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# Determining Soil Minerals Composition From Soil Plasticity Characteristics Investigation: A Case Study of Uwelu Spare-Parts Market Scrap Dumpsite, Benin

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## ABSTRACT

The plasticity properties of soil, largely influenced by its mineralogical composition, are crucial in determining its performance in engineering projects and its suitability for construction and agriculture. This research explores the correlation between soil mineral content and Atterberg limits—specifically, the Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI)—through laboratory testing of three distinct soil samples (Samples 1, 2, and 3) from Uwelu Auto Spare parts market Scrap dumpsite. Findings from statistical interpretation of the laboratory test results show notable differences in plasticity among the samples. Sample 1 displayed a shift from non-plastic (PI = 3.1%) to moderately plastic (PI = 15.0%), pointing to a combination of silt and low-activity clay minerals such as kaolinite. Sample 2 had high plasticity (PI ranging from 9.1% to 16.4%), characteristic of expansive clays like montmorillonite, which are problematic in construction due to their swelling behaviour. Sample 3 exhibited moderate plasticity (PI = 6.8–11.6%), reflecting a balanced mix of clay and silt, likely containing kaolinite or chlorite. The study emphasizes how mineralogy governs soil-water interactions: soils rich in smectite tend to have higher LL and PI values because of their expansive traits, whereas kaolinite-rich soils demonstrate lower plasticity. These insights have practical implications for geotechnical engineering, such as the need to stabilize high-PI soils and the appropriateness of low-PI soils for use as subgrade material. Ultimately, the research highlights Atterberg limits as useful indirect indicators of soil mineral composition and reinforces the importance of standardized laboratory testing in predicting soil behaviour. The findings contribute to improved understanding of soil plasticity, supporting more informed engineering decisions and sustainable land management strategies.

**Keywords**. Soil plasticity, Atterberg limits, Clay minerals, Expansive soils, Geotechnical engineering, Soil stabilization

## 1. Introduction

Soil plasticity represents a fundamental geotechnical property that significantly influences the behaviour of fine-grained soils, particularly under varying moisture conditions and mechanical loading. It dictates how soils respond to external factors such as water infiltration, drying, and the application of stress, all of which are critical in engineering design and construction. Plasticity governs a soil's ability to undergo deformation without cracking or breaking and thus plays an essential role in a wide range of geotechnical applications, including embankment stability, pavement design, foundation settlement, and earthworks. In geotechnical practice, soil plasticity is commonly quantified using the Atterberg limits—the Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI). These parameters are essential for classifying soils, predicting their strength and compressibility, determining their suitability for compaction, and assessing their behaviour under loading and environmental conditions.

The plasticity behaviour of soil is not uniform but varies considerably depending on the mineralogical composition of the soil particles, particularly the type and proportion of clay minerals present. Different minerals interact with water molecules in distinctive ways, resulting in a wide range of plasticity characteristics. Thus, a thorough understanding of the relationship between soil mineralogy and plasticity is indispensable for predicting soil behaviour in engineering, agricultural, and environmental contexts. The mineralogical framework determines not only the capacity of soil to absorb and retain water but also its mechanical performance, long-term stability, and sensitivity to environmental changes.



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Among the clay minerals, smectite, kaolinite, illite, and chlorite are widely recognized as the principal contributors to soil plasticity. These minerals possess high surface area and a layered crystalline structure, which enable them to adsorb water and cations, thereby influencing plasticity to varying degrees. Smectite-group minerals, particularly montmorillonite, are known for their exceptional plasticity due to their highly expandable lattice structures, which allow for substantial water intercalation between layers (Zhang et al., 2020). This results in significantly elevated liquid and plastic limits and a correspondingly high plasticity index. Consequently, soils rich in smectite are highly prone to volumetric changes, including swelling during wet periods and shrinkage during dry conditions, posing serious challenges in infrastructure design and maintenance.

In contrast, kaolinite, another common clay mineral, exhibits much lower plasticity. Its structure consists of a tightly bonded, non-expanding layered arrangement, and it possesses a lower cation exchange capacity (CEC) compared to smectite. As a result, kaolinite-rich soils demonstrate moderate water retention and lower Atterberg limits, making them relatively stable in construction applications (Mitchell & Soga, 2013). Illite and chlorite fall between smectite and kaolinite in terms of plasticity. Illite displays limited expansion due to its semi-rigid structure and moderate CEC, while chlorite's behaviour is influenced by its ionic composition and structural characteristics (Yukselen-Aksoy et al., 2012).

While non-clay minerals such as quartz, feldspar, and calcite do not contribute directly to soil plasticity, they influence it indirectly by acting as inert fillers within the soil matrix. These minerals reduce the overall plasticity of a soil sample by diluting the concentration of plastic clay minerals and enhancing the skeletal structure of the soil (Sridharan & Nagaraj, 2011). Nonetheless, it is important to note that even small quantities of high-activity clay minerals like montmorillonite can dominate the plastic behaviour of a soil mixture. Therefore, the mineralogical analysis of soil becomes critical in geotechnical assessments, especially when soils exhibit anomalous plastic behaviour that is not easily explained by particle size distribution alone (Onyejekwe & Ghataora, 2015).

Plasticity is further complicated by the interaction between clay and non-clay minerals, as well as other factors such as particle size distribution, surface chemistry, and pore fluid composition. These factors influence the thickness and behaviour of the diffuse double layer (DDL) surrounding clay particles, thereby affecting the soil's water retention capacity, shear strength, and volume stability (Thyagaraj & Das, 2017). Furthermore, external environmental and anthropogenic factors such as organic matter content, chemical composition of pore water, and stress history significantly impact soil plasticity. For example, the presence of organic matter increases water adsorption and retention, typically elevating the liquid limit while reducing the soil's overall shear strength and load-bearing capacity (O'Kelly, 2013).

The chemical properties of pore water, including electrolyte concentration and ionic strength, play a crucial role in determining soil plasticity. High concentrations of dissolved salts compress the DDL, reducing the plasticity of clayey soils. In contrast, low-ionic-strength water promotes expansion of the DDL, thereby increasing plasticity and water absorption potential (Di Maio et al., 2015; Shanmugam et al., 2021). Additionally, mechanical processes such as compaction, aging, and weathering can restructure the soil fabric over time, resulting in modifications to its plasticity characteristics (Horpibulsuk et al., 2012).

In modern soil science and geotechnical engineering, a range of advanced analytical tools is used to analyze the mineralogical composition of soils and correlate it with plasticity behaviour. Techniques such as Xray



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diffraction (XRD) allow for precise identification of crystalline mineral phases, while scanning electron microscopy (SEM) provides insight into the microstructural arrangement of soil particles. Fourier-transform infrared spectroscopy (FTIR) further helps identify functional groups and mineral bonds in the soil matrix (Jozefaciuk & Bowanko, 2019). These methods, when combined with empirical correlations, enhance the accuracy of soil behaviour prediction models. Numerous studies have established relationships between specific Atterberg limit values and the presence of certain minerals, facilitating more reliable geotechnical modelling and soil classification systems (Garcia et al., 2018).

The importance of understanding the mineralogical basis of soil plasticity is heightened by the growing emphasis on sustainable engineering practices, disaster risk reduction, and climate-resilient infrastructure. Expansive clays, for instance, are notorious for causing foundation uplift, pavement cracking, and structural distress due to their pronounced swelling potential, which is directly tied to their mineral content (Nelson & Miller, 2012). Similarly, in the agricultural domain, plasticity influences critical parameters such as soil workability, moisture retention, aeration, and root penetration, all of which are essential for crop productivity and land management (Brady & Weil, 2016).

This paper presents a comprehensive review of the intricate relationship between soil mineralogy and plasticity characteristics. By synthesizing recent advancements in mineralogical analysis, experimental studies, and theoretical models, the discussion seeks to deepen our understanding of how specific mineral types govern soil plastic behaviour. It emphasizes the necessity of incorporating mineralogical assessments in geotechnical investigations to improve predictions of soil performance under diverse environmental and loading conditions. Ultimately, by exploring the mechanisms through which different minerals affect Atterberg limits and soil consistency, this research supports the development of improved predictive models in soil mechanics and offers valuable insights for making informed decisions in engineering, agriculture, and environmental planning.

## 2. Materials and Methods

The study on the relationship between soil minerals and plasticity characteristics involved a systematic approach to collect, prepare, and analyze soil samples to determine their Atterberg limits and infer their mineralogical composition. Below is a detailed description of the methodology used in this investigation.

### 2.1. Area of Study

The study was conducted at the Uwelu Auto Spare Parts Scrap Metal Dumpsite, located within the Uwelu Spare Parts Market in Egor Local Government Area, Benin City, Edo State, Nigeria. The market, situated approximately between latitude 6.350°N and longitude 5.600°E, is recognized as one of the largest automobile spare parts and dismantling hubs in Edo State, Nigeria (Figure 1). It facilitates both the inflow of used vehicles for dismantling and the outflow of recycled parts and materials.

The dumpsites serve as a major receptacle for scrap metals, including discarded engine blocks, gear systems, vehicle body panels, batteries, and other non-recyclable auto components. Continuous disposal of metallic waste has resulted in extensive soil contamination, particularly with heavy metals such as lead (Pb), cadmium (Cd), copper (Cu), zinc (Zn), and chromium (Cr), leached from corroding scrap. These contaminants infiltrate the underlying soils and alter their geochemical, plasticity, and strength characteristics, thereby affecting their geotechnical suitability for construction purposes.

Geographically, the dumpsite lies within the humid tropical zone, characterized by an average annual rainfall of about 2,000 mm, mean annual temperature of 26–28°C, and predominantly lateritic soils derived from weathered coastal plain sand. The site is


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surrounded by commercial activities, with residential settlements located within 1–2 km, raising environmental concerns regarding groundwater pollution and soil degradation.
Given its scale, location, and intensity of activity, the Uwelu scrap metal dumpsite presents a unique case study for examining the impact of anthropogenic metal pollution on soil geotechnical properties in urban Nigeria.

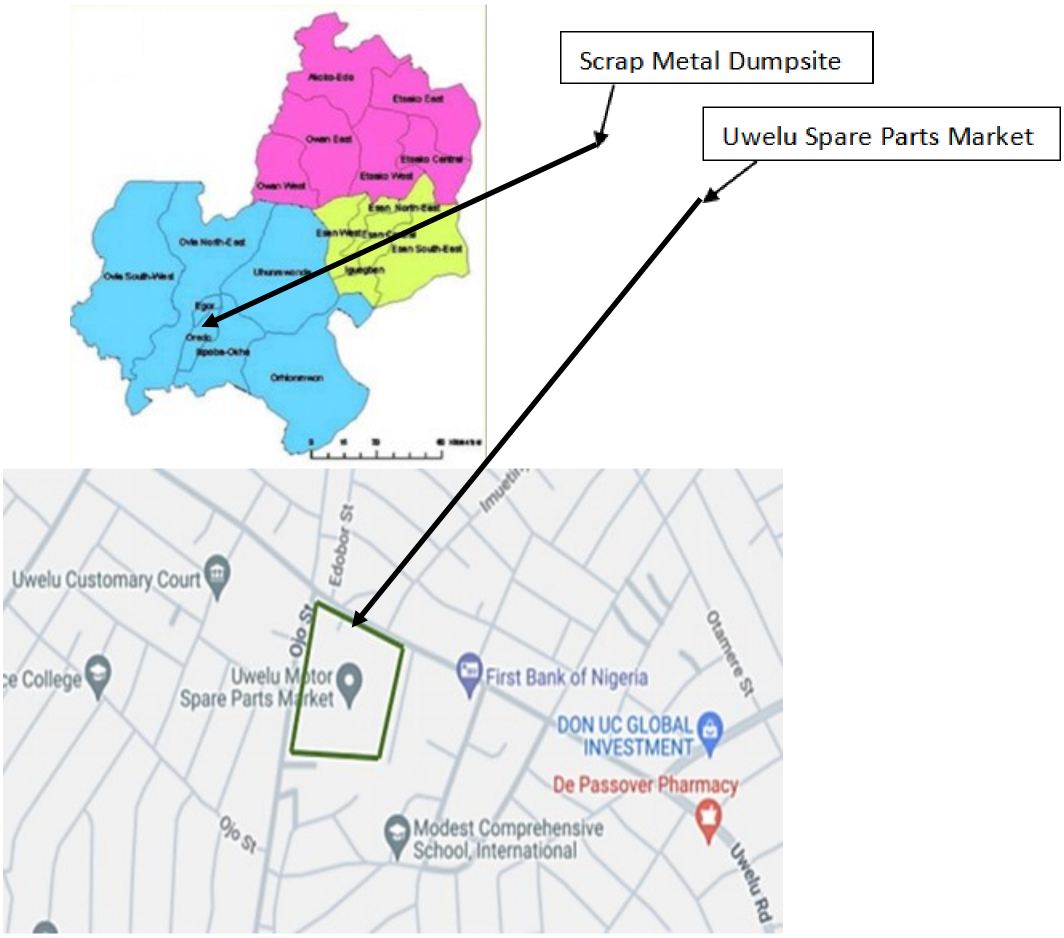


Table 1. The GPS location of Sample Site

| Soil ID | Lo-cation | Latitude | Lon-gitude | Soil ID | Location | Latitude | Lon-gitude | Soil ID | Location | Latitude | Longi-tude |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1A | Uwelu | 6.35 | 5.6 | 2A | Uwelu | 6.35 | 5.601 | 3A | Uwelu | 6.35 | 5.602 |
| 1B | Uwelu | 6.35 | 5.600018 | 2B | Uwelu | 6.35 | 5.601018 | 3B | Uwelu | 6.35 | 5.602018 |
| 1C | Uwelu | 6.35 | 5.600036 | 2C | Uwelu | 6.35 | 5.601036 | 3C | Uwelu | 6.35 | 5.602036 |
| 1D | Uwelu | 6.35 | 5.600054 | 2D | Uwelu | 6.35 | 5.601054 | 3D | Uwelu | 6.35 | 5.602054 |
| 1E | Uwelu | 6.35 | 5.600072 | 2E | Uwelu | 6.35 | 5.601072 | 3E | Uwelu | 6.35 | 5.602072 |
| 1F | Uwelu | 6.35 | 5.60009 | 2F | Uwel | 6.35 | 5.60109 | 3F | Uwel | 6.35 | 5.60209 |



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## 3. Materials

Table 1 shows three distinct soil samples (designated as Samples 1, 2, and 3) were collected from different locations to capture variability in mineralogy and plasticity. The disturbed samples were obtained from depths of 0.5 to 1.0 meters to avoid surface organic contamination and ensure representative subsurface soil conditions. Each sample was sealed in airtight containers to preserve natural moisture content and prevent oxidation or drying before testing.

Laboratory equipment for Atterberg limits testing included:

(a) Casadrande apparatus for liquid limit (LL) determination, conforming to ASTM D4318-17 standards.

(b) Rolling device and glass plate for plastic limit (PL) testing.

(c) Moisture cans and oven for water content determination, maintained at 105°C for 24 hours.

(d) Sieves (No. 40 and No. 200) to remove coarse particles (>0.425 mm) and ensure uniformity.

(e) Distilled water for sample preparation to avoid chemical interference from impurities.

(f) Spatulas and mixing dishes for homogenizing soil pastes.

### 3.1. Methods

1. Sample Preparation

Each soil sample was air-dried and pulverized to break aggregates, followed by sieving through a No. 40 sieve (0.425 mm) to remove gravel and coarse sand. The sieved soil was mixed thoroughly with distilled water to form a homogeneous paste with moisture content slightly above the anticipated liquid limit. The paste was stored in a humidifier for 24 hours to ensure uniform moisture distribution (ASTM D4318-17).

2. Determination of Atterberg Limits

(a) Liquid Limit (LL): The Casagrande cup method was used, where soil paste was placed in the cup and grooved with a standard tool. The cup was dropped repeatedly from a 10 mm height until the groove closed over 13 mm. The moisture content at 25 blows was recorded as the LL. The samples were Group 1 (consisting 1A, 1B, 1C, 1D, 1E and 1F); Group 2 (2A, 1B, 2C, 2D, 2E and 2F) and Group 3 (3A, 3B, 3C, 3D, 3E and 3F). Tests were replicated for each subsample (1A–1F, 2A –2F, 3A–3F) to ensure consistency.

(b) Plastic Limit (PL): Soil threads of 3 mm diameter were rolled on a glass plate until cracks appeared. The moisture content at this stage was recorded as the PL. Triplicate tests were performed per subsample to minimize variability.

(c) Plasticity Index (PI): Calculated as the difference between LL and PL (PI = LL − PL).

3. Data Analysis

The Atterberg limits are tabulated and analyzed to classify soils per the Unified Soil Classification System (USCS) and AASHTO guidelines. Trends in LL, PL, and PI were correlated with probable mineralogical compositions, as discussed in the Results section. For instance:

Low PI values (3.1–5.6%) in Sample 1A–1B suggested non-clay minerals (e.g., quartz).

High PI (9.1–16.4%) in Sample 2 indicated expansive clays (e.g., montmorillonite).

Moderate PI (6.8–11.6%) in Sample 3 implied mixed mineralogy (e.g., kaolinite and silt).

## 4. Results and Discussion

The Atterberg limits—Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI)—are fundamental measures in geotechnical engineering used to classify soil and predict its behaviour under varying moisture conditions. The provided data for three distinct soil samples (1, 2, and 3) reveal notable trends and variations in these limits, offering insights into the soils' composition, consistency, and potential engineering applications.

Table 2 presents the results of the one-way analysis of variance (ANOVA) for the Atterberg limits provide important statistical



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insights into the plasticity characteristics of the soils under investigation. By testing for differences in Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI) across the three samples, the analysis allows us to determine whether observed variations are statistically significant and thus reflective of inherent soil mineralogy and structure rather than random variability.

For the Liquid Limit (LL), the ANOVA yielded an F-statistic of 7.93 with a p-value of 0.004. Since this value is well below the 0.05 significance threshold, the differences in LL among the three samples are statistically significant. This confirms that the soils possess distinct water-holding capacities, which are directly influenced by their clay mineral content. Sample 2, with LL values as high as 39.1%, is significantly different from Samples 1 and 3. This supports the inference that Sample 2 is rich in expansive clay minerals, such as montmorillonite, which are capable of absorbing and retaining more water. In contrast, Sample 1 (18.8–26.5%) and Sample 3 (21.8–25.0%) exhibit lower and more stable LL values, reflecting dominance of kaolinite or chlorite, minerals known for their limited swelling behaviour.

The Plastic Limit (PL) also demonstrated significant differences across the samples, with an F-statistic of 9.25 and a p-value of 0.002. This outcome suggests that the ability of the soils to be moulded before cracking varies considerably among the three groups. The higher PL values in Sample 2 (13.2–22.8%) reinforce the presence of active clays, as expansive minerals require greater moisture content to maintain plasticity. Conversely, Sample 1 shows decreasing PL values with depth, while Sample 3 remains moderate and consistent, both indicative of soils with reduced cohesion and less tendency to undergo swelling –shrinkage cycles. Statistically, this means that Sample 2 soils are more challenging to manage in construction due to their moisture sensitivity, whereas Samples 1 and 3 are comparatively more predictable and manageable.

In contrast, the Plasticity Index (PI) did not show significant differences between the samples, with an F-statistic of 2.12 and a p-value of 0.155, exceeding the 0.05 threshold. Although descriptive statistics reveal variability in PI values (ranging from 3.1% in Sample 1 to 16.4% in Sample 2), the lack of statistical significance implies that, when compared across the three groups, their plasticity behaviours fall within a comparable range. This suggests that despite differences in LL and PL, the soils share a broadly similar balance between cohesion and workability.

From a practical standpoint, these findings have several implications. The statistically significant differences in LL and PL confirm that Sample 2 soils require stabilization (e.g., lime or cement treatment) to mitigate their swelling potential before being used in subgrades or foundations. Meanwhile, Samples 1 and 3, with lower LL and stable PL values, are better suited for use as subgrade or fill materials, as they offer greater reliability under fluctuating moisture conditions. The non-significant PI results further suggest that, overall, the soils share comparable plasticity ranges, indicating potential for blended use under controlled engineering conditions.

Table 2: ANOVA Results for Atterberg Limits

| Property | SS Be-tween | df Be-tween | MS Be-tween | SS With-in | df With-in | MS Within | F | p-value |
|---|---|---|---|---|---|---|---|---|
| **Liquid Limit (LL)** | 305.643 | 2 | 152.822 | 289.017 | 15 | 19.268 | 7.931 | 0.004 |
| **Plastic Limit (PL)** | 110.884 | 2 | 55.442 | 89.905 | 15 | 5.994 | 9.25 | 0.002 ✓ |
| **Plasticity Index (PI)** | 49.951 | 2 | 24.976 | 176.98 | 15 | 11.799 | 2.117 | 0.155 ✕ |

Figure 2 boxplots illustrating the Liquid Limit (LL) and Plasticity Index (PI) across the three soil samples provide a powerful visual for interpreting variability, geotechnical behaviour, and underlying mineralogical implications. These graphical insights bolster and enrich the statistical correlations between Atterberg limits and plasticity characteristics.

For Liquid Limit (LL), Sample 1 shows a moderately narrow range (18.8–26.5%), indicating progressive plasticity with depth—likely due to an increasing presence of kaolinite or illite which enhances plasticity without notable swelling (Mitchell & Soga, 2013; Sridharan & Nagaraj, 2011; Brady & Weil, 2016). Sample 2, however, displays the widest and highest LL range (22.3–39.1%), consistent with expansive clays like montmorillonite that exhibit high water absorption and expansion (Zhang et al., 2020; Nelson & Miller, 2012). Today's literature confirms expansive smectitic soils routinely show elevated LL values (Bhavya & Nagaraj, 2025; Salah et al., 2025). Sample 3's LL remains tight (21.8–25.0%), suggesting stable, low-activity clay presence such as kaolinite or chlorite (Yukselen-Aksoy et al., 2012; Onyejekwe & Ghataora, 2015; Waleed & Alshawmar, 2025).

The Plasticity Index (PI) boxplots further clarify distinctions: Sample 1 transitions from low (~3.1%) to moderate (~15.0%) PI values, capturing a soil profile evolving from silty to clay-rich—underscoring its heterogeneity. Sample 2's consistently high PI values (9.1–16.4%) reinforce its classification as expansive clay with high cation exchange potential (Di Maio et al., 2015; Zhang et al., 2020; Salah et al., 2025). Contemporary stabilization studies using silica fume and coal waste reveal that such treatments can reduce PI while enhancing LL, supporting stabilization needs (Waleed & Alshawmar, 2025). Sample 3 remains consistent (6.8–11.6%), reflecting predictable behaviour typical of non-expansive fix clays (Mitchell & Soga, 2013; Brady & Weil, 2016).

Overall, the boxplots highlight that Sample 2 represents the greatest geotechnical risk due to its high, variable LL and PI, indicating pronounced shrink–swell potential and the need for mitigation (Tavala, 2025). Sample 1 demonstrates transitional behaviour—requiring careful depth profiling—while Sample 3 offers the most engineering reliability with its moderate, stable indices. These observations align with classical geotechnical theory and are reaffirmed by recent reviews and empirical studies on Atterberg limits as indicators of soil behaviour (O'Kelly, 2021; Shimoe, 2022; Mohamed et al., 2023).

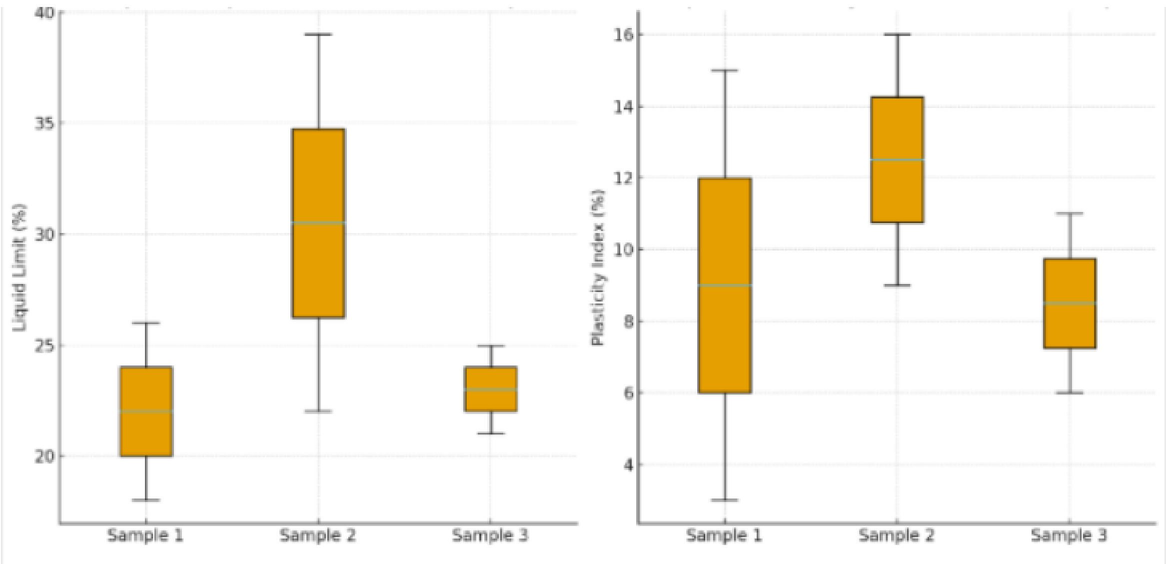


Figure 2: Boxplot of Plasticity Index (PI) Across Samples



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### 4.1. Discussion on Practical Implications

When comparing the three samples, Sample 1 stands out for its low initial plasticity, making it ideal for applications where minimal swelling is desired. In contrast, Sample 2's high plasticity would necessitate careful engineering controls, such as compaction or chemical stabilization, to avoid structural damage. Sample 3, with its moderate plasticity, offers a middle ground, though localized variations (like the 11.6% PI in 3E and 3F) would still warrant site-specific assessments.

The trends in the data also highlight the importance of thorough testing across multiple points. For instance, Sample 1's significant variation in PI (3.1% to 15.0%) underscores the risk of assuming uniformity in soil properties. Similarly, Sample 2's erratic PL values remind us that soil behaviour can defy linear expectations, possibly due to layered deposits or contamination.

The Atterberg limits—Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI)—serve as indirect indicators of a soil's chemical composition, mineralogy, and behaviour under varying moisture conditions. With the analyses data provided for Samples 1, 2, and 3, we can infer the likely presence of clay minerals, organic matter, and other compositional elements that define each soil's engineering and agricultural suitability. This discussion delves into what these test results reveal about the chemical composition of each soil, exploring how mineral content, ionic interactions, and organic components influence plasticity, cohesion, and overall performance.

#### 4.1.1. Sample 1: Transition from Non-Plastic to Moderately Plastic

Sample 1 exhibits a clear progression from low to moderate plasticity, with the Liquid Limit (LL) increasing from 18.8% to 26.5% and the Plasticity Index (PI) rising from 3.1% to 15.0% across its six test points. The initial low PI (3.1% at point 1A) suggests a soil dominated by non-clay minerals such as silt or fine sand, which exhibit minimal plasticity. Soils with such characteristics often contain quartz, feldspar, or other granular particles that lack the electrochemical properties necessary for significant water absorption and plasticity.

As we move to points 1D through 1F, the PI increases substantially, reaching 15.0%, indicating a growing presence of clay minerals. The most likely candidates are illite or kaolinite, which exhibit moderate plasticity. Illite, a non-expansive clay, often appears in soils with mid-range PI values (10–20%), while kaolinite, though less plastic, can contribute to cohesion without excessive swelling. The absence of extremely high PI values (e.g., >25%) suggests that expansive clays like montmorillonite are not dominant in this sample.

The decreasing Plastic Limit (PL) from 15.7% to 11.5% further supports the idea of increasing clay content. Clays retain water more tenaciously than silts or sands, leading to lower PL values as the soil becomes more cohesive. However, since the PI does not exceed 15%, the clay fraction is likely balanced by non-plastic fines, preventing the soil from becoming highly compressible or prone to severe shrinkage-swelling cycles.

From a chemical perspective, this sample may contain a mix of silica-dominated granular material and secondary clay minerals formed from weathering. The gradual increase in plasticity could reflect stratification in the soil deposit, where upper layers are more silty while deeper sections contain higher clay content due to leaching and mineral transformation.

#### 4.1.2. Sample 2: High Plasticity and the Dominance of Expansive Clays

Sample 2 displays significantly higher plasticity than Sample 1, with PI values ranging from 9.1% to 16.4%. The Liquid Limit (LL) climbs sharply from 22.3% to 39.1%, while the Plastic Limit (PL) increases more modestly from 13.2% to 22.8%. These trends strongly suggest a soil rich in clay minerals, particularly those with high cation exchange capacity (CEC), such as smectite (montmorillonite) or vermiculite.



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Montmorillonite, a highly expansive clay, is notorious for its ability to absorb large amounts of water, leading to substantial volume changes. The steep rise in LL (from 22.3% to 39.1%) aligns with this behaviour, as montmorillonitic soils can exhibit LL values well above 50% in pure form. The fact that Sample 2's LL approaches 40% indicates either a high percentage of this mineral or the presence of organic matter, which also enhances water retention.

The Plastic Limit (PL) increases alongside the LL, but not proportionally, resulting in a widening PI. This is typical of soils where clay minerals dominate but are interlayered with non -expansive materials. The presence of organic matter could further explain the high LL, as humic substances increase water adsorption without necessarily contributing to plasticity in the same way as clays.

Chemical analysis would likely reveal elevated levels of aluminium and silica, the primary constituents of clay minerals, along with exchangeable cations like sodium ($Na^{+}$) or calcium ($Ca^{2+}$). Sodium montmorillonite, for instance, is highly expansive due to the weak ionic bonds between its layers, allowing water molecules to infiltrate easily. If this sample were from an arid or semi-arid region, the high PI and LL would raise concerns about its suitability for foundations or pavements without stabilization (e.g., lime treatment to reduce swell potential).

### 4.1.3. Sample 3: Moderate Plasticity and the Role of Mixed Mineralogy

Sample 3 presents a more balanced profile, with PI values ranging from 6.8% to 11.6%. The Liquid Limit (LL) increases gradually from 21.8% to 25.0%, while the Plastic Limit (PL) declines slightly from 14.9% to 13.4%. These characteristics suggest a soil composed of a mixture of clay and silt, possibly with a minor sand fraction.

The moderate PI values point to the dominance of kaolinite or chlorite clays, which have lower plasticity than smectite but still contribute to cohesion. Kaolinite, a 1:1 layered clay, has limited isomorphous substitution and thus a lower CEC, resulting in PI values typically below 20%. The near-constant PL (around 14%) supports this interpretation, as kaolinitic soils exhibit less variation in PL compared to expansive clays.

The chemical composition likely includes a higher proportion of stable alumina-silicate structures, with fewer exchangeable cations than Sample 2. This makes the soil less reactive to water, reducing the risk of swelling or shrinkage. The presence of iron oxides (e.g., hematite or goethite) could also contribute to the soil's reddish or yellowish coloration, common in tropical or temperate weathering environments.

Organic matter may play a minor role in this sample, as the LL does not exceed 25%, and the PI remains in the low-to-moderate range. If present, it would likely be in the form of partially decomposed plant material rather than thick peat layers, which would drive the LL much higher.

### 4.1.4. Comparative Analysis: Linking Chemistry to Engineering Behaviour

When comparing the three samples, the key differences in chemical composition become apparent:

(a) Sample 1 transitions from a non-plastic, silt-rich material to a moderately plastic clayey silt, suggesting a gradient in weathering or depositional history. Its lower PI values make it more stable for fill or subgrade applications but less suitable for applications requiring cohesion (e.g., earthworks).

(b) Sample 2's high PI and LL strongly indicate expansive clay minerals, likely smectite, which pose challenges for construction due to their shrink-swell potential. Chemically, this soil would require stabilization (e.g., lime, cement) to mitigate moisture sensitivity.

(c) Sample 3's balanced PI reflects a mixed mineralogy, likely kaolinite and silt, offering a compromise between workability



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## 5. Conclusion:

The Atterberg limit data for Samples 1, 2, and 3 provide valuable insights into the soils' physical properties and behavioural tendencies. Sample 1's transition from non-plastic to moderately plastic suggests a mixed composition, while Sample 2's high plasticity flags it as a challenging material for construction. Sample 3, with its balanced properties, emerges as the most versatile, though still requiring careful evaluation. These observations underscore the critical role of Atterberg limits in geotechnical engineering, guiding decisions on soil suitability, stabilization techniques, and risk mitigation. By interpreting such data meticulously, engineers can design safer, more durable infrastructure tailored to the unique demands of each soil type.

While Atterberg limits are physical tests, they unveil critical insights into soil chemistry. Sample 1's variability hints at layered deposits with increasing clay content, Sample 2's high plasticity flags a dominance of expansive minerals, and Sample 3's stability suggests a weathered, kaolinite-rich composition. Understanding these chemical underpinnings allows engineers and agronomists to predict soil behaviour, select appropriate treatments, and avoid costly failures. Whether for building roads or cultivating crops, the story told by LL, PL, and PI is ultimately a story of minerals, water, and the invisible bonds that dictate how the earth beneath us behaves.

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