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Full length article

INVESTIGATING SHEAR STRENGTH CHARACTERISTICS OF COHESIVE SOILS: STATISTICAL ANALYSIS IN KPK, PAKISTAN

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ABSTRACT

It is crucial to determine the shear strength parameters (Cohesion (C) and Angle of internal friction (Φ)) in order to encounter soil stability issues such as slope stability, bearing capacity and lateral earth pressure on retaining structures. The shear strength of cohesive soils is an essential parameter in Geotechnical Engineering design and construction. In Khyber Pakhtunkhwa (KPK), Pakistan, the soil is predominantly cohesive. it is essential to evaluate these parameters accurately to ensure safety and stability in civil engineering structures. In this research an effort has been made to evaluate statistically shear strength parameters of cohesive soils in KPK Pakistan. Engineers and construction experts can use the study's findings to influence judgments about the design and building of structures in the area. It highlights the importance of conducting proper soil testing and analysis before designing and constructing any engineering structure in the region. The study was conducted by collecting soil samples from different locations in KPK including Peshawar, Charsadda, Bannu, Swabi, Nowshera, Swat, Abbottabad, Haripur, Lakki Marwat, Tribal Areas, DI Khan, Mardan, and Kohat. The results of the statistical analysis indicate that the Cohesion(C) and Angle of Internal Friction (Φ) in KPK vary significantly across different locations, they are also presented in map of KPK showing values of Cohesion and Angle of Internal Friction using QGIS software. The average values of Cohesion (C) range from 12-47 kPa while mean values of Angle of Internal Friction (Φ) range from 16.2 – 41.1 degrees. The Standard Deviation & Coefficient of Variation was relatively high, indicating significant variation within each location.

KEYWORDS: shear strength, slope stability, retaining structure, bearing capacity, cohesive soil

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1. INTRODUCTION

The seriousness and attention that soil investigation should receive are not currently being given in Pakistan. The majority of investors think that geotechnical investigations are a waste of money and do not comprehend the significance of geotechnical engineering. Despite this, geotechnical research is now being prioritized more so than before the devastating earthquake of 2005. The earthquake caused many buildings to be demolished. The results of the subsequent analysis showed that the structures could not withstand the seismic stresses since they had not been built using soil research. A 2005 government regulation required a geotechnical study report to be given before a construction could be built. Thus, a wealth of dispersed geotechnical data is available and must be gathered and presented in a usable manner [1].

Over the past few decades, numerous research projects have been carried out in the area of soil mechanics [2]. Soil mechanics is often used to address complicated technical problems in the realm of civil engineering by applying mechanical, hydraulic, or even chemical rules. Additionally, soil's multi-phase composition, which includes air, water, and particles, gives it special engineering properties [3]. The internal resistance a soil mass can provide per unit area to withstand failure along any plane inside of it is known as shear strength. Any intervention that discourages or promotes soil particle interlocking will unavoidably change soil shear strength since soil shear strength is largely surface dependent. In order to analyses soil stability issues such as bearing capacity, slope stability, and lateral earth pressure on retaining structures, the shear strength determination is crucial [4]. Because soils have complex structures and compositions, their stress and strain relationships are more complex than those for commonly used materials. Simple tensile or compressive loads rarely cause soil to break. A critical mixture of normal and shear loads causes the tensions in a soil mass to break. Designing retaining walls, embankments, bracing for excavations, and foundations is influenced by the soil's shear strength [5]. The soil stress concept is defined in terms of Mohr-Coulomb failure criteria. The equation that describes the stress levels at soil mass failure is,

$$\tau = \sigma tan\emptyset + c \qquad (1)$$

If the failure plane forms an angle θ with the major primary plane, formulae for the normal stress and shear stress on the plane are given, [6] as presented in figure 1

$$\sigma = \frac{\sigma1+\sigma2}{2} + \frac{\sigma1-\sigma2}{2} cos2\theta \qquad (2)$$

$$\tau f = \frac{\sigma1-\sigma2}{2} sin2\theta \qquad (3)$$

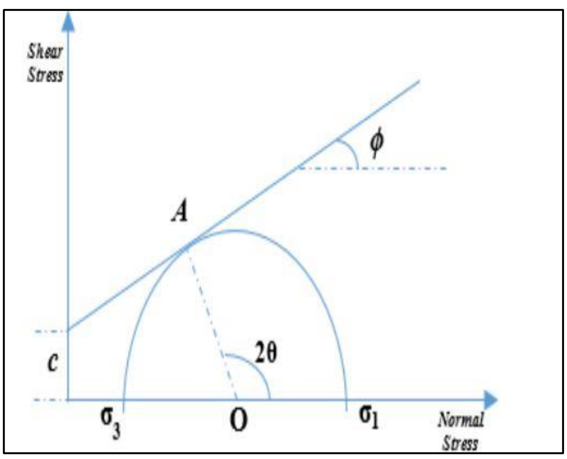

Figure 1: Mohr circle and Failure envelope

The shear box apparatus stands as a fundamental tool in geotechnical engineering for assessing the shear strength properties of soils. This apparatus, conforming to established standards, facilitates controlled shear testing under various conditions, offering crucial insights into soil behavior crucial for engineering design and construction. Because of the irregularity of the stress and strain delivered to the sample, the direct shear box test is frequently derided [16]. The limit equilibrium approach was used to conduct the analyses. Direct shear testing was used to characterize the debris. To achieve this, large specimens were subjected to direct shear tests utilizing a large shear box (300 × 300 × 100 mm) [17]. The shear box apparatus operates by subjecting soil specimens to controlled shear forces along predefined planes, simulating real-world loading conditions encountered by soil masses. By varying parameters such as normal stress, shear displacement rate, and moisture content, researchers can investigate the effects of different factors on soil shear behavior, including cohesion, friction angle, and dilation. In the context of this research, the shear box apparatus serves as the primary tool for evaluating the shear strength parameters of cohesive soils in Khyber Pakhtunkhwa (KPK), Pakistan. In this research the standard size for the shear box is typically rectangular, with internal dimensions of approximately 2.5 inches (63.5 mm) by 2.5 inches (63.5 mm) by 5 inches (127 mm) is used.

Shear strength, a fundamental mechanical property of soils, governs their stability under various loading conditions. In cohesive soils, shear strength primarily depends on factors such as mineral composition, moisture content, soil structure, and stress history. Moreover, external factors such as climate, topography, and anthropogenic activities can significantly influence soil properties, adding complexity to the characterization of shear strength [15]. One of the most important issues facing a geotechnical engineer is the absence of soil data at the site. Without understanding the geotechnical properties of the region beneath the foundation, the design cannot be completed. Using geographic information systems (GIS), a geotechnical map of the soil characteristics in Thi Qar Governorate was created for the project [14]. Using rigorous statistical analytic approaches, this study work aims to investigate the shear strength features of cohesive soils in KPK, Pakistan. Prior studies provided important insights into cohesive soils' shear strength behavior worldwide.

But to fully understand the precise parameters determining shear strength in this region, regional research are required due to the unique geological and environmental circumstances of KPK. Furthermore, potential to improve the precision and consistency of soil strength forecasts are presented by statistical analytic technique developments, which strengthen geotechnical designs and risk assessments. Using rigorous statistical analytic approaches, this study work intends to investigate the shear strength features of cohesive soils in KPK, Pakistan.

There are certain statistical terms whose understanding is very essential. It is a measure of variability that demonstrates how far a value deviates from the mean. It can be computed using the formula below [8].

$$SD = \sqrt{\frac{\sum(x-\mu)2}{N}} \qquad (4)$$

The coefficient of variation (COV) is a standardized measure of dispersion of probability or frequency distribution. It is defined as the standard deviation to mean ratio.

$$COV = \frac{SD}{\mu} \qquad (5)$$

In table 1 Classification of soil based on Cohesion [13] is given, while in table 2 Classification of soil based on angle of internal friction [13] is given.

Table 1: Classification of soil based on Cohesion [13]

Description	**USCS**	**Cohesion C(kPa)**	
		Min-Max	**Specific value**
Clayey sands	SC	05	-
Clayey sands, sandy-clay mix – compacted	SC		31
Clays sand saturated compacted	CL		11
Organic silts and organic silty clays of low plasticity	OL		05
Inorganic clay of high plasticity	CH		25
Sand silt clay with slightly plastic fines – compacted	SM, SC		50
Inorganic slit of high plasticity	MH		05
Silt clay clay compacted	OL, CL, OH, CH	90-105	
clay loam Silt Loam - Compacted	ML, OL, MH, OH	60-90	

Table 2: Classification of soil based on angle of internal friction [13]

Description	**USCS**	**Angle of internal friction (Degree)**	
		Min-Max	**Specific value**
Clayey sands	SC	30-40	-
Clayey sands, sandy-clay mix – compacted	SC		31
Clays sand saturated compacted	CL		28
Organic silts and organic silty clays of low plasticity	OL		05
Inorganic clay of high plasticity	CH	22-32	

Sand silt clay with slightly plastic fines – compacted	SM, SC		35-42
Inorganic slit of high plasticity	MH		05
Silt clay clay-compacted	OL, CL, OH, CH	23-33	
clay loam Silt Loam - Compacted	ML, OL, MH, OH	18-32	

2. Methodology

The determination of shear strength parameters is a crucial aspect in geotechnical engineering, particularly when dealing with cohesive soils. Understanding the shear strength characteristics of these soils is essential for the design and analysis of different geotechnical structures such as foundations, slopes, and retaining walls. In the province of Khyber Pakhtunkhwa (KPK), Pakistan, where cohesive soils are prevalent, accurate assessment of shear strength parameters becomes even more significant due to the region's diverse topography and geological conditions. Our methodology aims to provide a systematic approach for determining shear strength parameters of cohesive soils in KPK, Pakistan, along with their statistical evaluation from which engineers and geotechnical practitioners in KPK can effectively evaluate the shear strength properties of cohesive soils, thereby enhancing the accuracy and safety of their geotechnical designs. The data obtained from direct shear test for different locations are divided into two sections as, City wise Distribution & Zone wise Distribution. Figure 2 shows methodology flow chart.

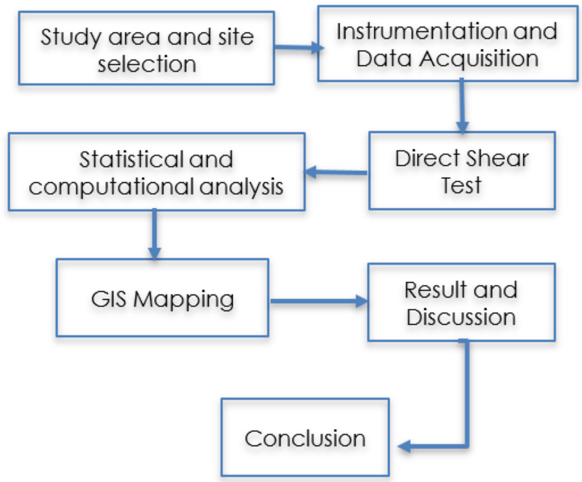

Figure. 2 Methodology Flow Chart

2.1 Study Area and Site Selection

Choosing testing sites wisely and carefully examining the research region are the first steps in conducting an extensive investigation of shear strength parameters in cohesive soils in Khyber Pakhtunkhwa (KPK).The study area presented in figurer 3.

2.1.1. Geographic Overview of Khyber Pakhtunkhwa (KPK)

It is essential to thoroughly investigate the topographical and geological features of KPK in order to establish a foundation for understanding. Situated in Pakistan's northwest, KPK offers numerous types of terrain and a variety of geological formations. The terrain varies from the mountainous landscapes of the Himalayas and the Hindu Kush to the low-lying plains along the Indus River. Such geographic diversity inevitably influences soil behavior, introducing a spectrum of soil types, each with distinct mechanical properties. As shown in figure 3

2.1.2. Identification of Major Cities

The selection of major cities within KPK is not arbitrary but governed by a set of carefully defined criteria. Geological diversity, topographical variations, and engineering significance collectively guide the identification process. Cities such as Peshawar, Charsadda, Mardan, Swabi, Abbottabad, Tribal Areas, Bannu, Kohat, Swat, D.I Khan, Haripur, and Lakki Marwat are chosen for their representative nature, encompassing the varied geological and topographical features that characterize the entire province.

2.1.3. Site-specific Considerations

Recognizing that each city possesses unique characteristics that can influence shear strength parameters, a detailed exploration of site-specific considerations is undertaken. Local geological formations, such as the presence of sedimentary rocks or alluvial deposits, are examined for their potential impact on soil behavior. Anthropogenic factors, such as urbanization and land use patterns, are also taken into account, as they can introduce variations in soil properties. Addressing these site-specific considerations ensures that the direct shear tests conducted in each city encapsulate the diverse range of conditions present in KPK, contributing to a more nuanced and robust understanding of shear strength parameters in cohesive soils across the province. The results that are obtained from the direct shear test for these cities in KPK were analyzed by using statistical tools and to show the variation in the values of cohesion and angle of internal friction and also to determine the maximum value of cohesion and angle of internal friction for a specific location in these cities.

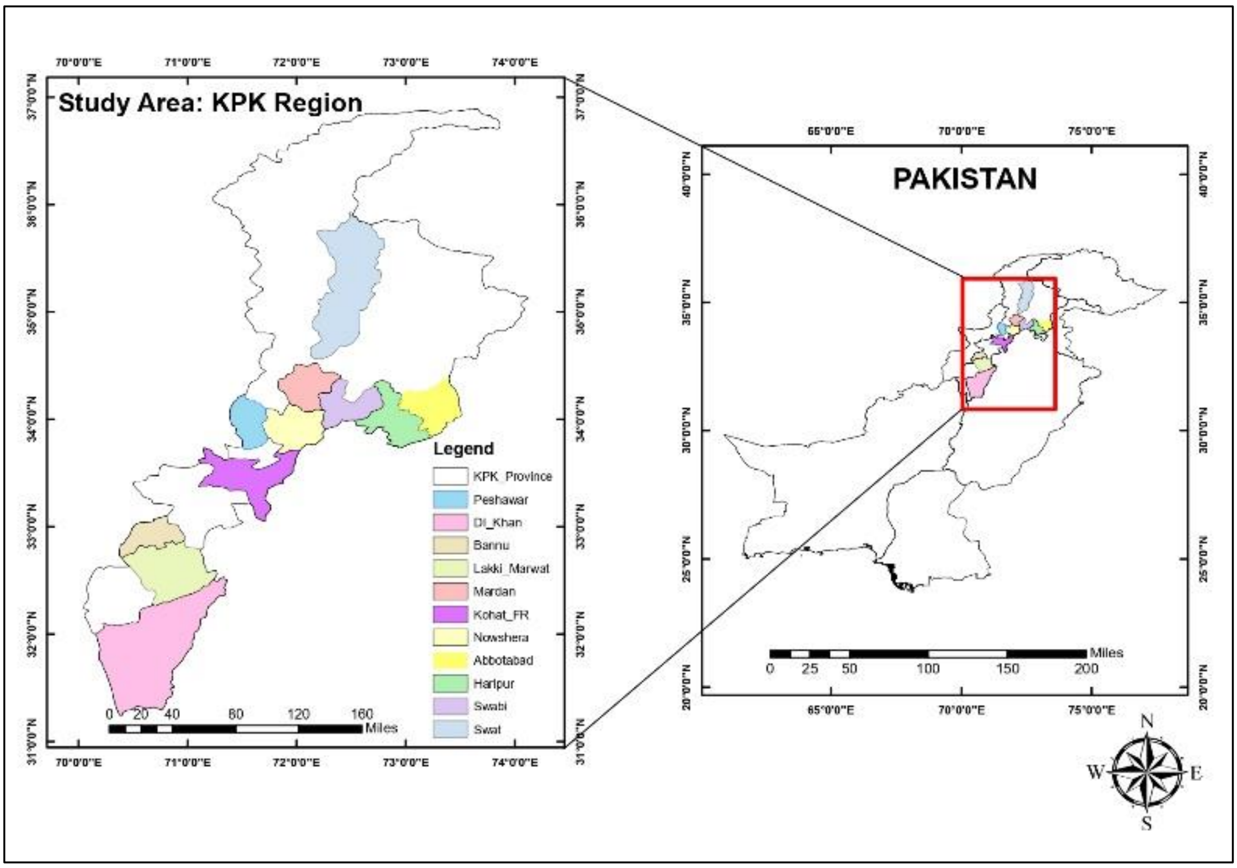

Figure 3: Map of KPK

2.2. Instrumentation and Data Acquisition

In the realm of direct shear testing for cohesive soils in Khyber Pakhtunkhwa, the calibration of instruments holds paramount importance in ensuring the accuracy and reliability of obtained data. The calibration process is meticulously conducted before each test session or as dictated by manufacturer recommendations. Following industry standards and guidelines, our procedures involve zero-point adjustments, load cell calibration, and meticulous verification of displacement measurements. All calibration activities are thoroughly documented, encompassing adjustments made, observed deviations, and confirmation of calibration targets. Routine instrument maintenance is also part of our protocol, ensuring that instruments remain in optimal condition between calibration sessions. This comprehensive approach to instrument calibration not only adheres to industry best practices but also serves as a foundational element in the reliability of our direct shear test results. Complementing our commitment to instrument calibration, the data acquisition system utilized in our testing processes is a sophisticated and integral component of our methodology. This system comprises sensors, transducers, and amplifiers, chosen based on criteria such as sensitivity, range, and compatibility with soil characteristics. Real-time monitoring, facilitated by the data acquisition system, allows continuous observation of key parameters during shear testing, offering insights into the dynamic behavior of cohesive soils. The system seamlessly interfaces with the direct shear testing apparatus, ensuring synchronization and robust communication. The selection of an appropriate sampling rate is crucial, capturing critical events in the dynamic soil behavior during testing. Our data acquisition system is designed for efficient storage and retrieval, with meticulous attention to data format, storage media, and archival practices. Engineers and researchers benefit from real-time visualization, either through graphical interfaces or numerical displays, providing immediate insights into the evolving soil conditions. Additionally, built-in quality checks within the data acquisition system identify anomalies or irregularities during testing, contributing to the overall reliability and integrity of our shear strength data. Figure 4 show the soil sample preparation

Figure 4: Sample preparation

2.4. Zone Definition

Geotechnical zones are demarcated based on shared geological, topographical, and geotechnical characteristics. The Zone wise distribution is presented in Table 3. These zones serve as critical units for analysis, allowing for the categorization of regions with similar soil behaviors. For instance, areas characterized by similar geological formations, such as mountainous terrains versus alluvial plains, may fall into distinct zones. The relevance of these zones lies in their ability to capture the underlying heterogeneity of soil properties, facilitating a more granular examination of shear strength parameters within the province. KPK divide into 4 zones.

Table 3: Zone wise Distribution

Zone	Cities
Zone 01	Peshawar, Charsadda, Mardan
Zone 02	Swabi, Abbottabad, Tribal Areas, Bannu
Zone 03	Kohat, Haripur, Swat
Zone 04	Nowshera, DI Khan, Lakki Marwat

From these areas, more than 600 soil samples data are collected. Many tests, such as Van shear test, Tri-axial Test & direct shear test can be used to establish the shear strength parameters (Cohesion (C) and Angle of Internal Friction (Φ)) but in this case we choose the direct shear test due to its simple operating procedure & accurate results.

2.4.1. Data Aggregation

The aggregation of shear strength data across different cities within each zone is a pivotal step in our methodology. This process involves consolidating the results obtained from direct shear tests conducted in various cities situated within a specific geotechnical zone. By aggregating data, we create a comprehensive dataset that encapsulates the range of soil behaviors present within a given zone. This holistic approach ensures that our analysis is not confined to individual cities but extends to consider broader regional patterns. It allows us to discern commonalities and divergences in shear strength characteristics across the diverse cities within a particular zone, contributing to a more robust understanding of geotechnical variation in KPK.

2.4.2. Comparative Analysis

Now that the combined data is available, a comparison of the shear strength parameters between the various zones takes center stage. The process entails examining the Angle of Internal Friction and Cohesion between zones and recognizing any patterns or differences that go beyond variances unique to individual cities. By comparing the shear strength characteristics among zones, we gain insights into broader geological and geotechnical patterns that may influence soil behavior. This comparative analysis not only enhances our understanding of regional variations but also provides valuable information for geotechnical practitioners and engineers involved in diverse projects across KPK. Ultimately, this approach contributes to a more holistic and informed perspective on the shear strength properties of cohesive soils in Khyber Pakhtunkhwa.

3. Result and Discussion

3.1. City Wise Distribution

3.1.1. Peshawar

The Cohesion (C) value in Peshawar range from 6-51.3 kPa. The Taj Abad Street number 02 has the greatest Cohesiveness (C) value (51.2 kpa). The soil is categorized as Sand Silt Clay with Slightly Plastic Fines-Compacted (SM SL) in Tab 1. Peshawar's coefficient of variation is 60.5%. It demonstrates that the value of Cohesion (C) varies greatly depending on the location. Angle of Internal Friction (Φ) values range from 2-45.1 degrees. Peshawar's ring road has the highest Angle of Internal Friction (Φ) values (45.1 degrees). The COV for Angle of Internal Friction is 42.16 percent. It demonstrates the wide range in the Angle of Internal Friction's value.

3.1.2. Charsadda

In Charsadda the value of Cohesion (C) ranges from 30-52 kPa. SDO office at Shabqadar has the highest value of Cohesion (C) (52kpa). According to table 1 the soil is classified as Sand Silt Clay with slightly plastic fines–compacted. The coefficient of variation for Charsadda is 18%, it shows that the values of C among different locations in Charsadda are very close to each other. The value of Angle of Internal Friction (Φ) ranges from 21-37 degree. BS block GPGC Charsadda has the highest value of Φ (36.80). The COV is 21.5%, it shows that the variation in the value of Φ is less and the soil is classified as Clay Sand.

3.1.3. Mardan

In Mardan the value of Cohesion (C) range from 14-90 kPa. Shami road Mardan has highest value of C (89.96Kpa). The COV for Mardan, which has been observed as 68.4%, indicates that there is a significant variance in the value of C. The soil is categorized as compacted clay loam silty loam (ML, OL, CL, MH, OH). Angle of Internal Friction (Φ) values range from 6-31 degrees. For Shami Road The maximum internal friction angle (30.90) was recorded in Mardan. Since the COV is 60.65%, indicating significant fluctuation in the value of Φ in the several locations of Mardan city.

3.1.4. Swabi

In Swabi the value of Cohesion (C) range from 6-28 kPa. Grid station at Baja Bamal Swabi has highest value of C (27.8Kpa). The COV is 58.4%, it means that the variation in the value of C among the different regions of Swabi is more. The soil is classified as inorganic silty clay.

The value of Angle of Internal Friction (Φ) range from 7-36 degrees. By comparing all values of Φ of different site, it has been observed that Jahangari road Swabi has largest value of Angle of Internal Frication (35.40). The COV is 51.46%, it means that the variation in the value of Φ is high. The soil is classified as organic clay of high plasticity (OH).

3.1.5. Abbottabad

In Abbottabad the value of Cohesion (C) range from 6-35 kPa. The Abbottabad Chamak Mera Dam has the highest value of C. The corresponding COV is 71.5%, that indicates that there is a significant fluctuation in the value of C (35Kpa). The soil is classified as inorganic clay of high plasticity. The value of Angle of Internal Friction (Φ) range from 20-28 degrees. The COV is 0.2%, it means that values Φ for different regions in Abbottabad are approximately equal to each other. The soil is classified as Inorganic clay, silty clay and Sandy clay of low plasticity.

3.1.6. Tribal Areas

In Tribal areas the value of Cohesion (C) range from 6-36 kPa. The GPS Samandar khan kali at Kurram Agency has highest value of C (35.3Kpa). The COV is 58.4%, it means the variation in the value of C among the different region of tribal Areas is more. The soil is classified as inorganic silty clay. The value of Angle of Internal Friction (Φ) range from 16-44 degrees. In Tribal areas it has been found that Sarshah Weir Mohmand Agency has highest value of Φ (43.1). The COV of 43%, it means that the variation is so much larger. The soil is classified as Inorganic silts, silty or clayey fine sands, with slight plasticity (ML).

3.1.7. Bannu

In Bannu the value of Cohesion (C) range from 7-112 kPa. The Baran Dam site is having greatest value of C (112Kpa). The COV is 100.84%, it means that there are huge differences in values of C among the different location of Bannu. The value of Angle of Internal Friction (Φ) range from 17-37 degrees. The value of Φ is larger for Chashmah Bannu (36.4). The COV is 26.14%, it means that the variation in the value of Φ is not larger. The soil is classified as organic clay of high plasticity.

3.1.8 Kohat

In Kohat the value of Cohesion (C) range from 25-40kPa. FR Kohat has highest value of C (35.5Kpa) and COV is 21.6% which means that the variation is not larger. The soil is classified as inorganic clay of high plasticity. The value of Angle of Internal Friction (Φ) range from 26-38 degrees. By comparing the values, it has been found that the house Al-Asar Academy has larger value of Φ. Also, the COV is 18%, it means that the values of Φ are close to each other. The soil is classified as clay sand.

3.1.9. Swat

In Swat the value of Cohesion (C) range from 7-37 kPa. The value of C is larger for New Grid Station in Swat. The COV is 75%, it means the variation is high among the different sites of Swat. The value of Angle of Internal Friction Φ range from 20-42 degrees. By comparing all the values, it has been found that Hydropower Station at Swat has highest value of Φ (42.20). The COV is 47.1%, which indicates the variation is too large. The soil is classified as Inorganic silts, silty or clayey fine sands, with slight plasticity (ML).

3.1.10. Nowshera

In Nowshera the value of Cohesion (C) range from 6-43 kPa. Construction of overhead reservoir Jalozai housing scheme has highest value of C. The COV (38.1%), which is maximum. The soil is classified as Clay Loam, Silty Clay Loam – Compacted Century Gothic throughout the entire manuscript body, except where stated specifically. The value of Angle of Internal Friction Φ range from 18-38 degree. Mardan dam Nowshera has highest value of Φ (54.37). The COV is 38%, it means that variation is high.

3.1.11. DI Khan

In D.I Khan the value of cohesion C ranges from 6-42 kPa. The Grid station at Bandkuri DI khan has highest value of C the COV for DI Khan is 87.3% it means that the variation is too large. The value of angle of internal friction range 13-39 degree. Construction of Storage tank DI khan has largest value of angle of internal friction. The

COV 29.7% it means that the values are close to each other. The soil is classified as Clay (CL, CH, OH, OL).

3.1.12. Haripur

In Haripur the value of Cohesion (C) range from 8-23 kPa. Women & Children Hospital at Haripur has highesr value of C (26.85Kpa).The COV is 38%, it means that the variation in the value of C is not larger. The soil is classified as inorganic clay of high plasticity. The value of Angle of Internal Friction range from 30-36 degrees. Woman and Children Hospital has largest value of C. Furthermore, the COV is 3%, it means that C values are too close to each other. The soil is classified as Inorganic clays, silty clays, and sandy clay of low plasticity.

3.2. Mean Standard deviation coefficient of variation in value of Cohesion C for KPK

It has been found that among all cities in KPK Charsadda have highest mean value of cohesion C also the coefficient of variation for Charsadda is very small 18.8% it means that the value of cohesion in Charsadda are very close to each other. In Kohat COV 21.6% it means that values of cohesion in Kohat are also very close to each other. Mean value of cohesion Standard deviation and coefficient of variation for the different cities in KPK are presented in table 4

Table 4: Mean SD COV in value of cohesion for KPK

Location	Mean value of Cohesion (kPa)	SD	COV %
Peshawar	23.1	13.95	60.65
Charsadda	42.1	7.92	18.8
Mardan	46.6	31.88	68.4
Swabi	20.7	9.56	46.24
Abbottabad	20.4	14.63	71.4
Tribal Areas	12.6	8.55	67.9
Bannu	35.65	35.96	100.86
Kohat	32.5	7.04	21.6
Haripur	19.14	7.28	38
Swat	16.09	12.02	74.97
Nowshera	26.38	23.85	90.4
DI Khan	18.2	16.44	87.3
Lakki Marwat	12	6.4	53.1

3.3. Mean Standard deviation coefficient of variation in value of angle of internal friction C for KPK

The mean value of Angle of Internal Friction (Φ) is maximum for Lakki Marwat 41.10 and Coefficient of Variation is minimum for Abbottabad 0.2%, it means that in Abbottabad the values of Angle of Internal Friction (Φ) are very close to each other. Mean value of angle of internal friction Standard deviation and coefficient of variation for the different cities in KPK are presented in table 5

Table 5: Mean SD COV and angle of internal friction for KPK

Location	Mean value of Cohesion (kPa)	SD	COV %
Peshawar	25.5	12.34	42.15
Charsadda	28.9	6.3	21.52
Mardan	16.2	10.6	65.31
Swabi	23.6	12.12	51.46
Abbottabad	27.05	0.002	0.2
Tribal Areas	30.1	8.57	28.5
Bannu	28.35	7.4	26.14
Kohat	32.3	6.1	18.9
Haripur	34.9	1.24	3.6
Swat	27.7	13.05	47.1
Nowshera	30.4	11.7	38.1
DI Khan	22	6.54	29.7
Lakki Marwat	27.05	0.002	0.2

3.4. Zone wise Distribution

3.4.1. Zone 01

In Zone 01, the analysis reveals that Mardan exhibits the highest mean value of Cohesion (C) as 46.6kPa, surpassing the cohesion levels observed in Charsadda and Peshawar. Zone 01 comprises Charsadda, Mardan, and Peshawar, and the cohesion values provide valuable insights into the social dynamics within these cities. Figure 4 shows mean values of cohesion for zone 1.

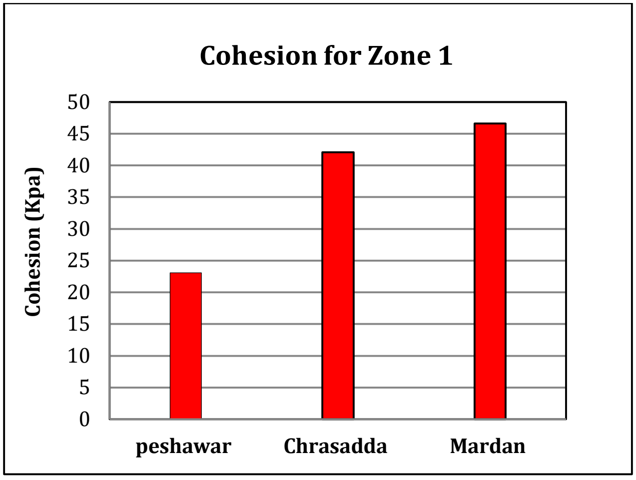

Figure 5: Cohesion C (kPa) for zone 01

In the present study, the analysis of soil samples collected from different locations reveals a noteworthy variation in the angle of internal friction (Φ) across the studied regions. As it is clear from the figure 6 particularly, the data illustrates that Charsadda exhibits a substantially higher value of Angle of Internal Friction (Φ) when compared to other locations under investigation. This distinctive characteristic is indicative of the soil in Charsadda being classified as Inorganic clay of high plasticity (CH), according to the Unified Soil Classification System (USCS). The elevated Angle of Internal Friction (Φ) in Charsadda signifies a notable resistance to shear forces within the soil, emphasizing its unique geotechnical properties. This observation prompts further exploration into the geological and geotechnical factors contributing to this variation, fostering a comprehensive understanding of the soil mechanics in the region.

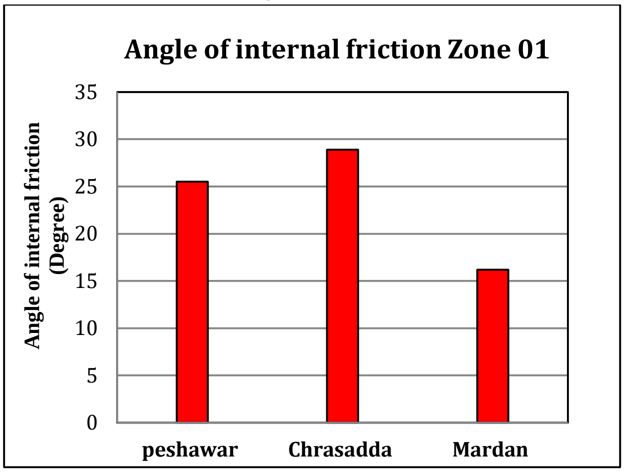

Figure 6: Angle of internal friction for zone 01

3.4.2. Zone 02

Based on the graph, presented in Figure 6 it is evident that Bannu boasts the highest Cohesion (C) value among all the cities in Zone 2, registering at an impressive 35.65 kPa. Zone 2 encompasses Swabi, Bannu, Abbottabad, and Tribal Areas, presenting an opportunity to delve into the distinctive soil mechanics of these regions. The graphical representation underscores Bannu's preeminence, with a prominent peak Bannu's soil possessing significant inherent strength, which is vital for considerations in geotechnical engineering applications, such as foundation design, slope stability, and infrastructure development. The cohesive strength of Bannu's soil at 35.65 kPa implies a greater resistance to shear forces, which can be critical in mitigating risks associated with slope failures or other geotechnical challenges. This finding may have implications for construction practices and engineering decisions within Bannu and neighboring regions. In conclusion, the graph emphasizes Bannu's exceptional position in Zone 2 with the highest soil cohesion value of 35.65 kPa. This observation calls for further investigations into the geological and geotechnical factors contributing to Bannu's superior soil cohesion, providing valuable insights for engineers and researchers working in the broader context of soil mechanics and geotechnical engineering within Zone 2. In the cohesion profile, clearly surpassing the values observed in Swabi, Abbottabad, and the tribal areas. This visual distinction highlights Bannu as a standout region in terms of soil cohesion within Zone 2.

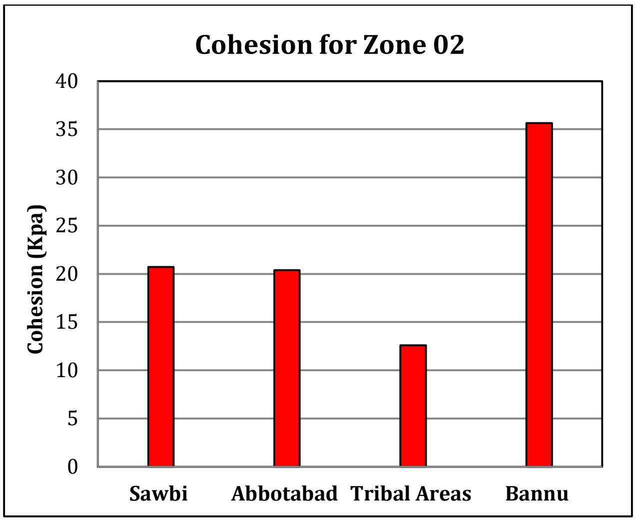

Figure 7: Cohesion C for zone 02

In our investigation, the graphical analysis that shown in Figure 7 reveals a notable discrepancy in the angle of internal friction (Φ) among the surveyed regions, with the Tribal areas displaying a substantially higher value. This distinctive characteristic is indicative of the soil in Tribal areas being classified as Inorganic clays of high plasticity (CH) according to the Unified Soil Classification System (USCS). The elevated angle of internal friction observed in Tribal areas underscores a heightened resistance to shear force within the soil.

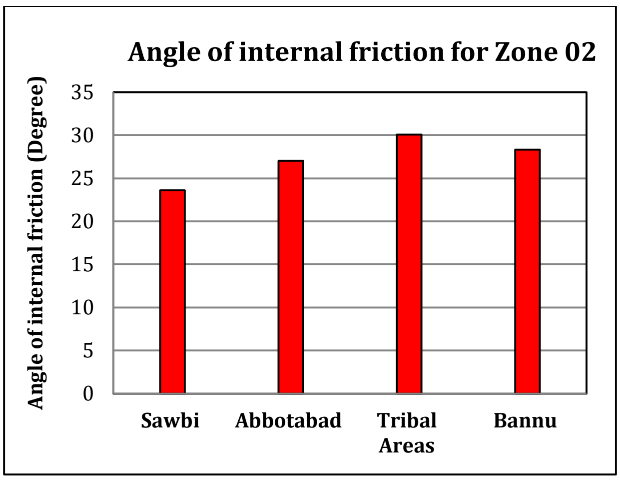

Figure 8: Angle of internal friction for zone 02

3.4.3 Zone 03

In the context of the presented graph Figure 8 it is evident that Kohat exhibits a notably higher cohesion value, measuring 32.5 kPa, as compared to other zones. Zone 3, encompassing Kohat, Haripur, and Swat, stands out for its distinctive cohesion characteristics. This observation implies a unique geotechnical behavior within Zone 3, with Kohat being a prominent contributor to the overall cohesion profile as shown in figure 9.The elevated cohesion value in Kohat suggests a stronger inter particle bonding and soil structure, potentially indicating enhanced stability and resistance to deformation in comparison to the other zones. This finding could have significant implications for geotechnical engineering practices in the studied regions. The cohesive attributes of Kohat, when juxtaposed with Haripur and Swat within Zone 3, highlight the spatial variability in geotechnical properties across the study area. Such disparities underscore the importance of site-specific investigations and considerations in geotechnical analyses, as different regions may exhibit distinct mechanical behaviors. Further research and exploration in this direction could contribute to a more comprehensive understanding of the geotechnical landscape in Zone 3 and aid in the development of tailored engineering solutions for construction and infrastructure projects in the respective areas.

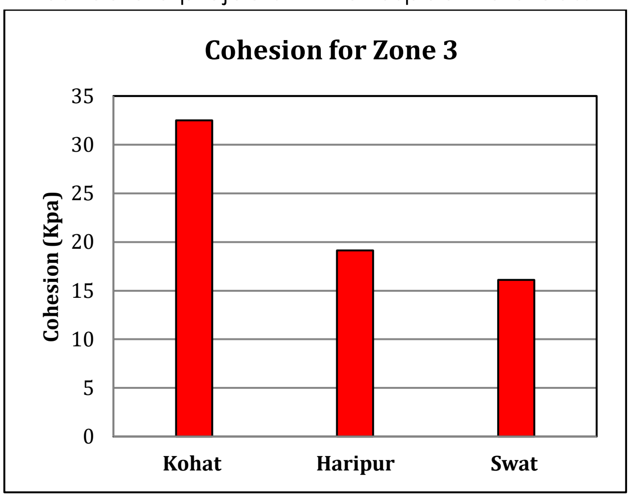

Figure 9: Cohesion C for Kohat

Upon analysis of the graphical data presented in the Fig 9 it is evident that Haripur exhibits a notably higher value of the angle of internal friction (Φ) compared to other locations in the study. This distinctive characteristic leads to the classification of the soil in Haripur as organic clays of high plasticity (OH) according to the Unified Soil Classification System (USCS). The elevated angle of internal friction observed in

Haripur signifies a heightened resistance to shear forces within the soil, indicative of unique geotechnical properties in this specific region.

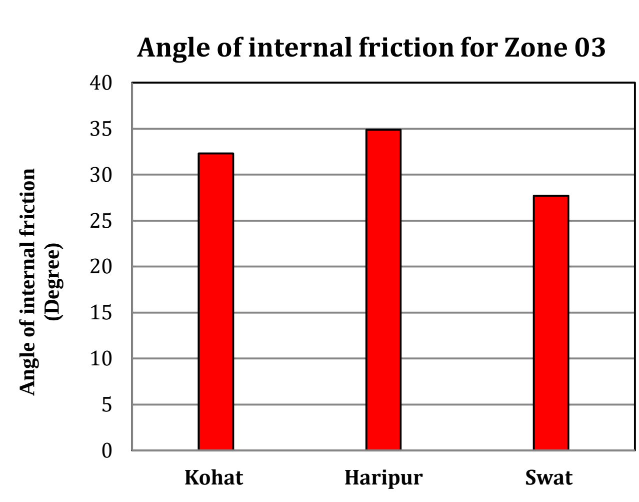

Figure 1O: Angle of internal friction for zone 03

3.4.4. Zone 04

Based on the findings illustrated in the provided graph, presented in Figure 10 , it is evident that Nowshera exhibits a notably higher cohesion value. Consequently, the soil in this region is aptly classified as Inorganic Clays of High Plasticity (CH). Zone 4, which encompasses Nowshera, DI Khan, and Lakkai Marvat, is characterized by this distinctive soil classification. The identification of Nowshera as Inorganic Clays of High Plasticity (CH) underscores the prevalent geotechnical properties in this specific region. This classification implies a soil composition with high plasticity, indicating a propensity for significant deformation under stress and notably sensitivity to change in moisture content**.**

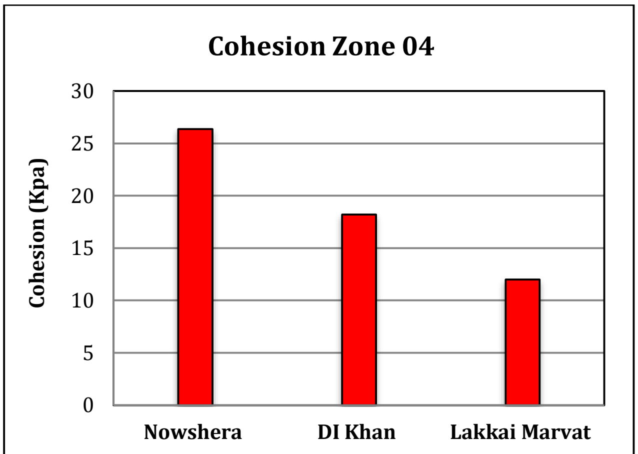

Figure11: Cohesion C for Zone 04

Upon careful examination of the presented graph shown in Figure 11 it is evident that Nowshera stands out with a substantially higher value of cohesion (C) in comparison to other surveyed locations. This distinctive characteristic leads to the classification of the soil in Nowshera as Inorganic clays of high plasticity (CH) according to the Unified Soil Classification System (USCS). The elevated cohesion observed in Nowshera signifies a notable strength in the soil's ability to resist shear forces, indicating unique geotechnical properties specific to this region. In zone 04 Lakki Marwat have highest value angle of internal friction (41.1 Degree)

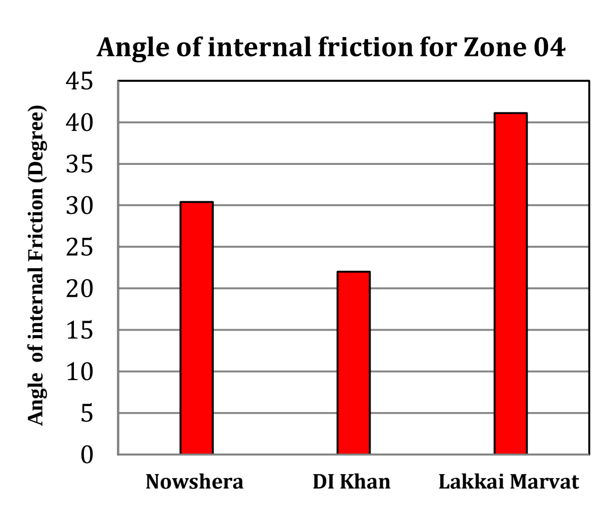

Figure 12: Angle of internal Friction for Zone 04

1.5 Region Having Maximum Cohesion

In the analysis of cohesion C among various cities in Khyber Pakhtunkhwa (KPK), it was identified that Charsadda stands out with the highest cohesion value.As it is clear from the figure 12. Moreover, the coefficient of variation for Charsadda is notably small at 18.8%. This indicates a relatively low degree of variability in the cohesion values within Charsadda, suggesting a consistent and uniform pattern. The small coefficient of variation of 18.8% implies that the cohesion values in Charsadda are closely packed around the mean. This tight distribution underscores the stability and homogeneity of cohesion within the city. The low variability signifies that the social fabric and connections among individuals in Charsadda are consistently strong, contributing to an overall high cohesion level. Based on calculation mean value of cohesion Standard deviation and Coefficient of variation for different cities of KPK are tabulated in table 6

Table 6: Regions having Maximum Cohesion for KPK

City	Location
Peshawar	Taj Abad street # 02 (50kpa)
Charsadda	SDO office Shabqadar (50.85kpa)
Mardan	Shami Road Mardan (89.96kpa)
Swabi	Chamak Mera Dam (34.97kpa)
Abbottabad	132KV Grid station Baja Bamal (27Kpa)
Tribal Areas	GPS Samandar Khan Kali (35.33kpa)
Bannu	Rising Baran Dam (112.1kpa)
Kohat	FR school Kohat (35.52kpa)
Haripur	Women &Children Hospital at Haripur (26.85kpa)
Swat	Construction of new grid station at swat (36.35kpa)
Nowshera	Construction of overhead reservoir at Jalozai housing scheme (73.2kpa)
DI Khan	Construction of 132Kv Grid station Bandkuri (42kpa)
Lakki Marwat	Construction of pezzo Dam Lakki Marwat (15.5kpa)

1.6 Region Having Maximum Angle of internal Friction

The region having maximum angle of internal friction for different regions of KPK are presented in the given table 7

Table 7: Regions having Maximum angle of internal friction for KPK

City	Location
Peshawar	Ring Road Peshawar (45 Degree)
Charsadda	BS GDPC Charsadda (38.5 Degree)
Mardan	Shami Road Mardan (39.9 Degree)
Swabi	Jahangari Road Swabi (35.4 Degree)
Abbottabad	upgraded DHQ Abbottabad (27.1 Degree)
Tribal Areas	Sarshah weir Mohmand Agency (43 Degree)
Bannu	Chashmah Bannu (36.4 Degree)
Kohat	Al Asar Academy Kohat (38.4 Degree)
Haripur	Women &children hospital Haripur (36.2 Degree)
Swat	Geotechnical investigation for Feasibility study of Artistic Hydropower Swat (42 degree)
Nowshera	Construction of Multi building story at pebbi station (29 degree)
DI Khan	Construction of storage tank DI khan (28.5Degree)
Lakki Marwat	Construction of pezzo Dam at Lakki Marwat (43.5 degree)

3.7 Soil Map Profile for KPK

We present a comprehensive summary of the soil characteristics across various cities in the Khyber Pakhtunkhwa (KPK) region in the Figure 12 as delineated by values of Cohesion (C) in kilopascals (kPa) and the Angle of Internal Friction (Φ) in degrees. Employing Geographic Information System (GIS) software, we seamlessly integrated and visualized the collected data to generate a detailed and informative soil map of KPK.The soil map reveals significant spatial variations in both cohesion and angle of internal friction, reflecting the diverse geotechnical nature of the region. Notably, certain cities, such as Nowshera, exhibit elevated cohesion values, leading to their classification as Inorganic clays of high plasticity (CH) based on the Unified Soil Classification System (USCS). Similarly, variations in the angle of internal friction highlights distinct soil behaviors, with specific areas, like Tribal areas, demonstrating higher values. The soil map reveals significant spatial variations in both cohesion and angle of internal friction, reflecting the diverse geotechnical nature of the region. Notably, certain cities, such as Nowshera, exhibit elevated cohesion values, leading to their classification as Inorganic clays of high plasticity (CH) based on the Unified Soil Classification System (USCS). Similarly, variations in the angle of internal friction highlight distinct soil behaviors, with specific areas, like Tribal areas, demonstrating higher values. This spatial representation of soil characteristics serves as a valuable tool for understanding the geotechnical heterogeneity across KPK. The GIS-generated soil map provides a visual reference for engineers, geologists, and decision-makers, aiding in informed and site-specific geotechnical considerations for construction and infrastructure development. The integration of GIS technology enhances the applicability and accessibility of our findings, contributing to the broader understanding of regional soil mechanics and facilitating sustainable development practices in the Khyber Pakhtunkhwa province.

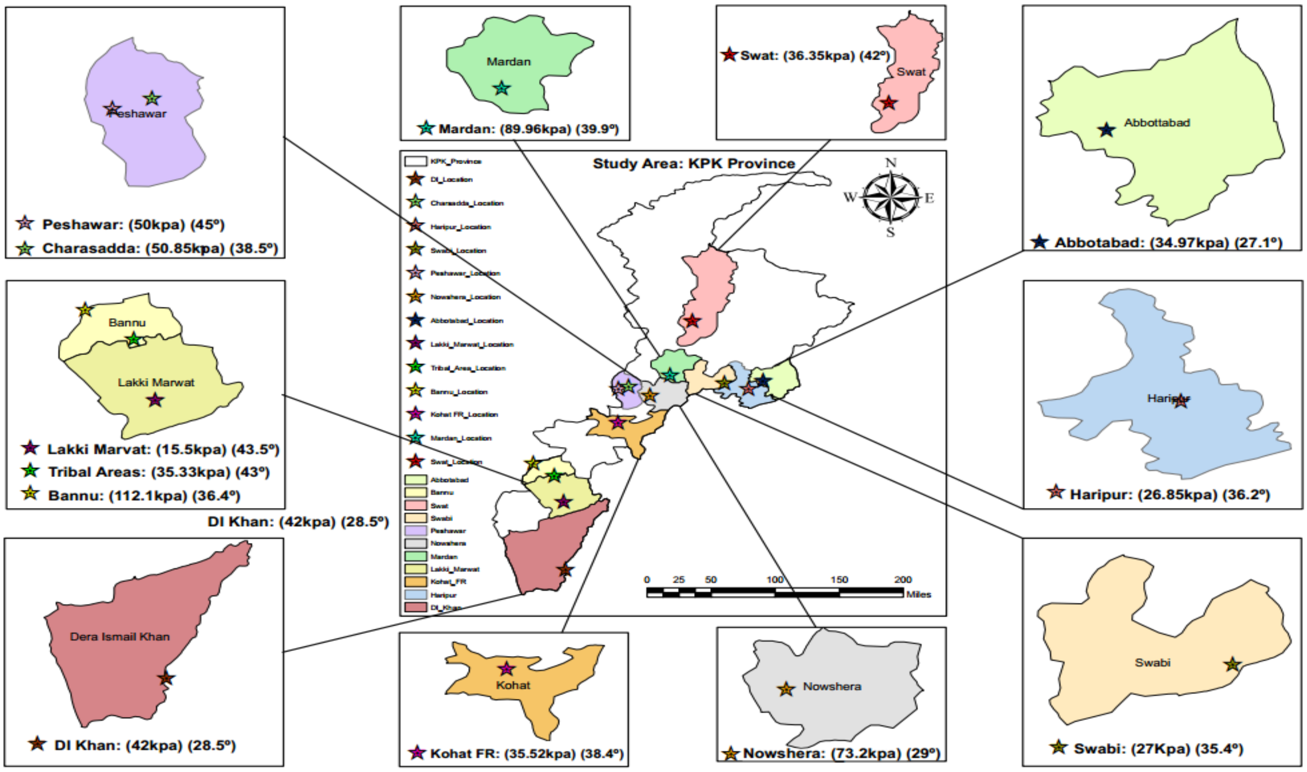

Figure 13: City Presentation of KPK for values of Cohesion C in kPa and Angle of Internal Friction in degrees

CONCLUSION

The research highlights significant spatial variability in soil properties, with some regions showing consistent values of cohesion and angle of internal friction, while others exhibit pronounced fluctuation. Geographical location plays a pivotal role, with areas like Abbottabad and Haripur demonstrating relatively stable soil characteristics, whereas Mardan and Tribal Areas display considerable variability. Understanding these geographical fluctuations is essential for specialized engineering methods and highlights the significance of thorough soil assessments for well-informed decision-making in infrastructure projects.

DECLARATIONS

Data availability statement:

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

Authors Contribution

Muhammad Safdar proposed topic, **Umar Farooq** worked on basic study Plan. Literature review, and manuscript writing, was done by **Fazle Ghaffar** and **Hamza Ahmad Qureshi**. **Inam Jan and Muhammad Hammad** worked as quality insurer by removing SI and Template formatting.

Conflict of interest

The authors declare no conflict of interest.

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