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Comparative Studies of Subsurface Layers' Competence Evaluation using TOPSIS and AHP Models at Ilaramokin, Southwestern Nigeria

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Abstract

The incessant collapse of buildings associated with geotechnical incompetence in different parts of Nigeria and the rapid growth of Ilaramokin town near Akure Southwestern Nigeria motivated this work. Two multi-criteria decision analysis approaches were used in integrating geoelectric parameters (topsoil resistivity, weathered layer resistivity and bedrock resistivity), static water level measurements and geology in evaluating the subsurface geotechnical competence of Ilaramokin. Thirty (30) vertical electrical sounding, eighty-six (86) static water level measurements and geological maps were used. The vertical electrical sounding (VES) results delineated three to five geoelectric layers which correspond to four geologic layers namely; the topsoil, weathered layer, partially weathered/fractured basement and presumed bedrock. The resistivity of the geologic layers varies respectively from 48 - 701, 31 - 1065, 14 - 139, 132 - 6582 Ωm, while their thickness varies from 0.4 - 4.1, 1.3 - 11.6 and 4.0 - 20.1 m in the three upper layers respectively. The VES results were presented as topsoil, weathered layer and bedrock resistivity maps. The VES results, static water level measurement and geology were integrated using both the Technique for the Order of Prioritization by Similarity to Ideal Solution (TOPSIS) and Analytic Hierarchy Process (AHP) models to produce geotechnical competence maps. Consistency test and grain size analysis were carried out on 10 soil samples obtained across the area to validate the geotechnical competence model maps produced using both TOPSIS and AHP models. The validation showed that the geotechnical model map produced from the TOPSIS model has a higher percentage (90%) of correlation with consistency tests and grain size analysis compared to that of the AHP model (70%).

Keywords: Subsurface; competence; geoelectric parameters; geotechnical.

I. INTRODUCTION

Provision of adequate housing for the growing population of any country is an important criterion for measuring the development and general well-being of the people [1]. To prevent loss of lives and properties engineering structures such as buildings, roads, and dams among others are designed and constructed purposely to last long [2]. The sustainability of an engineering structure is its ability to survive and retain its functionality over time. For an engineering system to be sustainable, it should be functional, reliable, and durable [3]. Over the years, there have been incessant collapse of engineering structures in the world and Nigeria in particular. This often results in the loss of lives and properties. A recent study [4] revealed that a sizeable number of buildings collapsed between the year 2009 and 2019 in Nigeria. South-west Nigeria alone accounts for about 60.71% of the collapse between the years 2014 - 2016. Poor building design, use of substandard materials, and faulty design of foundation are all scientific factors believed to be responsible for many of the collapsed buildings in southwest Nigeria [5]. Apart from the aforementioned factors, it is believed that there are other factors such as geologic structures (fault, joint and void), degree of weathering, static water level, and soil strength among others can also be responsible for the failure of engineering structures and building collapse [6]. All structures erected on the earth have their substructures (foundations). Foundation design depends on the characteristics of both the subsurface geologic structures (voids, joints, fractures, and faults) and the subsurface soil or rock [6, 7, 8, 9]. Therefore, the competence of the subsurface materials is a major factor to be considered before erecting any engineering structures [10, 11]. When the foundation of a structure is not competent enough, failure and collapse are inevitable.

A detailed assessment of the subsoil is required to understand the subsurface layer's geotechnical ability. Non-destructive techniques such as the geophysical method that gives the response of soil particles through some physical parameters that are related to subsoil competency are often considered. A cost-effective geophysical method has been found suitable for engineering site investigation [6, 11, 12, 13]. The electrical resistivity technique which measures resistivity or conductivity contrast has proven to be a major tool in engineering studies [14, 15, 16, 17, 18]. This technique is suitable for determining the depth of the bedrock, detecting the presence of bedrock structures (voids, joints, fractures, and faults) and other potentially dangerous subsurface conditions before the erection of any engineering structure [15].

In recent times, there has been an influx of people into Ilaramokin near Akure, Southwestern Nigeria. This is probably due to the proximity of the town to the Federal University of Technology, Akure and the recent establishment of Elizade University in the town. This increase in population also reflects an increase in the number of buildings in the town and environment. This growth in population and buildings necessitates the need to evaluate the subsurface layers' geotechnical competence in Ilaramokin, Southwestern Nigeria.

A data mining technique was adopted for this evaluation. The data mining technique is a process that integrates useful patterns from a large amount of datasets [19]. Analytical hierarchy process (AHP) and Technique for the order of prioritization by similarity to ideal solution (TOPSIS) are widely used data mining techniques in engineering site investigation [20]. AHP was used in the context of multi-criteria decision analysis (MCDA), being a knowledge-driven approach that is widely used in the field of geophysics and for engineering investigation. TOPSIS model, a data-driven approach is widely adopted in the field of engineering site investigation as well. In an attempt to evaluate geotechnical competence in different geologic settings in the world, several works have been done by integrating geophysical and other relevant parameters using one MCDA technique [21, 22]. In this study, foundation competence was evaluated using parameters obtained from geophysical and geological sources. The parameters were subsequently integrated using both AHP and TOPSIS MCDA techniques. The final geotechnical evaluation maps were validated using the geotechnical test results. Validated results of AHP and TOPSIS MCDA techniques were compared to determine the suitability of each technique for competence evaluation.

A. *Description of the study area*

Ilaramokin is located along the Ilesha-Akure highway, and it is situated about 5 km west of Akure metropolis in the southwestern part of Nigeria (Fig. 1a-c). The town is situated within Easting 732150 - 734150 mE and Northing 811300 - 814300 mN of the Universal Transverse Mercator (UTM). Other minor roads connect Ilaramokin to other rural towns and villages around it. The study area is situated on moderately undulating terrain with elevation varying from 325 and 395 m above mean sea level (Fig. 2). The Area falls within the humid tropical climatic zone which is characterised by two seasons. A typical wet season extends from April to October, while the dry season extends from November to March. Annual rainfall ranges between 100 and 1500 mm, with average wet days of about 100. Annual temperature varies between 180 and 340 °C [23].

Ilaramokin is underlain by rocks of the Precambrian Basement Complex of Southwestern Nigeria (Fig. 3). The lithological units identified in Ilaramokin include variably migmatized biotite-hornblende gneiss with intercalated amphibolite. Low-lying outcrops of the migmatite-gneiss complex are situated on the western and northeastern parts of the town while boulders of amphibolites/charnockite rocks are in the central and northcentral areas of the town.

II. METHODS

Vertical Electrical Sounding (VES) techniques of the Electrical resistivity method and Geotechnical Test were adopted for this research.

A. *Vertical Electrical Sounding (VES)*

VES techniques using Schlumberger electrode configuration were utilized in this work. A total of thirty (30) Vertical Electrical Sounding (VES) stations were occupied in the study area (Fig. 4). The VES data were acquired using the Omega Resistivity meter. Schlumberger electrode array was adopted for this work (Fig. 5) [24]. The data acquisition was carried out by gradually increasing the electrode spacing about a fixed centre of the array. The electrode spread of AB/2 was varied from 1- 65 m. The ground resistance (Ω) value obtained was multiplied by the geometric factor (k) for each electrode separation to obtain the apparent resistivity values in ohmmeter (Ω-m) based on the relationship given in (1).

$$\rho_a = 2\pi R \left[\frac{L^2}{4l}\right] \tag{1}$$

The VES data were presented as depth-sounding curves by plotting on a bi-log paper the apparent resistivity (Ω-m) values against electrode spacing (AB/2) m. The VES curves were interpreted using the partial curve matching method and the interpreted results were iterated using Window Resist, a 1-D forward modelling software [25]. The VES results were used to generate different isoresistivity maps (topsoil resistivity, weathered layer resistivity and bedrock resistivity) of the study area. The resistivity of each layer (topsoil, weathered and bedrock) has a role to play in geotechnical competency study. The higher the resistivity, the better the layer geotechnical competence [26].

B. Static water level

This is the level of wells under normal undisturbed circumstances and at the peak of the rainy season. A total of 85 accessible wells were visited to acquire static water level measurements. The surface elevation and location of each well were determined using a handheld Global Positioning System (GPS) device. Static water level measurement was taken through a measuring tape. The total static water level measurements obtained across the study area were used to generate the area static water level map.

C. Geology

There is no existing geological map for Ilaramokin prior to this study. Thus, the study area was traversed, and several outcrops (hilly and low-lying) were visited and mapped to produce a simplified geological map of the area. At each location, rock samples were cut with a geologic hammer for closer and proper observation. The rock sample locations were georeferenced. The coordinates of these identified rock samples were used to produce a simplified geological map of the area. Four different rock types were mapped which are migmatite-gneiss, migmatite biotite-hornblende gneiss, older granites, and Quarzitic rock (Fig. 3). The rate of weathering and fracturing/faulting of these rocks was observed to vary from one rock type to the other and this may affect their geotechnical competence.

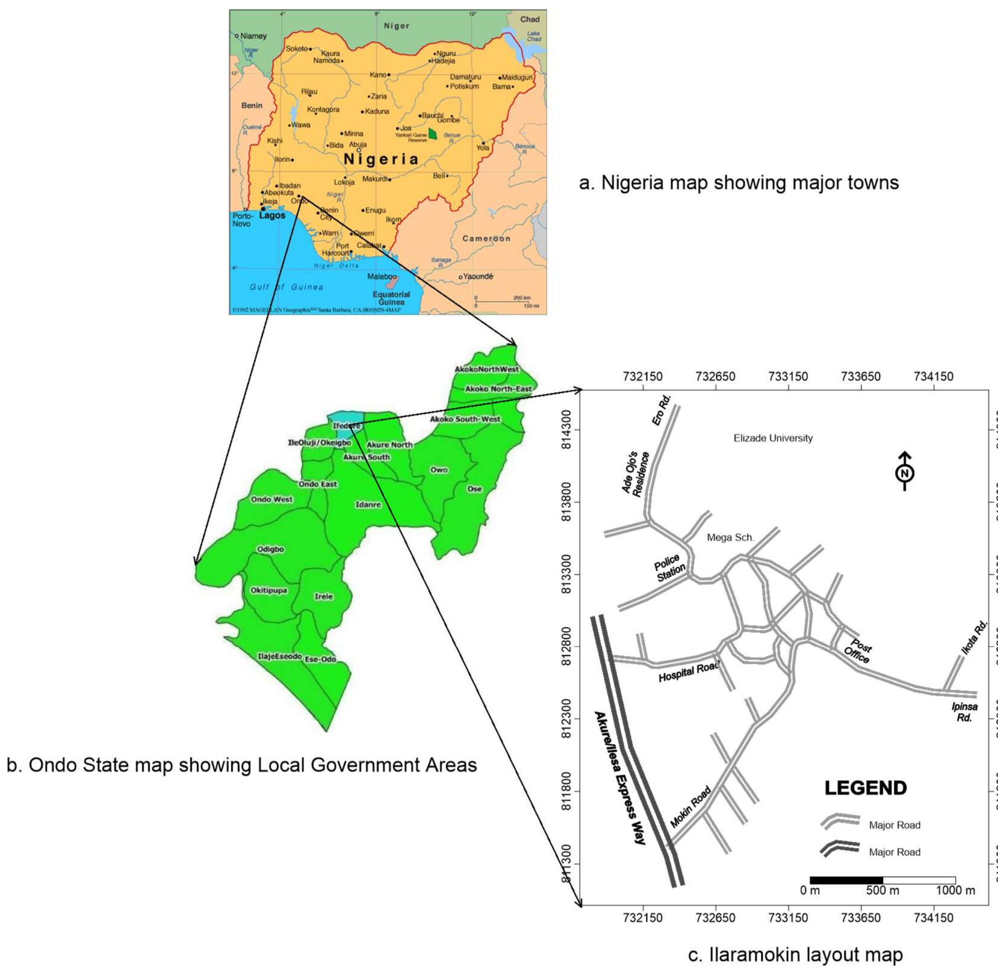

Fig. 1 (a-c): Location map of the study area

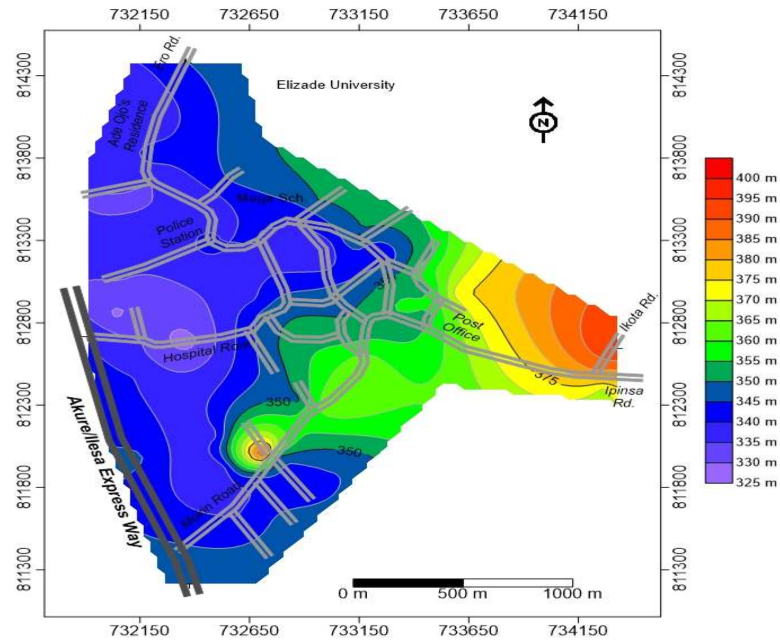

Fig. 2: Topography map of the Ilaramokin

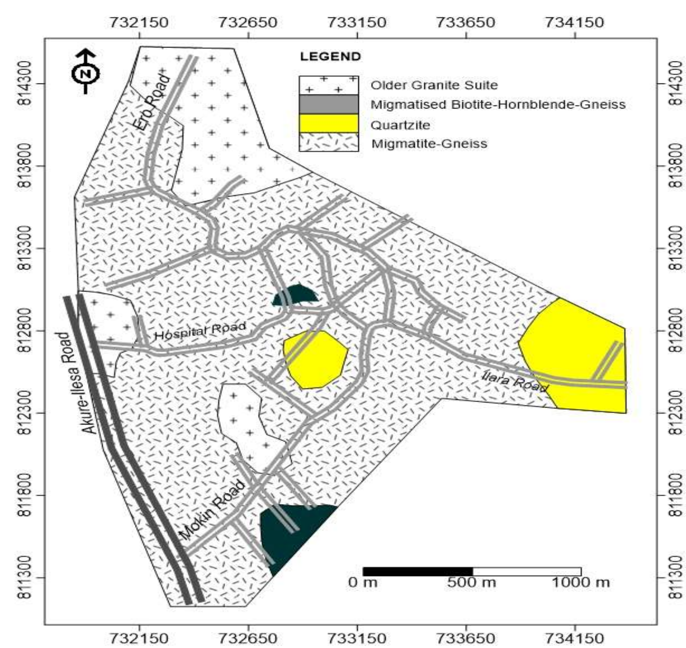

Fig. 3: Simplified geological map of Ilaramokin

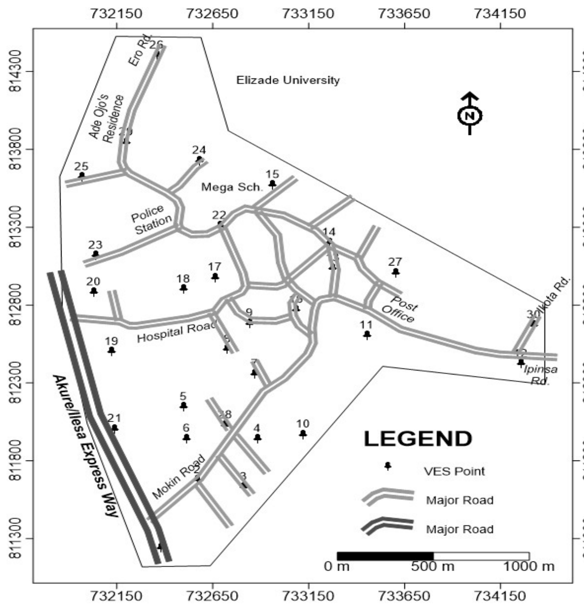

Fig. 4: Layout map of Ilaramokin showing VES stations distribution.

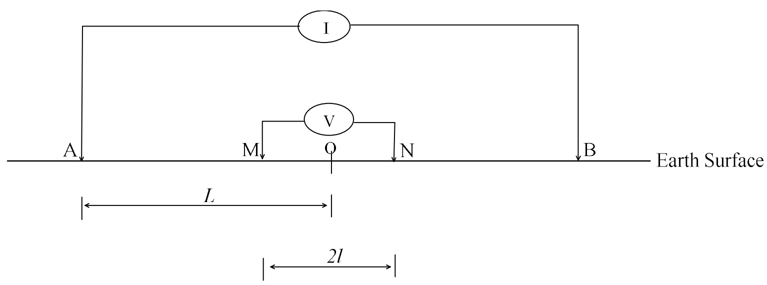

Fig. 5: Schlumberger Electrode Configuration [24]

1) The multi-criteria decision analysis (MCDA)

Multi-criteria decision analysis (MCDA) is a collection of techniques for solving decision-making problems or evaluating complex problems which have many conflicting goals and criteria [27, 28]. The MCDAs applied for this study are the Analytic Hierarchy Process (AHP) and the Technique for the order of prioritization by similarity to the ideal solution (TOPSIS).

2) Analytic Hierarchy Process (AHP)

AHP was first suggested by [29], which helps to decompose problems into a hierarchy of criteria for easy analysis and to be compared individually. The following are the stages of this method.

Step 1: The pairwise comparison of selected factors

This involves the selection of those factors responsible for geotechnical competency. It is an objective approach (expert-driven). It is done by comparing two different factors at the same time using the Saaty scale [30] which ranges from 1 - 9 (Table I).

Step 2: Construction of pairwise comparison matrix

The method is based on the pairwise comparison matrix using (2).

$$p = \parallel pij \parallel \, (i, j = 1,2, \ldots\ldots -m) \qquad (2)$$

R_i and R_{ij} (I, j = 1, 2, …., m)

Where m is the number of the criteria compared.

$$p = \begin{pmatrix} p_{11} & p_{12} \cdots & p_{1m} \\ p_{21} & p_{22} \cdots & p_{2m} \\ \vdots & \vdots & \vdots \\ p_{mi} & p_{m2} \cdots & p_{mm} \end{pmatrix} = \begin{pmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} \cdots & \frac{w_1}{w_m} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} \cdots & \frac{w_2}{w_m} \\ \frac{w_m}{w_1} & \frac{w_m}{w_2} \cdots & \frac{w_m}{w_m} \end{pmatrix} \qquad (3)$$

This comparison is qualitative. It indicates how significant each criterion is to the other.

Step 3: Determination of factors weightage

To determine the weightage factors, the average of the normalized column (ANC) method was used. This was done by dividing the factors of each column by the sum of the column and then adding the factors in each resulting row and dividing the sum by the number of factors in the row (n). This is a process of averaging over the normalized column. Mathematically, this can be calculated as given in (4).

$$W_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_i^n a_{ij}}, i, j = 1,2, \dots n \quad (4)$$

Step 4: Consistency index examination of the pair-wise matrix. Since the comparisons are done using the subjective approach, some degree of insistency may have occurred. To be sure that the judgement is consistent, the consistency ratio (CR) must show the consistency among the pairwise compared. The consistency ratio (CR) is determined by the ratio of consistency index (CI) to Random index (RI) (Table II). This involves three steps which are as follows.

Step 1: Calculation of the eigenvalue ($\lambda\lambda_{max}$).

Step 2: By calculating the consistency index (CI). The formula below was used.

$$CI = \frac{\lambda max - n}{n-1} \quad (5)$$

Step 3: This is by calculating the consistency ratio (CR). The formula used is:

$$CR = \frac{CI}{RI} \quad (6)$$

If the consistency ratio is equal to or less than 10 per cent, it is considered consistent.

3) *Technique for the Order of Prioritization by Similarity to Ideal Solution (TOPSIS)*

This is a pragmatic model method. It is a method of ranking alternatives based on the shortest distance from the ideal solution and the farthest from the negative ideal solution [31]. The procedure of MCDA in the context of TOPSIS procedure is as follows.

Step 1: Determination of the weight criteria and construction of the decision matrix.

Weightage determination is done by either a subjective or objective approach [32]. The subjective approach is expert-driven (based on the decision maker's knowledge). The objective approach is based on a mathematical calculation procedure. Different weighting techniques can be adopted but Criteria Importance Through Intercriteria Correlation (CRITIC) weightage was used for the weight calculation.

4) *CRITIC weightage technique*

CRITIC method uses linear correlation techniques [33, 34].

Step 1: Normalization of correlated matrix

The correlated matrix is first normalized by (7) and (8). During normalization, there are benefit criteria and cost criteria stages. The benefit criteria are those factors that favour foundation competency, and the cost criteria are those factors that are not favourable to foundation competency.

$$p_{ij} = \frac{y_{ij} - y_i{}^{min}}{y_j{}^{max} - y_j{}^{min}} \quad i = 1, \dots, m; j = 1, \dots, n \quad (7)$$

For benefit criteria

$$p_{ij} = \frac{y_j{}^{max} - y_{ij}}{y_j{}^{max} - y_j{}^{min}} \; i = 1, \dots, m; j = 1, \dots, n \quad (8)$$

For cost criteria, the weight is generated through a linear correlation coefficient between the criteria using the following (9), (10) and (11).

$$v_{ik} = \frac{\sum_{i=1}^{m}(p_{ij} - \overline{p_j})(p_{ik} - \overline{p_k})}{\sqrt{\sum_{i=1}^{m}(p_{ij} - \overline{p_j})^2 \; \sum_{i=1}^{m}(p_{ik} - \overline{p_k})^2}} \quad (9)$$

J, k =1, ... n

$$w_j = \frac{\beta_j}{\sum_{k=1}^{n}\beta_k} \quad (10)$$

Where,

$$\beta_j = \delta_j \sum_{k=1}^{n}(1 - v_{jk}) ; j = 1, \dots, n \quad (11)$$

Table I: Saaty scale of relative importance [30]

Scale	Numerical Rating	Reciprocal
Extremely preferred	9	1/9
Very strong to extreme	8	1/8
Very strongly preferred	7	1/7
Strongly to very strongly	6	1/6
Strongly preferred	5	1/5
Moderately to strongly	4	¼
Moderately preferred	3	1/3
Equally to moderately	2	½
Equally preferred	1	1

Table II: Random Index (RI) Table [31].

N	1	2	3	4	5	6	7	8	9	10
R	0	0	0.5	0.	1.1	1.3	1.4	1.4	1.4	1.4
I			8	9	2	2	1	5	5	9

Step 2: Calculation of the normalized decision matrix

To transform various attributes into a non-dimensional unit, [35] gave (12) which is frequently used for normalization.

$$R = \left(r_{ij}\right)_{mxn} = \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{pmatrix} U_1 & U_2 & \cdots & U_n \\ r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{pmatrix} \quad (12)$$

Where,

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} \left(x_{ij}\right)^2}} \quad (13)$$

For benefit attribute $x_{ij}, i \in M, j \in N$

$$r_{ij} = 1 - \left(\frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} (x_{ij})^2}}\right) \quad (14)$$

For cost attribute $x_{ij}, i \in M, j \in N$.

Step 3: Calculation of the weighted normalized decision matrix.

The weightage calculated from the CRITIC method is normalized by multiplying the decision matrix by the normalized weights of criteria using (15).

$$v_{ij} = w_j \times r_{ij} \quad (15)$$

Where,

i = 1, ..., m; j = 1, …, n, m is the number of attribute values in each criterion, n is the number of criteria, and w_j is the normalized weight of the jth criterion, given as $w_j = \frac{W_j}{\sum_{j=1}^{n} W_j}$, so that $\sum_{j=1}^{n} w_j = 1$, W_j is the original weight assigned to each criterion.

Step 4: Determination of the positive ideal solutions and negative ideal solutions

The positive ideal solution minimizes the cost criteria and maximizes the benefit criteria; on the contrary, the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria created from the normalized weightage using (16), (17) and (18).

$$A^+ = \left[v_1^+, \dots \dots, v_j^+, \dots., v_n^+\right]$$
$$A^- = \left[v_1^-, \dots \dots, v_j^-, \dots \dots, v_n^-\right. \quad (16)$$

Where A^+ denotes the positive ideal solution, A^- denotes the negative ideal solution and

$$\{v_j^+ = \max\{v_{ij}\} i = 1,2, \dots., m$$
$$\{v_j^- = \min\{v_{ij}\} i = 1,2, \dots.., m \quad (17)$$

If the jth criterion is a beneficial criterion

$$\{v_j^+ = \min\{v_{ij}\} \, i = 1,2, \dots.., m$$
$$\{v_j^- = \max\{v_{ij}\} \, i = 1,2, \dots., m \quad (18)$$

If the jth criterion is a cost criterion

Where v_{ij} denotes the attribute values of each cell for the jth layer.

Step 5: Calculation of the separation of each alternative from the positive ideal solution and negative ideal solution.

In this step, after the determination of positive ideal solution and negative ideal solution. The separation from each alternative is done using (19) and (20). This then leads to the creation of two different surface layers S_i^+ and S_i^-.

The separation from the positive ideal solution for each alternative is given as:

$$S_i^+ = \sum_{j=1}^{n} \left|v_{ij} - v_j^+\right| = \sum_{j=1}^{n} D_{ij}^+ \quad (19)$$

The separation from the negative ideal solution for each alternative is given as:

$$S_i^- = \sum_{j=1}^{n} \left|v_{ij} - v_j^-\right| = \sum_{j=1}^{n} D_{ij}^- \quad (20)$$

Step 6: Calculation of the relative closeness to the positive ideal solution and ranking.

In this step, the relative closeness to the positive ideal solution is calculated using (21).

$$C_i^+ = \frac{S_i^-}{S_i^+ + S_i^-} \quad (21)$$

Where, $0 \leq \; C_i^+ \; \leq 1, i = 1,2, \dots \dots . m$

5) Geotechnical investigation

This involved the collection of soil samples at different locations in the study area for analysis (Fig. 6). This analysis is used as validation for the model map generated. The geotechnical investigation such as liquid limit test, plastic limit test, plasticity index, and grain-size analysis helps to know how competent an area is.

6) Liquid limit test

This is the measurement of the amount of water a soil can retain. It is usually called the moisture content and the better the liquid limit, the more competent the area which is calculated by the formula below.

$$moisture\ content = \frac{weigh\ \ of\ water}{weight\ of\ oven-drie\ \ soil} \times 100 \quad (22)$$

7) Plastic limit test

This is the moisture content at which the soil begins to crumble when rolled into a thread using a ground glass plate. When the plastic limit is higher, it signifies higher clay content which is not a good material due to its aggressive nature.

$$plastic\ limit = \frac{weigh\ \ of\ water}{weight\ of\ over\ dried} \times 100 \quad (23)$$

8) Plasticity index

The plasticity index of soil is the numerical difference between the liquid limit and the plastic limit. The lesser the plasticity index, the better the material for foundation competency.

$$Plasticity\ index = liquid\ limit - plastic\ limit \quad (24)$$

9) Linear Shrinkage

The linear shrinkage is the degree to which the moisture content is reduced from the liquid limit to an oven-dry state. The higher the ability for the material to shrink, the non-competence the material.

10) Grain-size analysis

This is the classification of different grain sizes present in a soil sample. The lesser the percentage passing, the more competent the value. The standard value for the percentage passage is 35% and below according to [36] classification.

III. RESULTS AND DISCUSSION

A. Vertical Electrical Sounding (VES) Results

The VES results from the study area are presented in Table III. Six curve types were delineated in the study area, namely: A, H, K, KH, QH and HKH. The H curve is the predominant curve type in the area with a percentage occurrence of 40%, the A curve has 30% occurrence, the KH curve has 20% occurrence, while the QH, HKH, and K curves are the least with 3.33% occurrence each (Table III).

B. Topsoil resistivity

Topsoil resistivities across the study area were presented as a map (Fig. 6). Based on the classification of [26] as presented in Table IV. The topsoil resistivity map (Fig. 7) classified the largest portion of the study area (about 70%) as moderately competent (100 - 350 Ωm), while about 25% of the area is incompetent (0 - 100 Ωm). The area adjudged to be incompetent lies mainly in the eastern and southwestern parts of the study area. Only a few (5%) portions of the study area are considered competent.

C. Weathered layer resistivity

The weathered layer resistivity map (Fig. 8) indicates that the layer resistivity varies from 17 - 1065 ohm-m across the study area. The central and southern parts of the area are essentially incompetent layers (0 - 100 Ωm), while the largest parts of the area are moderately competent (100 - 350 Ωm). Only the easternmost part is moderately and highly competent.

D. Bedrock resistivity

The bedrock resistivity map (Fig. 9) revealed that the largest portion (65%) of the area is highly competent (>750 Ωm) and about 5% of the area shows a moderately competent portion. The northern, southwestern, and eastern parts of the area are considered competent. With very few exceptions, the study area can be highly competent, and this suggests that it is safe to place the foundation of engineering structures on bedrock in almost every part of the study area.

E. Static water level

Static water level data across the study area was utilized to generate the static water level map of the area. The static water level map (Fig. 10) indicates that about 5% of the area has a relatively high static water depth ranging between 6 - 8.5 m this area is highly competent, while about 45% of the area has a static water depth between 4 - 6 m which corresponds to competent zones. About 45% of the study area is characterized by a shallow static water level between 2 - 4 m (moderately competent zone), and about 5% of the area indicates a very shallow static water level ranging from 0.5 - 2 m (incompetent zone).

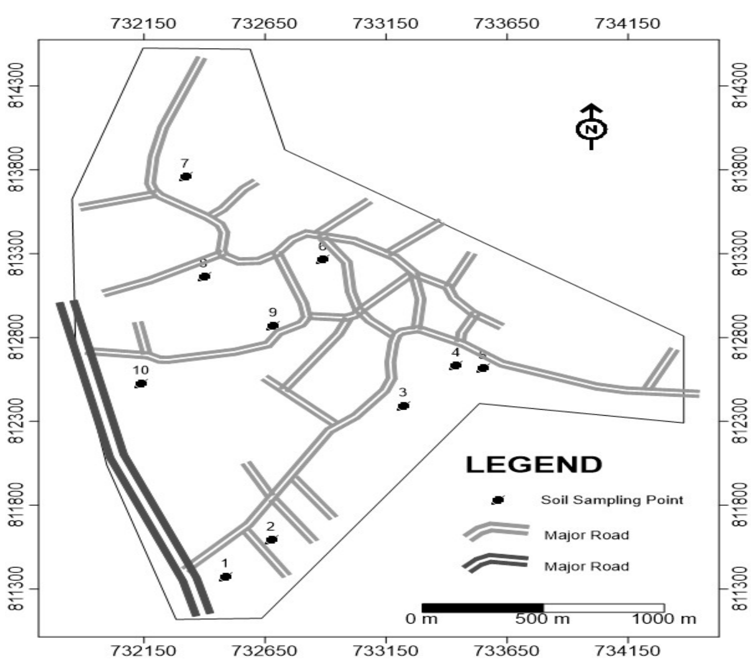

Fig. 6: Map of Ilaramokin showing the soil sampling points.

Table III: Summary of the VES Results

VES No	Easting	Northing	Resistivity ($\rho_1/\rho_2/\ldots/\rho_n$)	Thickness ($h_1/h_2/\ldots/h_n$)	Curve Type
1.	732378	811215	79/135/26/663	0.8/1.8/8.1	KH
2.	732572	811649	77/117/399	1.2/6.2	A
3.	732812	811603	184/368/80/489	1.0/1.3/4.7	KH
4.	732883	811913	74/97/920	0.9/9.2	A
5.	732499	812118	219/52/1075	1.8/5.5	H
6.	732515	811914	180/49/764	0.4/5.4	H
7.	732870	812330	92/50/1904	1.2/3.3	H
8.	732727	812487	242/124/1045	4.0/3.4	H
9.	732843	812655	58/61/886	1.2/1.5	A
10.	733122	811941	158/60/1724	4.1/2.2	H
11.	733453	812577	53/46/5400	2.2/1.2	H
12.	734257	812394	147/97/76/463	0.8/8.9/20.1	QH
13.	733277	813009	239/47/1656	0.4/7.9	H
14.	733258	813173	114/32/1337	0.6/3.7	H
15.	732963	813544	109/130/6582	1.0/7.4	A
16.	733086	812743	136/31/962	0.6/1.8	H
17.	732662	812949	216/359/135/2910	2.6/5.0/11.0	KH
18.	732497	812873	88/254/89/860	2.4/3.7/8.1	KH
19.	732124	812471	118/221/1409	1.1/3.7	A
20.	732032	812855	123/115/387	0.6/1.7	H
21.	732141	811977	111/661/14/337	1.2/3.1/18.0	KH
22.	732688	813281	141/189/1306	2.0/4.0	A
23.	732042	813090	98/428/17/742	1.7/3.1/14.0	KH
24.	732583	813699	420/249/976	0.7/2.3	H
25.	731969	813594	110/147/382	1.0/6.0	A
26.	732360	814375	115/147/3256	1.7/4.3	A
27.	733605	812980	48/55/2228	1.3/2.9	A
28.	732716	812001	701/130/563/139/2935	0.7/1.2/4.0/9.5	HKH
29.	732200	813818	129/72/2415	1.0/1.9	H
30.	734326	812644	207/1065/132	3.2/11.6	K

Table IV: Soil Competence Rating [26]

Resistivity (Ωm)	Possible Lithology	Competence Rating
<100	Clay	Incompetent
100-350	Sandy clay	Moderately Competent
350-750	Clayey sand	Competent
>750	Sand/Laterite/Bedrock	Highly competent

F. Geology

The geology of the study area is as earlier presented in Fig. 3. Migmatite-gneiss, migmatite biotite-hornblende gneiss rock, Quartzite and Older granite rock units were observed to underlie the study area (See Fig. 3). The dominant rock types in Ilaramokin are migmatite-gneiss and migmatite biotite-hornblende gneiss rocks which are characterized with banding. Their outcrops show evidence of weathering and fracturing/faulting thus the geotechnical competence of these rock types is relatively low [36, 37]. Quartzitic rocks were encountered in the central and eastern parts of the area. This rock type was noted for its well-developed fracturing/fault system and thus its geotechnical competence is low [38]. Buildings constructed on this lithology often exhibit cracking and splitting. The Older granite rocks are mapped at the northern, western, and central parts of Ilaramokin. Older granite is noted for its strength and compactness [10, 36, 39, 40]; thus, the geotechnical competence of these rock types is relatively high [6, 10, 39].

G. Weight assignment for AHP

Saaty's scale for weight assignment and interpretation is contained in Table I. The scale for the weight assignment ranges from 1 - 9 for pairwise comparison (Table V). The eigenvector of a square reciprocal matrix of pairwise comparisons between criteria is used for weight derivation [29]. Table VI shows the weight assigned to each of the geotechnical competence factors considered in the study. This is done by comparing two factors at a time. The degree of acceptability is based on the consistency ratio (CR) which must be less than 10%. For the study, the CR is 6.45%.

H. Rating

Rating (R) was assigned to each of the parameters within the factors influencing the geotechnical competence. This helps in estimating the geotechnical competence index (GCI) of the study area.

I. Geotechnical Competence Index

This was obtained by the summation of the products of the assigned weights often denoted as W and the ratings denoted as R. The following equation was used in estimating the geotechnical competence index.

$$GCI = TSR_W \times TSR_R + WLR_W \times WLR_R + BRR_W \times BRR_R + Lith._W \times Lith._R + SWL_W \times SWL_R \quad (25)$$

$$GCE = 0.0512TSR + 0.256WLR + 0.4324BRR + 0.087SWL + 0.149Lith \quad (26)$$

Where,

$TSR_W = Topsoil\ resistivity\ weight$

$TSR_R = Topsoil\ rating$

$WLR_W = weathered\ resistivity\ weight$

$BRR = Bedrock\ resistivity\ rating$

$SWL_W = static\ water\ level\ weight$

$SWL_R = Static\ water\ level\ rating$

$Lith._W = Lithology\ weight$

$Lith._R = Lithology\ rating$

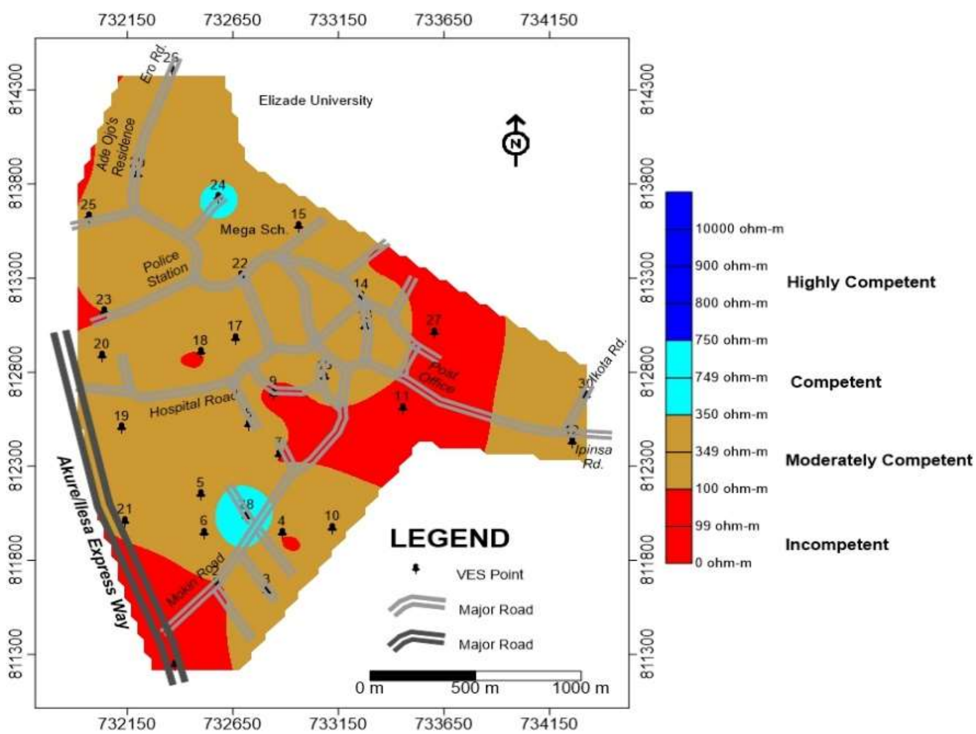

Fig. 7: Topsoil resistivity map of Ilaramokin.

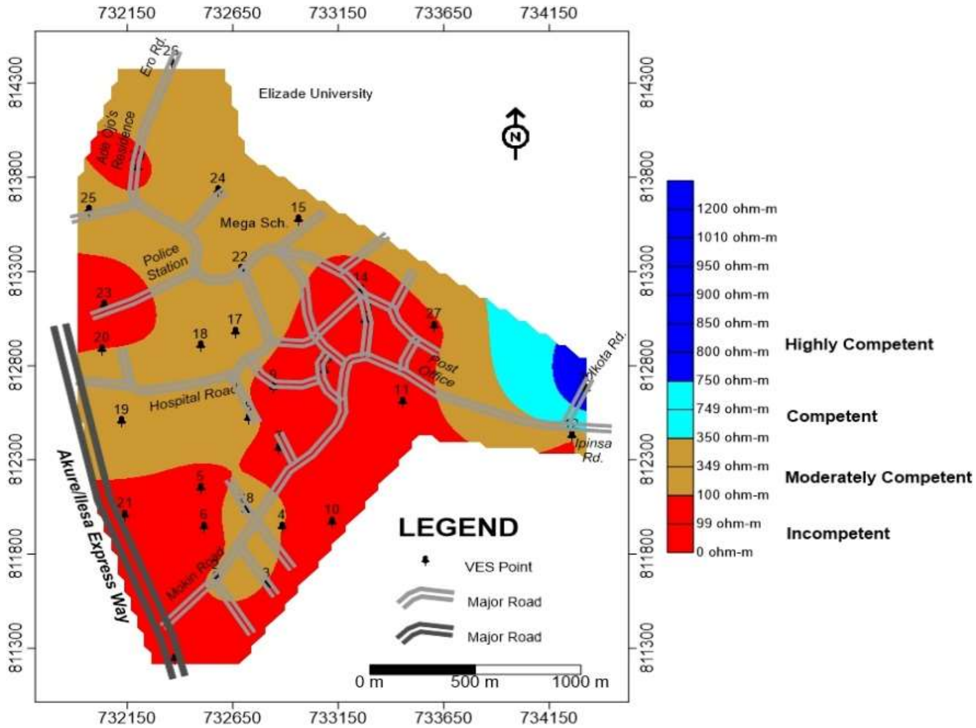

Fig. 8: Weathered layer resistivity map of Ilaramokin.

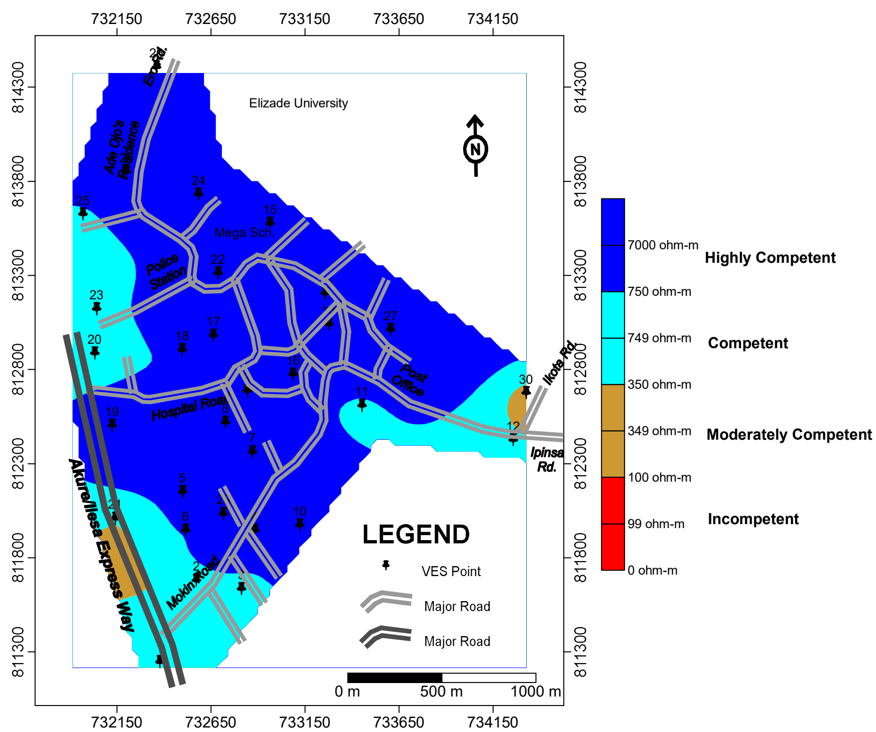

Fig. 9: Bedrock resistivity map of Ilaramokin.

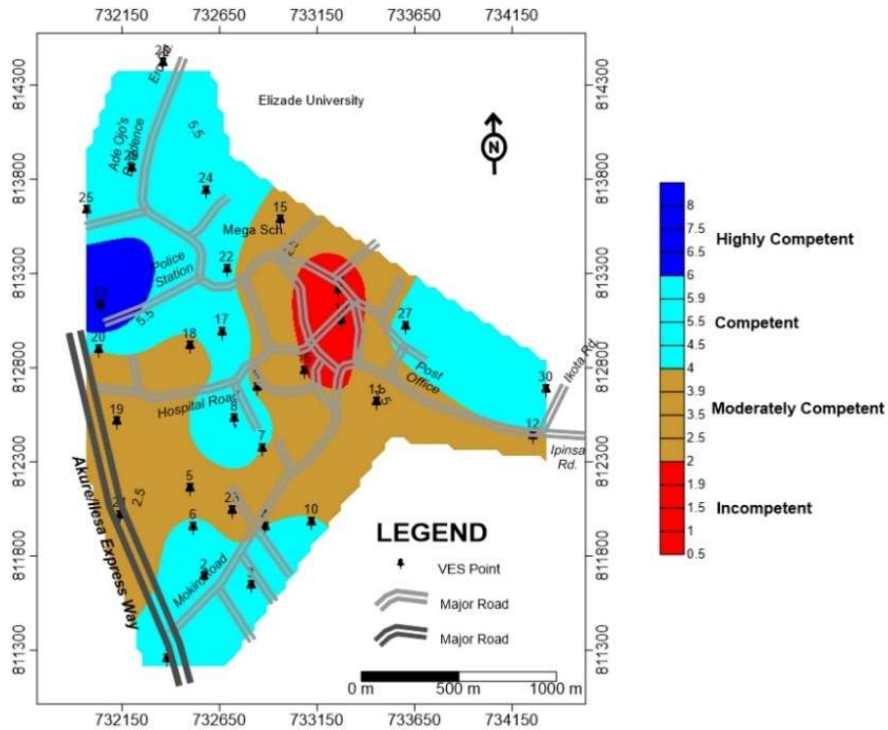

Fig. 10: Static water level map of Ilaramokin.

Table V: Pairwise comparison for criterion considered

Parameters	SWL	BR Res.	Lith.	WL Res	TS Res
SWL	1	1/5	1/2	1/3	2
Lith.	2	1/3	1	½	3
BR Res	5	1	3	2	7
WL Res	3	½	2	1	5
TS Res	½	1/7	1/3	1/5	1
Sum	11.5	2.48	6.83	4.03	18

Table VI: Determination of relative weight for each criterion

Parameters	SWL	BR Res.	Lith.	WL Res	TS Res	Weights
SWL	0.087	0.081	0.073	0.083	0.111	0.087
Lith.	0.174	0.134	0.146	0.124	0.167	0.149
BR Res	0.433	0.403	0.439	0.496	0.389	0.4324
WL Res	0.261	0.202	0.293	0.248	0.278	0.256
TS Res	0.043	0.058	0.049	0.050	0.056	0.0512
Sum	1	1	1	1	1	~ 1

J. Geotechnical competence map of Ilaramokin using AHP.

The AHP geotechnical competence index map (Fig. 11) was produced by superimposing the GCI obtained from all the criteria using Surfer 13 software. The AHP model geotechnical competence map (Fig. 11) indicated that about 15% of the study area is incompetent, while about 50% portion of the study area is moderately competent. The remaining 38% of the study area is competent.

K. TOPSIS Model

1) Weight assignment for TOPSIS

CRITIC weight assignment is based on the results of each criterion point. According to [33] each criterion's best and worst possible value is first calculated (Table VII). The standard deviation of the normalized matrix of each criterion was calculated (Table VIII), and then a linear correlation between the two criteria produced a symmetric matrix (Table IX). The symmetric matrix was then used to calculate the

measure of the conflict created by criteria (Table X). The summation of each row value is calculated and multiplied by the standard deviation value (Table X).
The summation of all the calculated values is divided by each value to estimate the weight for each criterion. Table XI shows the CRITIC weight assignment. The weight generated through the CRITIC weight is attributed to each normalized attributed criterion considered. The normalized matrix helps in determining the ideal solutions (positive and negative) based on how the criteria favours geotechnical competency (Table XII). Figs. 12 and 13 shows the two surface that was created from the ideal solutions.

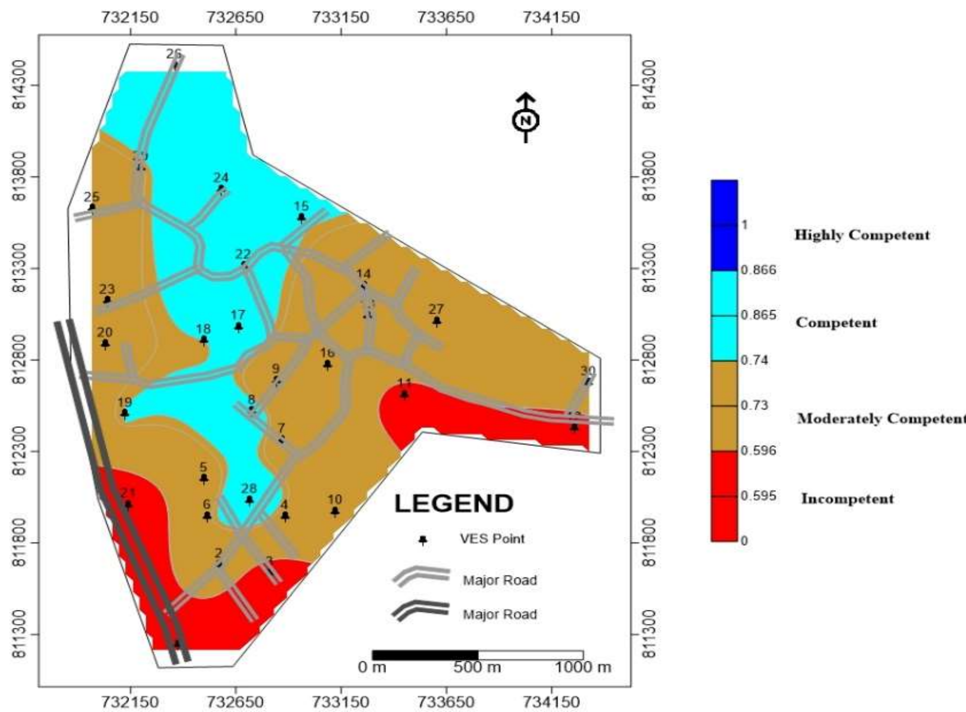

Fig. 11: Geotechnical competency map of Ilaramokin (using AHP model).

Table VII: Best and worst value for each criterion.

	Topsoil Resistivity	Weathered layer Resistivity	Bedrock Resistivity	Lithology	Static water level (SWL)
Best	701	1065	6582	5	8.13
Worst	48	17	132	2	0.65
	653	1048	6450	3	7.48

Table VIII: Standard deviation of each criterion.

Sigma Topsoil Resistivity	Sigma Weathered Resistivity	Sigma Bedrock Resistivity	Sigma Lithology	Sigma SWL
0.194704	0.178501	0.197679	0.204983	0.220771

Table IX: Linear correlation of criterion

Parameters	Topsoil Resistivity	Weathered layer Res	Bedrock Resistivity	Lithology	Static water level
Topsoil	1	0.210248	0.158168	0.325722	0.026074
Weathered layer	0.210248	1	-0.09691	-0.1758	0.201867
Bedrock	0.158168	-0.09691	1	0.282323	-0.04364
Lithology	0.325722	-0.1758	0.282323	1	0.045977
SWL	0.026074	0.201867	-0.04364	0.045977	1

Table X: Normalized matrix of each criterion with the decision

	Topsoil Resistivity	Weathered Layer Res	Bedrock Resistivity	Lithology	SWL	Decision
Topsoil	0	0.789752	0.841832	0.674278	0.973926	3.279787
Weathered	0.789752	0	1.096912	1.175805	0.798133	3.860601
Bedrock	0.841832	1.096912	0	0.717677	1.043635	3.700056
Lithology	0.674278	1.175805	0.717677	0	0.954023	3.521783
SWL	0.973926	0.798133	1.043635	0.954023	0	3.769717

Table XI: CRITIC weightage assignment

Parameters	Objective Weight
Topsoil resistivity	0.176372
Weathered layer resistivity	0.190329
Bedrock resistivity	0.204056
Lithology	0.199384
Static water level	0.229859

Table XII: Positive and negative ideal solution

VES No	Easting	Northing	si+	si-
1	732378	811215	0.224750172	0.043421754
2	732572	811649	0.218708782	0.044054518
3	732812	811603	0.21491727	0.042010751
4	732883	811913	0.215751466	0.044136642
5	732499	812118	0.212595893	0.043400841
6	732515	811914	0.214163395	0.053319183
7	732870	812330	0.211050941	0.050849386
8	732727	812487	0.197577842	0.069461781
9	732843	812655	0.222254423	0.036931864
10	733122	811941	0.206148179	0.053654131
11	733453	812577	0.231211492	0.024550250
12	734257	812394	0.219256319	0.035162047
13	733277	813009	0.211950772	0.046772705
14	733258	813173	0.224783074	0.031856627
15	732963	813544	0.180452504	0.132404085
16	733086	812743	0.222986968	0.031420913
17	732662	812949	0.177146640	0.081767029
18	732497	812873	0.216648724	0.035098330
19	732124	812471	0.198959849	0.048271812
20	732032	812855	0.217302057	0.043635223
21	732141	811977	0.232145377	0.025990694
22	732688	813281	0.197011873	0.054798239
23	732042	813090	0.220905983	0.076719040
24	732583	813699	0.175390311	0.092137123
25	731969	813594	0.212204295	0.053241307
26	732360	814375	0.184073686	0.085729527
27	733605	812980	0.208706609	0.064051830
28	732716	812001	0.163366633	0.125564715
29	732200	813818	0.198580933	0.070264566
30	734326	812644	0.153708977	0.170524566

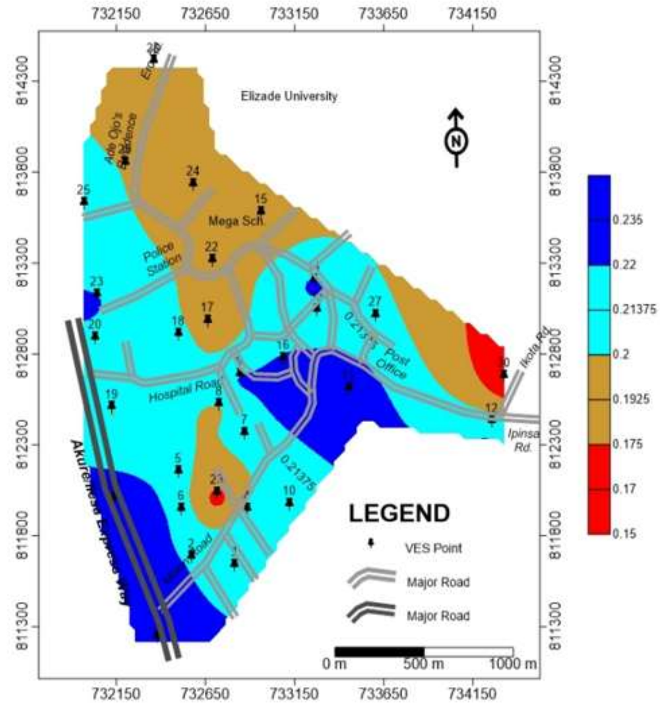

Fig. 12: Distance from the best ideal solution.

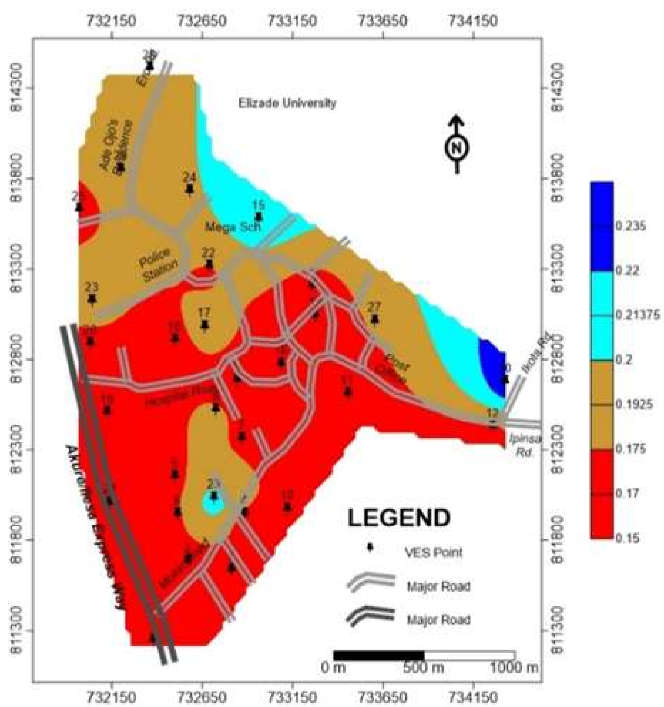

Fig. 13: Distance from the worst ideal solution.

Table XIII: Relative closeness to the positive ideal solution

VES No	Easting	Northing	Pi
1	732378	811215	0.161917599
2	732572	811649	0.167658565
3	732812	811603	0.163511754
4	732883	811913	0.169829402
5	732499	812118	0.169536699
6	732515	811914	0.199337032
7	732870	812330	0.194155488
8	732727	812487	0.260117881
9	732843	812655	0.142491583
10	733122	811941	0.206519069
11	733453	812577	0.095988749
12	734257	812394	0.138205616
13	733277	813009	0.180782608
14	733258	813173	0.124129769
15	732963	813544	0.423210152
16	733086	812743	0.123506052
17	732662	812949	0.315808081
18	732497	812873	0.139419031
19	732124	812471	0.195249313
20	732032	812855	0.167224946
21	732141	811977	0.100686021
22	732688	813281	0.217617308
23	732042	813090	0.257770800
24	732583	813699	0.344402523
25	731969	813594	0.200573326
26	732360	814375	0.317748355
27	733605	812980	0.234829875
28	732716	812001	0.434583218
29	732200	813818	0.261356676
30	734326	812644	0.525931291

L. Ranking for TOPSIS

The ranking was done using the relative closeness to the positive ideal solution (Table XIII). The best sites are those that have higher values of relative closeness. They are preferable and must be chosen [41].

M. Geotechnical competence map of Ilaramokin using TOPSIS.

The geotechnical competence index map (Fig. 14) was produced by overlaying the GCI obtained for each of the contributing factors to geotechnical competence in the area using the Surfer 13 software. From the study, it was revealed that about 63% of the study area is incompetent while about 35% of the study area is of moderate competence. Only a small portion (about 2%) of the study area is competent which is seen at the extreme eastern part of the map.

N. Geotechnical Tests

The summary of the geotechnical results is presented in Table XIV. The liquid limits range from 24.4 - 44.1%, the plasticity index ranges from non-plastic (0) to 19.12%, the plastic limits vary from 0 to 31.0%, the linear shrinkage ranges from 3.7 - 10.7%, the moisture contents vary from 12.0 - 27.5%, and the percentage passing ranges from 33.6 - 77.6%. The American Association of State Highway and Transportation Officials standards [36] for soil classification and foundation bed competence were utilized in this study. Generally, the lower the linear shrinkage, the lesser the tendency for the soil to shrink when desiccated [36, 42]. Locations 7 and 9 show a non-plastic plasticity index (Table XIV, Fig. 13 and 14), and the percentage passing of locations 7 and 9 of about 35% fall within the classification of good geotechnical competence [36, 42].

The grain-size analysis and Atterberg limit tests revealed that some locations (1, 2 and 5) have very poor foundation competence due to the clay content of such locations. Location 5 and 10 have the highest plasticity index of 19.69 and 19.12% respectively which indicates that such location has a medium plasticity. Location 8 has a lesser linear shrinkage of 3.7% and this suggests that the subsurface materials in this location have a lesser tendency to shrink. Location 10 with 10.7% has the highest linear shrinkage.

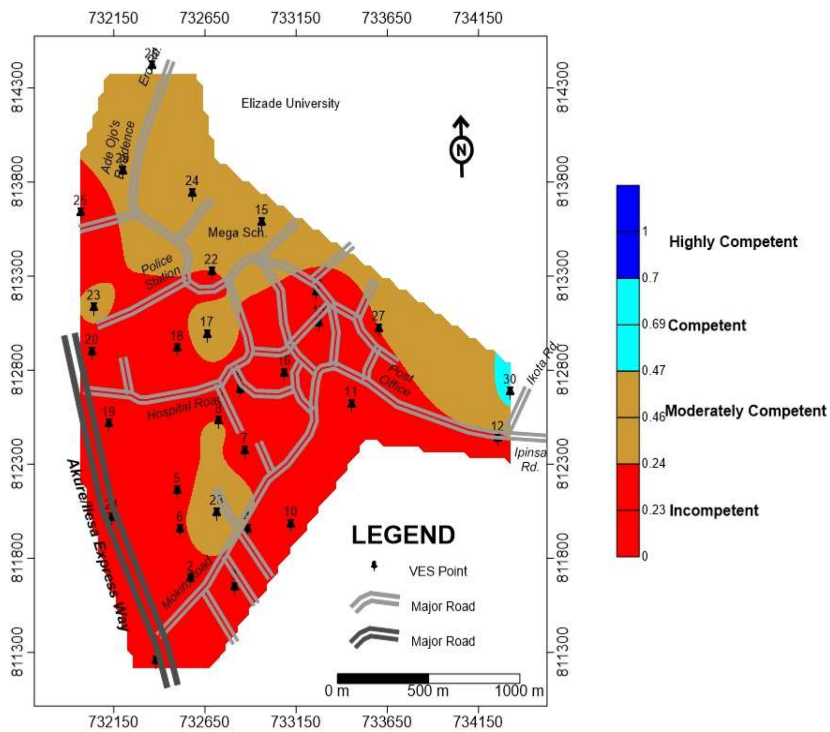

Fig. 14: Geotechnical competency map of Ilaramokin (using TOPSIS model).

Table XIV: Summary of geotechnical results

Location Number	Moisture contents (%)	Liquid limits (%)	Plastic limits (%)	Plasticity Index (%)	Linear Shrinkage (%)	Percentage passing (%)	Soil Classification
1	24.3	39.7	27.3	12.5	10.0	76.3	A-7
2	27.5	39.3	31.0	8.4	9.3	70.2	A-5
3	20.3	38.3	31.9	6.4	7.1	65.6	A-5
4	19.5	28.1	12.5	15.6	7.1	58.8	A-7
5	24.2	41.4	21.7	19.7	8.6	77.6	A-7
6	17.5	37.8	25.0	12.8	5.7	41.6	A-7
7	13.3	26.4	Non plastic	Non plastic	5.7	34.5	A-2-4
8	12.4	24.4	18.2	6.3	3.7	39.7	A-4
9	12.0	27.8	Non plastic	Non plastic	6.7	33.6	A-2-4
10	22.8	44.1	25.0	19.1	10.7	49.4	A-7

O. Validation of the geotechnical results with the competency models generated.

The generated models which involve several criteria were tested over the study area, the models are used to predict the foundation competency of the area, which indicates the parts that are suitable for sitting engineering structures and parts that are not suitable. These generated models were then validated with the geotechnical data obtained across the study area. From the geotechnical results, location 7 and location 9 show that they are suitable for sitting engineering structures (Fig. 15 and 16). The generated models and the geotechnical data agreed together in selecting points that are suitable for sitting engineering structures and parts that are not suitable (Table XV).

The northern, northeastern, northcentral, and southern parts of the study area are moderately competent to competent. These areas are good enough for sitting engineering structures. The south-south (locations 1 and 2) and southeastern (locations 4 and 5) are characterized as geotechnical incompetent zones. These areas are considered unsuitable for sitting engineering structures.

Table XV: Validation results from the soil sampling points

Location Number	Moisture contents (%)	Liquid limits (%)	Plastic limits (%)	Plasticity Index (%)	Linear Shrinkage (%)	Percentage passing (%)	AHP	TOPSIS
1	24.3	39.7	27.3	12.5	10.0	76.3	Pass	Pass
2	27.5	39.3	31.0	8.4	9.3	70.2	Pass	Pass
3	20.3	38.3	31.9	6.4	7.1	65.6	Pass	Pass
4	19.5	28.1	12.5	15.6	7.1	58.8	Pass	Pass
5	24.2	41.4	21.7	19.7	8.6	77.6	Pass	Pass
6	17.5	37.8	25.0	12.8	5.7	41.6	Fail	Fail
7	13.3	26.4	Non plastic	Non plastic	5.7	34.5	Pass	Pass
8	12.4	24.4	18.2	6.3	3.7	39.7	Fail	pass
9	12.0	27.8	Non plastic	Non plastic	6.7	33.6	pass	Pass
10	22.8	44.1	25.0	19.1	10.7	49.4	Fail	Pass

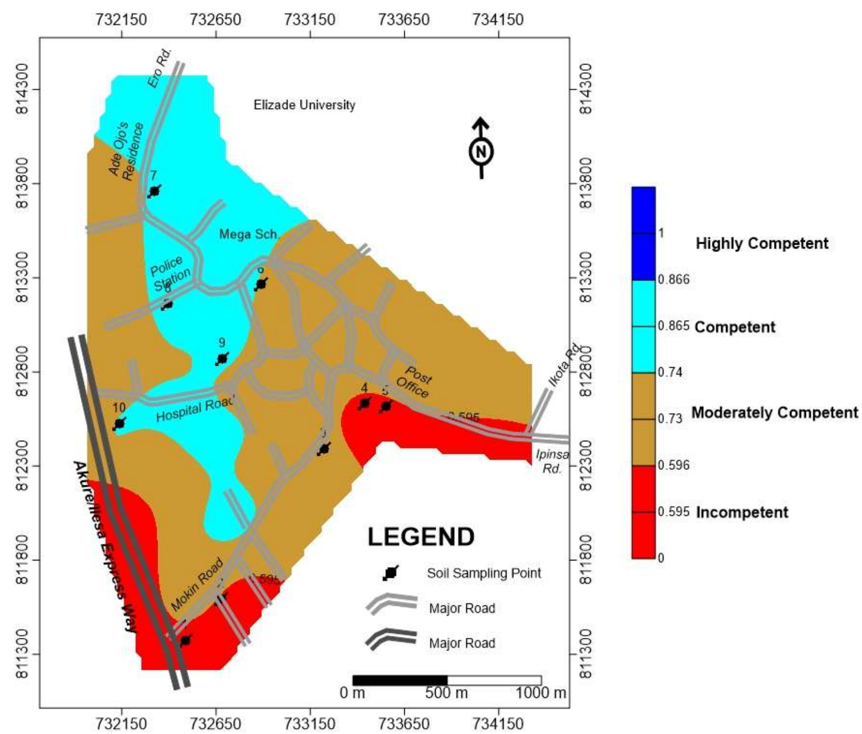

Fig. 15: Geotechnical competency map of Ilaramokin (using AHP model) with soil sample points.

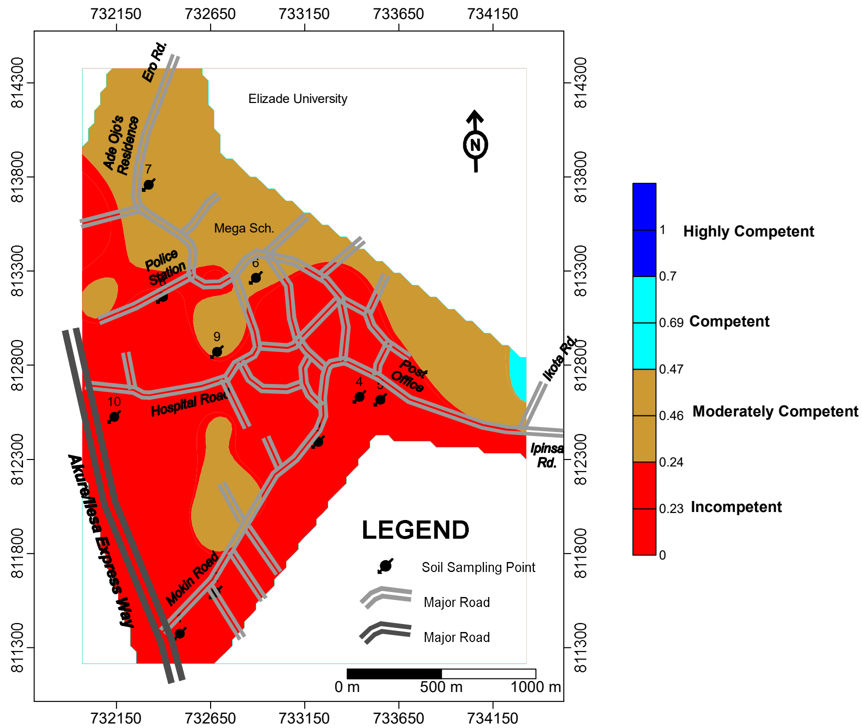

Fig. 16: Geotechnical competency map of Ilaramokin (using TOPSIS model) with soil sample points.

IV. CONCLUSION

This study has successfully utilized the Analytical Hierarchy Process (AHP) and Technique for the Order of Prioritization by Similarity to Ideal Solution (TOPSIS) in integrating geoelectric, static water level and geologic parameters to evaluate the foundation bed competence of Ilaramokin, Southwestern Nigeria. The two results were validated with the conventional geotechnical approach. Geoelectric 1-D modelling (vertical electrical sounding) technique involving Schlumberger electrode configuration was adopted in obtaining the geoelectric parameters of the study area. The VES interpretation delineated 6 curve types (A, H, K, KH, QH and HKH) across the study area. Three distinct subsurface geoelectric/geologic layers were delineated in the area namely topsoil (48 - 701 ohm-m), weathered layer (26 - 1065 ohm-m) and bedrock (132 - 6582 ohm-m). Three geoelectric parameters were utilized in this study (topsoil resistivity, weathered layer resistivity and bedrock resistivity). These parameters were synthesized with geology (lithology) and 84 static water level measurements to obtain geotechnical competence maps of the area using two different approaches. The parameters were subjected to pairwise comparison weighting and ranking using analytical hierarchy process techniques to generate the foundation competence map of the area. Again, the parameters were subjected to an objective weighting approach (CRITIC weightage) and ranking using the similarity to the ideal solution for the TOPSIS approach to generate another foundation competence map of the study area.

Ten collected soil samples were subjected to various geotechnical tests. The variation of the geotechnical test results are as follows; liquid limit (24.4 - 44.1 %), moisture content (12.0 - 27.5 %), plastic limit (non-plastic - 31.9 %), plasticity index (non-plastic - 19.69), linear shrinkage (3.7 - 10.7 %) and grain size (33.6 - 77.6 %) shows the competency distribution of the study area. The results were compared with foundation competence maps generated from the two adopted MCDA techniques. AHP and TOPSIS show a high degree of similarity to geotechnical test results. TOPSIS however show a higher degree (about 90 %) than that of AHP (about 70 %).

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