearly lower than those of NEPAs. Table 2 also shows that all EPA 1–3 have relatively high sand content (75.3, 75.7, and 72.1%) and low clay content (7.2, 8.7, and 11.5%). This aligns with expectations of very high sand and low clay percentages in highly erodible soil. The findings are consistent with those of Ojiako et al. (2017) and Oli et al. (2021).

3.3. Chemical Stabilization of Erosion-prone Soil

Figure 9 shows the result of chemical stabilization of 15 g each of two erosion-prone soils treated with 5 mL (25g/250 cm^3) each of stabilization chemicals.

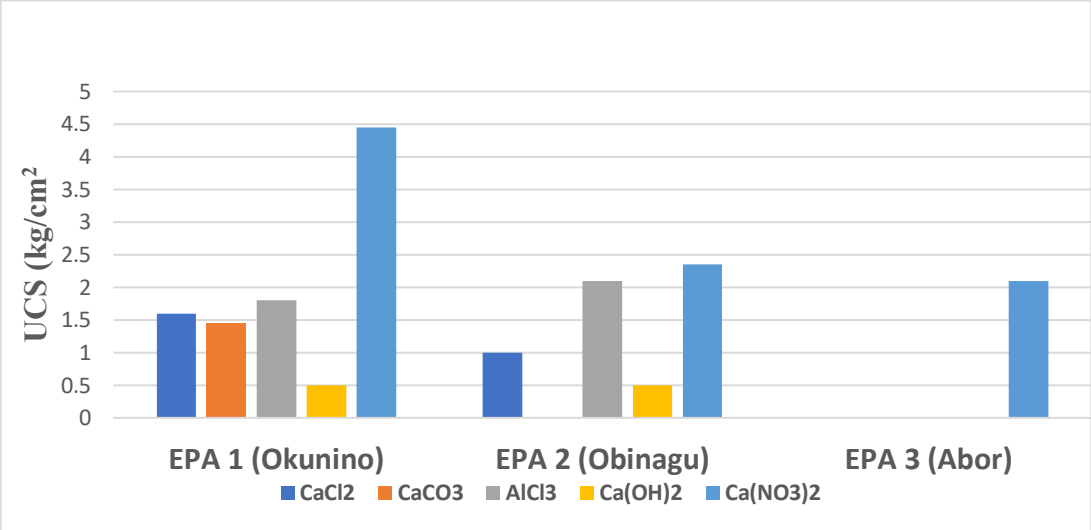

Figure 9: Chemical stabilization of 15 g each of two erosion prone soils treated with 5 mL (25g/250 cm^3) each of stabilization chemicals.

The mean stabilization capacity of the five chemicals at a concentration of (25g/250 cm3) was determined on 15 g of the soil samples. Soil samples treated with $CaCl_2$ had a mean stabilization of 0.87 kg/cm^2, those treated with $CaCO_3$ had 0.48 kg/cm^2, those treated with $AlCl_3$ had 1.30 kg/cm^2, those treated with $Ca(OH)_2$ had 0.33 kg/cm^2, while those treated with $Ca(NO_3)_2$ had 2.97 kg/cm^2

Figure 9 shows that the unconfined compressive strength (UCS) on application of $CaCl_2$ to erosion-prone soils of Okunino, Obinagu, and Abor were 1.6, 1.00, and 0.00 kg/cm^2, respectively. It was observed from the UCS values that $CaCl_2$ gave a better stabilization of the erodible soils of Okunino than that of Obinagu. Generally, the chemical has a very poor stabilization effect on Okunino and Obinagu soils, while Abor was not stabilized at all.

A $CaCO_3$ solution was applied to each of the different erosion-prone soils of Okunino, Obinagu, and Abor, and the resulting UCS values were 1.45, 0.00, and 0.00 kg/cm^2, respectively. In terms of stabilization, soils from Okunino were poorly stabilized, whereas those from Obinagu and Abor were not stabilized by the $CaCO_3$ solution. $CaCO_3$ was unsuitable for stabilizing all soil particles from the erosion sites. This could be traced to the low solubility of the salt.

The UCS values for the $AlCl_3$ salt solution were 1.80, 2.10, and 0.00 kg/cm^2, respectively. From the values obtained, the $AlCl_3$ solution administered to Obinagu provided better stabilization of the soil particles than that administered to Okunino, while the soil particles of Abor were not stabilized.

A $Ca(OH)_2$ solution was applied to the three erosion-prone areas of Okunino, Obinagu, and Abor, yielding results of 0.50, 0.50, and 0.00 kg/cm^2, respectively. $Ca(OH)_2$ solution was not suitable for stabilizing all the erosion-prone soils studied. The reason for this was due to very low solubility of the salt solution. Furthermore, true lime stabilization

requires days or weeks of curing to pozzolanically react with soil silica/alumina.

The UCS values obtained upon application of a $Ca(NO_3)_2$ solution to Okunino, Obinagu, and Abor were 4.45, 2.35, and 0.00 kg/cm^2, respectively. A higher level of stabilization was observed in Okunino. Therefore, the $Ca(NO_3)_2$ solution was well-suited to stabilizing the erosion-prone soil structure of Okunino. Obinagu and Abor soils showed fairly good stabilization. The findings of this research are consistent with the study by Oli et al. (2021), in which $Ca(NO_3)_2$ was shown to have a high stabilizing capacity for the erodible soils of Ninth Mile and Ugwuogo.

$Ca(NO_3)_2$ stabilizes soil particles primarily by providing a highly soluble source of divalent calcium ions (Ca^{2+}), which act as a binding agent and flocculant for clay particles and organic matter. Unlike lime, it does not rely on increasing soil pH to work, but rather on its immediate ionic interaction with the negatively charged surfaces of soil particles (Yan et al., 2023). Percentage stabilization by $Ca(NO_3)_2$ was consistently higher than that observed for other stabilizing agents in all the soils studied. This may be attributed to its high solubility in water, which is crucial for its effectiveness in soil stabilization, as it allows the compound to quickly dissolve and move through the soil profile. The interaction between soil particles and calcium nitrate, specifically the calcium ion, is dominated by electrostatic attraction, forming ionic bonds that improve structure and strengthen particles.

Table 3: ANOVA Results of the mean values of the stabilizing effect in soil samples

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	13.519	4	3.380	3.847	.038
Within Groups	8.787	10	.879		
Total	22.306	14			

Table 3 shows that a one-way ANOVA revealed a statistically significant difference in the mean stabilizing effect of the chemicals in different soil samples, $F(4,10) = 3.85$, $p < 0.05$. The post-hoc comparison using the Tukey HSD indicated that the mean stabilizing effect of $Ca(NO_3)_2$ ($M = 2.97$, $S.D = 0.29$) was significantly higher than that of $Ca(OH)_2$ ($M = 0.33$, $S.D = 1.29$) in the soil. But it did not differ significantly from $CaCl_2$, $CaCO_3$, and $AlCl_3$. The overall efficiencies of the chemical stabilizers, from highest to lowest, are: $Ca(NO_3)_2 > AlCl_3 > CaCl_2 > CaCO_3 > Ca(OH)_2$.

The difference in the stabilizing capacity of $Ca(NO_3)_2$ and $Ca(OH)_2$ stems primarily from their distinct chemical mechanisms, solubility, and reactivity with soil components in soil-stabilization applications. While both introduce calcium ions for stabilization, calcium hydroxide acts through pozzolanic reactions (long-term strength), whereas calcium nitrate acts through electrostatic bonding and acceleration of hydration (early strength and rapid set).

4.0. Conclusions

It has been established from the research that these chemical constituents, calcium and aluminum ions, contribute to the stability of the erosion-prone areas, while sodium disperses the soil particles and thus leads to the proneness of the sites studied to erosion.

Insight has also been given from this research into how the erosion problem can be solved through the use of chemical stabilizing agents. At the specific concentration tested, $Ca(NO_3)_2$ proved most effective. Further studies testing varying concentrations are required to determine the optimal proportion. $CaCO_3$ and $Ca(OH)_2$ cannot be considered suitable chemicals for stabilizing the soil particles of the erosion-prone areas studied. The overall efficiencies of the chemical stabilizers are ranked as follows: $Ca(NO_3)_2 > AlCl_3 > CaCl_2 > CaCO_3 > Ca(OH)_2$.

4.1. Recommendations

The destructive impact of erosion is a common experience world over, in Nigeria, and particularly in the south east, of which Enugu State is one. Therefore, further research is recommended on other erosion sites in the State and across the country to determine which chemicals are suitable for stabilizing soil particles. Field research is also recommended. From all indications, this research offers a solution to the erosion problem at the sites studied. A study should also be conducted to investigate the potential impacts of these chemicals on soil matrices, surface water, and groundwater. Furthermore, we recommend multidisciplinary research on this all-important subject, as it may provide deeper insight and, consequently, a long-lasting solution when a team of scholars examines it from various viewpoints.

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