ENGINEERING GEOLOGY AND THE SUSTAINABILITY OF STRUCTURES AND THE ENVIRONMENT: *THE EDUNABON MANUSCRIPTS*

A Valedictory Lecture delivered at the University of Ibadan

RECTE SAPERE FONS

in honour of

PROFESSOR GABRIEL OLADAPO
ADEYEMI,
PhD, FNMGS, FNAEGE, FNAH

On Friday, 4 October 2024

By

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Professor of Environmental and Engineering Geology,
University of Ibadan,
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The Vice-Chancellor, Deputy Vice-Chancellor (Administration), Deputy Vice-Chancellor (Academic), Deputy Vice-Chancellor (Research, Innovation and Strategic Partnerships), Registrar, Librarian, Bursar, The Chairman of the Day, Chief Launcher and other Launchers, Provosts of the College of Medicine and of The Postgraduate College, Dean of Students, Dean of the great Faculty of Science, All Other Deans, Head of Geology Department and other Heads of Department, Staff of the Department of Geology, Other members of Staff in the University, Colleagues, Distinguished guests, Friends and well-wishers, Gentlemen of the Press, my Lord Spiritual and Temporal, Ladies and Gentlemen.

Introduction

I stand before you today with gratitude to my Creator for this great opportunity which I am not taking for granted. It's a great privilege to deliver this valedictory lecture in honour of Professor Gabriel Oladapo Adeyemi who is retiring from the services of our great Citadel of Learning and Numero Uno. I am here with immense appreciation as 'the Chosen one' on this very special day which marks the 70th Birthday of a 'Living Ancestor, Teacher, Father, Legend, Pace Setter, and Trail blazer.

The first and only valedictory lecture in the Department of Geology to date was delivered by Late Prof. Thompson Adeyemi Badejoko (1945 to 2024) titled 'Solid Mineral Development: Solid Progress or Solid Waste' when he retired in 2005. May I crave your indulgence to request a minute silence in honour of Baba Badejoko, a teacher, astute scholar, fine gentleman, and quondam Head of the Department of Geology who we lost to the cold hands of death on Saturday 17 August 2024, at the age of 79 (May God console all those he left behind). I am however delighted to be delivering the first valedictory lecture in the history of the Department of Geology of this great citadel of learning to be delivered by a colleague Professor in honour of another colleague from the same Department. Moreover, it's the first valedictory lecture to be delivered by a former student in honour of his Undergraduate Teacher, M.Sc. Project, and Doctoral Thesis Supervisor (Combined Extraordinary Tutelage) in the Department of Geology. You will therefore agree with me (in Professor Adeyemi's Voice) that today is not just coincidental but divine.

How divine is this? What does pre-destination have to do with it? My path crossed with the then Dr Adeyemi as a 100 Level student of the Department of Earth Sciences, Ogun State University some 31 years ago when he took us the Introductory Geology Course. He came to class and announced one of my course mates as the class representative (Class Rep). As a young *'Omo Olopa'* with some 'Barrack mentality', energy and vibrance, I echoed my disagreement with his choice citing that in a democratic setting, we the students had a right to choose and had in-fact chosen who we wanted as our Class Rep. This was perhaps in tandem with the mood of the country as the result of the June 12, 1993, elections had just been annulled necessitating protests every now and then. In a very calm and fatherly way he noted that as much as we had our right, he also had a right as our Lecturer to pick his point of contact with his students. With benefit of hindsight, I don't know what came over me or where I found the courage to spill out my thoughts or even challenge his decision. However, and perhaps largely due to the very dominant *'Abiyamo too to*' gene in him, I got away with my youthful exuberance. As a result of this encounter, I tried to avoid him as much as possible. When the list of available projects for final year students was posted for selection, despite my interest in the Engineering Geology project topics listed, I refused to pick any as I did not want to have anything to do with him because I was afraid punishment was reserved for me. Alas, as much as I tried to avoid him, destiny had other plans in store for me.

I applied for M.Sc. Petroleum Geology/Sedimentology at the University of Ibadan upon completion of the Bachelor's degree at Ago-Iwoye, but my name was published in the newspaper for M.Sc. Geology. This meant I had to pick from options including Geochemistry, Economic Geology, Mineral Exploration and Engineering Geology/Hydrogeology. I was confused not because I didn't know which option I preferred, but I realised my teacher, Dr Adeyemi (who I avoided in Ago-Iwoye) had joined the Department of Geology, UI earlier. This meant that my avoidance must continue. I sought counsel from a man God obviously sent to me in person of Late Dr S.I. Nurudeen (May God continue to console all those he left behind) who without mincing words advised I choose Engineering Geology/Hydrogeology. Of course, I could not tell him my issues hence I accepted my cross.

During the M.Sc. program, our class representative Abdurrahman Olukade later informed us we were asked to indicate our preference of final project between Engineering Geology and Hydrogeology, and I naturally chose Hydrogeology. The only divine mistake I made was revealing to my course mates the reason for my choice and the fact that I did not want to work with Dr Adeyemi. Not too long after, the supervision list was released with my name listed under Dr Adeyemi. I resigned completely to fate. Abi, what else could I do? Little did I know that my brother, friend, and classmate Moroof Oloruntola (now Dr Oloruntola) who had preferred to be with Dr Adeyemi but who was listed under another supervisor, had told Dr Adeyemi I did not want to work with him. He wanted Oga to initiate a swap so he could be with him. Dr Adeyemi accosted me at the landing of the flight of stairs in front of the Engineering Geology Laboratory and queried;

> I am told you don't want to work with me, so I have asked the other supervisor to allow Moroof to join me, so you can join him.

I denied instantly that I said anything of such. *Haaaa* this was live burial and no escape route. I was stuck with Oga Adeyemi. Distinguished guests, Ladies and gentlemen, the rest as they say is history.

On the 21st of May 2024, I received a request from Professor Gabriel Oladapo Adeyemi via a WhatsApp message. I initially mis-read the message and thought he wanted me to be the Master of Ceremony (MC) at his Valedictory programme. Fortunately for me I discussed the request with my great brother, classmate, friend and quondam Head, Department of Geology UniOsun, Dr Tesleem

Kolawole who advised me to re-read the message. I was shocked, confused and scared to discover the request was to deliver this Valedictory Lecture in his honour.

Why me? Why not someone else? I had just left Nigeria a few weeks before and with the exchange rate and skyrocketing cost of flight tickets, what do I do? However, this Man from Edunabon (Edinburgh) who since 1981 has been involved in preconstruction investigation for buildings, dams, roads and highways, environmental impact assessments and evaluation of probable landfill sites is worthy of being celebrated, and I had an obligation to do it in person. This great teacher of teachers who perhaps holds the singular distinction of having taught Engineering Geology in practically all Universities in southwest Nigeria directly or by proxy (he must have taught whoever is currently taking the course) and has 14 of his known old students as full Professors (2 are Civil Engineers, 1 is a Chemist, 1 is a Medical Doctor, while 10 are Geoscientists) he as such deserves all the sacrifice possible. Whatever costs incurred is immaterial as long as it is to honour him.

Thank you, Sir, for this honour you have done my family and I. May you live long Sir, in great health and sound mind to further reap the fruits of your labour.

Engineering Geology and the Sustainability of Structures and the Environment: The Edunabon Manuscripts

What is Engineering Geology? What's the linkage between Engineering Geology and Sustainable Structures? How is the Environment involved? These and other questions beg for answers and will be revealed engaging the Manuscripts of Professor Gabriel Oladapo Adeyemi, an illustrious son of Edunabon.

The 1992 IAEG Statutes defined Engineering Geology as the science devoted to the investigation, study and solution of the engineering and environmental problems which may arise as the result of the interaction between geology and the works and activities of [humans] as well as to the prediction and of the development of measures for prevention or remediation of geological hazards (Delgado *et al.,* 2014; IAEG, 2024). This and other definitions (Table 1) highlights the importance and contributions of Engineering Geology to the delivery of sustainable structures.

In my very first encounter with the Edunabon Manuscripts, Adeyemi (1994) very simply and aptly described Engineering Geology as the application of Geological disciplines to solving Civil engineering and earthwork problems (applies geological science to engineering practice). You will therefore agree with me that this special discipline applies geological principles and knowledge to engineering practices ensuring that geological factors are recognized, adequately provided for, and thoroughly considered in the planning, design, construction, and maintenance of Civil Engineering works. Thus, it involves the study and interpretation of the Earth's materials (soil, rock, water), geological processes (such as landslides, earthquakes, and erosion), and the assessment of their potential impact on human-made structures.

The British Geological Survey in a news release on 15 March 2022 noted that to achieve the Sustainable Development Goals (SDGs) set forth by the UN, **Engineering Geologists are indispensable.** In addition to serving as a link between earth sciences and engineering, Engineering Geologists are crucial to achieving the SDGs. Crucially, Engineering Geologists offer a unique perspective to help build resilience to natural hazards, solve environmental problems caused by human activities, and lower the cost and risk of building and infrastructure construction because of their knowledge, skills, and understanding of the interfaces between science and engineering and the natural and built environments past, present, and future.

The need for Geologists on Engineering works gained worldwide attention on March 12, 1928, with the catastrophic failure of the St. Francis Dam in California and the death of over 426 people. More Engineering failures that occurred in the following years also prompted the requirement for Engineering Geologists to work on large Engineering projects. Hence, the science and practice of Engineering Geology only commenced as a recognized discipline in the late 19th and early 20th centuries.

Historically, Engineering Geology was founded as a discipline in 1938 by Karl Terzaghi a Structural Engineer who specialized in the design of dams when he was at the Massachusetts Institute of Technology (MIT) in the United States. He soon realised that the dams designed did not last long leading to loss of lives and properties. It became obvious that the careful design of a structure in itself alone, does not confer stability on such structure and hence the geological environment where the structure will be emplaced, and the geological characteristics of the materials used for the construction work must be considered. Therefore, Engineering Geology forms a link between Geology and Civil/Mining Engineering.

Table 1: Different definitions of Engineering Geology

SN	Definition of Engineering Geology	Citation
1	Engineering Geology is the science devoted to the investigation, study and solution of the engineering and environmental problems which may arise as the result of the interaction between geology and the works and activities of [humans] as well as to the prediction and of the development of measures for prevention or remediation of geological hazards.	IAEG (2024)
2	Engineering Geology involves the study and deployment of techniques, principles and geological data acquired to the investigation of rock, soil surficial materials and groundwater. The aim is to ensure that geological factors are recognized, appropriately integrated, and accounted for in the siting, design, construction, operation, and maintenance of engineering works.	Geological Society of America (2023)
3	Engineering geology is a field focused on the application of geologic knowledge to the engineering of structures and infrastructure, emphasizing the importance of understanding earth materials and processes. The discipline deals with the physical and mechanical properties of earth materials and the nature of the forces acting upon them all in a bid to provide solution for civil engineering problems, the design of engineering works, and the inspection of construction projects.	United States Geological Survey (2018)

4	Engineering geology is a vital component of civil engineering that ensures geological factors are considered in the design and construction of safe, resilient structures. It is a discipline that integrates geological knowledge with engineering principles to address issues related to the earth's materials and processes, focusing on the geological factors that impact the planning, design, and construction of civil engineering projects.	Institution of Civil Engineers (2015)
5	Engineering geology is the application of the geological sciences to engineering design and construction practice for the purpose of assuring that the geological factors affecting the location, design, construction, operation, and maintenance of engineering works are properly recognized and adequately provided for.	Bates and Jackson (1987)
6	Engineering geology is the discipline that applies geological science to civil engineering practice, ensuring the geological factors are properly accounted for in engineering design and construction.	Bell (2007)
7	Engineering geology is concerned with the application of geology to engineering study for the purpose of assuring that the geological factors regarding the location, design, construction, operation, and maintenance of engineering works are recognized and accounted for.	Fookes (1997)
8	Engineering geology is the _scientific study of geology as it relates to civil engineering projects such as the design of a bridge, construction of a dam or preventing a landslide'. Engineering Geology aims to ensure that geological factors are fully considered in the development, construction, and maintenance of infrastructure projects.	Hencher (2012)
9	The science of Engineering Geology is a wide frontier with diversity as its fundamental tenet. All branches of geology are relevant in the study of Engineering Geology.	Mark and Eggers (2016)
10	Engineering Geology is not a branch of the science of Geology; it is the application of all branches of the science to the practical problems of Engineering.	Burwell and Roberts (1950)
11	Engineering Geology is the application of Geological disciplines to solving Civil Engineering and earthwork problems	Adeyemi (1994)

What does Engineering Geology have to do with Sustainable structures?

The importance of Engineering Geology to infrastructural development and environmental management is multifaceted, influencing various stages of implementation and playing a crucial role to deliver construction projects that are safe, sustainable, and resilient. The interaction between geological conditions and engineering practices forms the foundation for successful infrastructure projects. It is essential for the sustainability of structures, providing and integrating critical geological insights that guide the design, construction, and maintenance of infrastructure. By ensuring that geological conditions and processes are fully considered, Engineering Geology helps to create structures that are durable, resource-efficient, and environmentally responsible throughout their lifecycle, contributing to a sustainable built environment. The different areas of influence, showing options of importance which highlights the significance and how Engineering Geology contributes to sustainability of structures and the environment are presented as follows:

Site Investigation and Selection

Engineering Geologists conduct thorough site investigations to assess the geological conditions at potential construction sites or locations, thereby serving as a critical tool for determining suitability of a site for construction and for identifying any necessary mitigation measures against possible or impending challenges. Site investigation is done to choose the best possible location for construction, minimizing environmental impact and maximizing stability. It involves detailed testing of soil and rock to inform construction techniques and materials using comprehensive geological surveys and site investigations. Coduto *et al.* (2014) indicated that before offshore oil platforms are constructed, geotechnical investigations of the seabed are conducted to help determine the type of foundations required to prevent sinking or tilting of the platforms due to weak or uneven seabed conditions. Methods include drilling, sampling, geophysical surveys, evaluating soil composition, rock formations and structures, groundwater conditions, and avoiding geologically hazardous areas with potential for geohazards like landslides, earthquakes, and sinkholes thus preventing future issues related to ground instability (Hack *et al*., 2004).

Adeyemi (2013) highlighted steps (Fig. 1.) usually followed during engineering geological study of site for a proposed structure to include:

a. Desk Study – Identified as the planning stage and entails terrain evaluation by the study of topographic maps, air photographs and/or radar/satellite imageries.
b. Basic Structural and geological mapping on a large scale because the larger the scale the better.
c. Surface geophysical surveys using techniques as electrical resistivity, seismic refraction, very low frequency electromagnetic (VLF-EM) techniques for generation of subsurface model. The techniques are cheaper and faster than geotechnical methods. They can be used to reduce the cost and duration of site investigation appreciably. Depths generated from geophysical surveys have been found to have strong positive correlations with those from geotechnical boreholes (Ako, 1976; Olayinka and Oyedele, 2001).
d. In-situ geotechnical tests at selected points to determine penetration resistance and hence Allowable Bearing Pressure from level to level for foundation design for structures using the Dutch cone penetrometer.
e. Sampling of soils, rocks, and water from bore-holes. This is usually done by boring through soils and coring of rocks. The depth to water table is often measured.
f. Laboratory testing of soils, rocks, and water.
g. Report writing.

The importance of site investigation and selection is emphasized by Adeyemi (1994) who observed that soils developed over different rocks (sandstone, quartz-schist and migmatite-gneiss) in the geological transition zone of Ishara and Ajebo areas had widely different mineralogical and geotechnical properties. Adeyemi and Ogundero (2001) observed that the position of soil in laterite profile had significant influence on most of the engineering properties of soils developed over migmatite gneiss in Oru-Ijebu southwestern Nigeria.

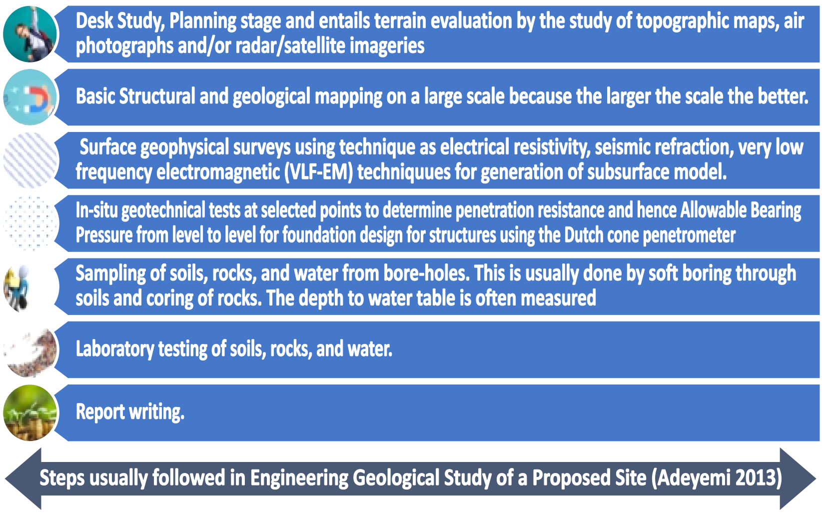


Fig. 1: Steps usually followed in Engineering Geological Study of a proposed site (Adeyemi, 2013)

Moreover Adeyemi (2003) found higher amounts of Kaolinite and ferric oxide, higher amounts of gravel-sized particles, lower amounts of fine fractions, lower plasticity and higher strength in soils taken from gentle slope than those from flat terrains in Ishara-Remo indicating that soils along gentle slopes are better drained and more lateritised than those from flat sites emphasizing the role of geomorphology. This indicates that it is reasonable to win soils for construction purposes from gentle slopes since such soils are likely to possess better engineering properties than those from flat sites. Furthermore, Adeyemi *et al*. (2012) noticed significant influences of mineralogy and texture on some geotechnical properties of soils derived from six distinct crystalline Basement Complex rocks from parts of southwestern Nigeria. The influence was found to be strongest on water absorption capacity and weakest on the true specific gravity. The Authors also noted that the relatively low amount of quartz and high amount of alkali feldspar observed could have been responsible for the high-water absorption capacity and low strength of soils developed over pegmatite. All these inputs as contained in the Edunabon manuscripts attest to the importance of the role of Engineering Geologists which engender proper site selection and testing to achieve structures with fail-safe conditions.

Foundation Design, Construction and Ensuring Structural Stability

The need to design foundations which are both stable and resource efficient cannot be overemphasized. The great importance and overriding influence of properly designed foundations is aptly captured in a quote by Venetian architect Andrea Palladio (1508–1580) as translated by Isaac Ware, 1738 cited in Coduto *et al.* (2014):

> The foundations are properly called the basis of the fabrick, viz. that part of it underground which sustains the whole edifice above; and therefore, of all the errors that can be committed in building, those made in the foundation are most pernicious, because they at once occasion the ruin of the whole fabrick, nor can they be rectified without the utmost difficulty.

The design and construction of foundations for buildings, bridges, dams, and other structures heavily depend on understanding the geological conditions. By accounting for geological factors, Engineering Geology contributes to the design of durable infrastructure that can endure geological and environmental stresses and provides critical data and insights on soil and rock properties, which influence the type and depth of foundations (e.g. shallow foundations, deep foundations, pile foundations) ensuring design optimization. Understanding these properties ensures that foundations and other structural elements are designed to bear the loads and stresses they will encounter, thereby ensuring the stability and safety of buildings, bridges, dams, other structures and ultimately assisting with longevity of the infrastructure. The whole idea is to ensure stability and integrity of structures by analysing soil and rock properties to determine appropriate foundation types and depths resulting in foundations being designed to support structures under various load conditions and environmental factors. Moreover, optimized use of construction materials, reducing waste and lowering the environmental footprint of foundation works is achieved. Accurate geological data ensure that foundations are designed to suit the ground conditions, preventing structural failures (Bell, 2007).

Adeyemi (2013) noted that appropriate design of foundation for any structure requires integrated use of geological, geophysical, and geotechnical methods which is the approach adopted in the developed parts of the world. However, in Nigeria, subsoils investigation for structures is usually limited to in-situ geotechnical tests and sampling of boreholes since only civil engineers are involved. Even then, the investigation is often limited to structures built by governments and multinationals. No wonder we witness incessant cases of building collapse, dam, and road failures (Fig. 2.)

Stability of flexible highway pavement has been shown to depend on clay mineralogy, major oxide geochemistry and geotechnical properties of both sub-base and sub-grade soils. Adeyemi (1992) showed that the degree of stability of the Lagos/Ibadan highway pavement increased with the amounts of Kaolinite, ferric oxide, CBR and unconfined compressive strength of the subgrade (foundation) soils. I recall with nostalgia a conversation I had with the late Erudite Professor of Engineering Geology and Inventor, Professor Ebenezer Ajibola Meshida (who incidentally supervised Professor Adeyemi's Ph.D. thesis between 1987 and 1991) on the side-lines of the First Nigerian Association for Engineering Geology and the Environment (NAEGE) conference held at the Airport hotel, Lagos in 2016. The conversation was with respect to the failure of many sections of the

Lagos/Ibadan Expressway. With sadness in his voice, he recalled how his proposal in the 1970's for the design and construction of the road was disregarded because it was to cost higher than the proposal submitted by an Engineer. Of course, his quote was bound to be higher considering the peculiarities associated with the design occasioned by the different geological terrains underlying the proposed pavement. I am sure we are all witnesses to the carnage and how many lives the failed road consumed before the recent re-construction.

In order to determine whether there is a geotechnical basis for the instability of certain sections of the flexible highway pavement, Adeyemi and Oyeyemi (2000) looked at some geotechnical properties of subgrade soils from sections of the Lagos–Ibadan expressway in Ibadan. They found that there is no need for significant differences to exist between the geotechnical properties of soils below stable zones and unstable sections before such parameters can be used as bases for predicting the stability of flexible highway pavements in tropical regions. The study of the geotechnical basis (as opposed to the frequently offered explanations) for the persistent occurrence and growth in the incidence of building failure and collapse with attendant loss of life and property in Lagos Southwestern Nigeria by Oyediran and Famakinwa in 2015 (Fig. 3.) was inspired by Adeyemi and Oyeyemi (2000).

For the purpose of gathering in-situ data and collecting soil samples, boreholes, vertical electrical sounding (VES), cone penetrometer test (CPT), and standard penetration test (SPT) points were established strategically (Fig. 4). Underlying the unstable areas were four (4) layers with notable thicknesses of near-surface very low bearing capacity peat and organic clay (Fig. 5.). Furthermore, considerable thicknesses of extremely compressible, highly plastic soils with low shear strength were also noted. Oyediran and Famakinwa (2015) came to the conclusion that geotechnical and hence geological factors play a major role in the instability and failures observed.

Great examples abound around the world where the

Fig. 2: Images of Roads and Buildings failures in Nigeria (Source: Google 2024)

importance of Engineering geologist to the delivery of stable structures with appropriate foundation investigation and subsequent design have been demonstrated. Constructing The Burj Khalifa in Dubai, the world's tallest building on challenging (extraordinary climatic and soil condition) desert geology, consisting loose sand and weak sedimentary rock requiring extensive geological and geotechnical investigations, led to the design of a deep foundation

Fig. 3: Building failure and instability at Arowojobe Estate, Maryland Southwestern Nigeria (Oyediran and Famakinwa, 2015)

system that ensured stability and longevity. A structurally sound skyscraper that exemplifies sustainable engineering practices in challenging environments was delivered.

Risk Assessment, Disaster Preparedness, Resilience Planning and Mitigation of Geological Hazards

Engineering Geologists identify potential geohazards and assess geological risks such as earthquakes, landslides, soil erosion and soil liquefaction with a bid to design infrastructure that can withstand natural disasters thereby extending their lifespan and reducing the need for frequent repairs or replacements. By recognizing these risks early and understanding them, they can develop mitigation strategies to protect infrastructure. This involves incorporating geotechnical and seismic data into design

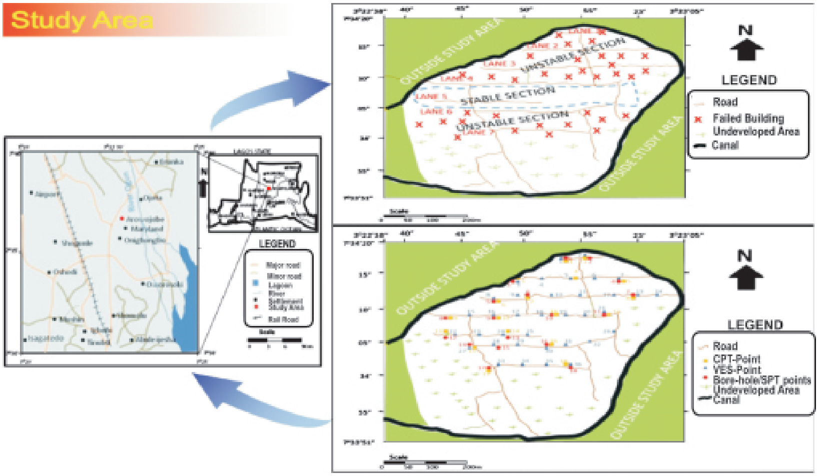


Fig. 4: Map showing distribution of Investigation and Sampling points (Oyediran and Famakinwa, 2015)

and construction and might include reinforcing structures, seismic reinforcement, slope stabilization, erosion control measures, selecting safer locations, or implementation of engineering solutions like retaining walls, seismic design principles and drainage systems to manage groundwater, designing appropriate foundations. For example, fault lines and soil types are analysed by Engineering Geologists in regions prone to earthquakes to aid engineers in the design of buildings that can absorb and dissipate seismic energy thereby reducing risk of collapse. Seismic hazard maps and vulnerability maps are produced based on the investigations and analyses by Engineering Geologists. By and Large, Engineering Geology promotes the delivery of infrastructure that is resilient to natural hazards, reducing the risk of catastrophic and structural failure due to geological events, enhancing their sustainability by preventing premature failure and reducing maintenance needs thereby enhancing public safety. This proactive approach not only saves lives but also reduces economic losses by preventing infrastructure failures. Turner and Schuster (1996) noted that geological assessments are integral to identifying and mitigating landslide risks in infrastructure projects.

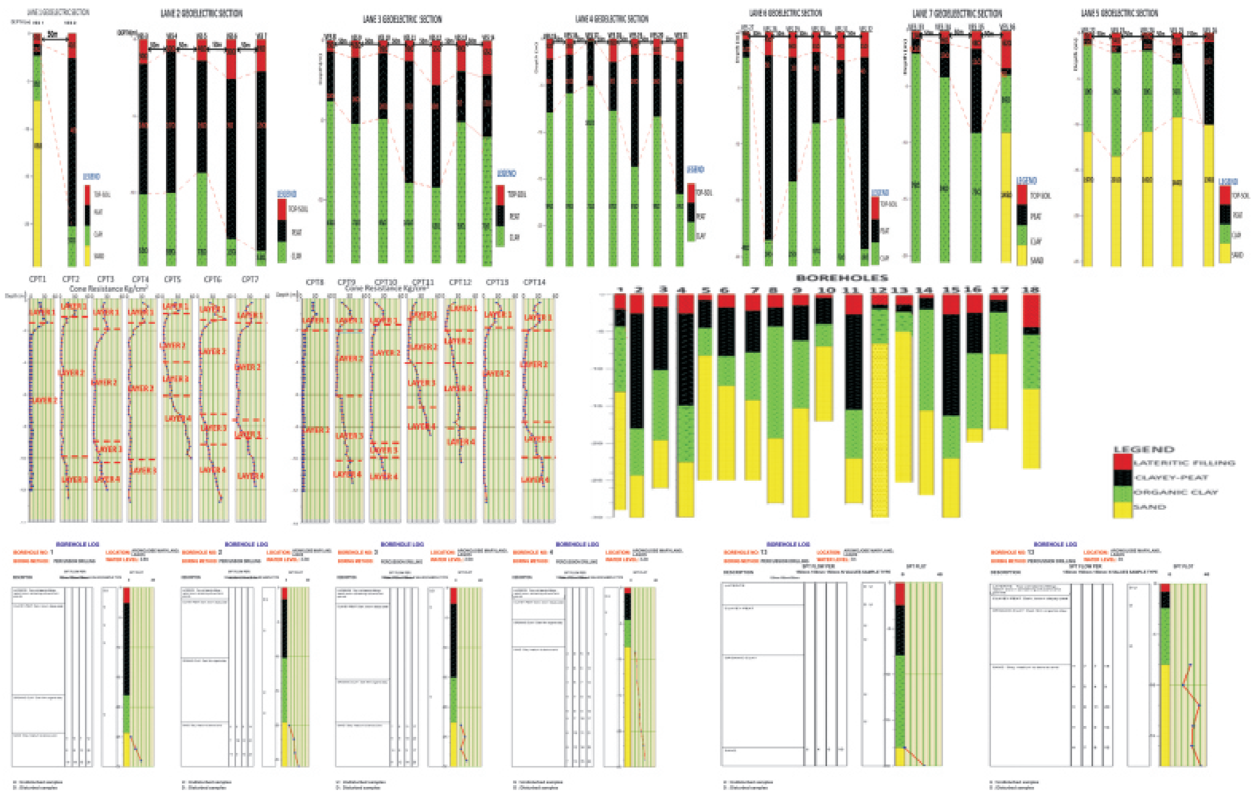


Fig. 5: Illustration of some of the results from the investigations (Oyediran and Famakinwa, 2015).

Oyediran and Adeyemi (2011a and b) undertook the evaluation of a site for landfill using integrated geological investigations. Multi-method geophysical investigations involving VLF-EM and ER methods were integrated into the geological mapping of the study area. These methods have been observed to yield valuable results in mapping (Telford et al., 1990; Benson et al., 1997) and are known to be responsive to water-bearing basement fracture columns due to their relatively high bulk electrical conductivities. As a result, they were deemed relevant and included in the investigation. Sixty-six Very Low Frequency-Electromagnetic (VLF-EM) stations from six NE-SW traverses were occupied at an interval of 10m while the Schlumberger Array was used to establish 36 Vertical Electrical Soundings (VES) spaced 20 meters apart along six traverses to assess the presence of linear structures, layer resistivity, bedrock depth, depth and features of the unsaturated zone, identification of any confined or perched water bearing strata, and subsurface features.

Eighty-four soil samples, consisting of fifty-six disturbed samples at 0.5 meters interval and twenty-eight undisturbed samples spaced 1.0 meters apart, were also taken from seven test pits down to a maximum depth of 4 meters. This allowed Oyediran and Adeyemi (2011a and b), to establish baseline data on soil vulnerability, which is important for determining whether a site is suitable for disposing of waste. Three wells were dug on site to determine the groundwater flow direction and hydraulic gradient (Fig. 6).

Geological field investigations of exposed rocks show that the area is underlain by Granite Gneiss which is medium grained and pinkish. The rock is crystalline with interlocking grains. The trend of the foliation is generally N-S while numerous E-W trending joints exist on the outcrops. The rocks are essentially dipping to the east. Thin section study of the samples of Granite gneiss shows the presence of quartz, biotite, plagioclase and microcline feldspars. Foliation is preserved (Plate 1 and 2) showing biotite (mafic mineral) with elongate structures and this defines the foliation trend. Quartz occurred as irregularly shaped crystals which were relatively unbroken. Plagioclase showed vivid polysynthetic twinning while

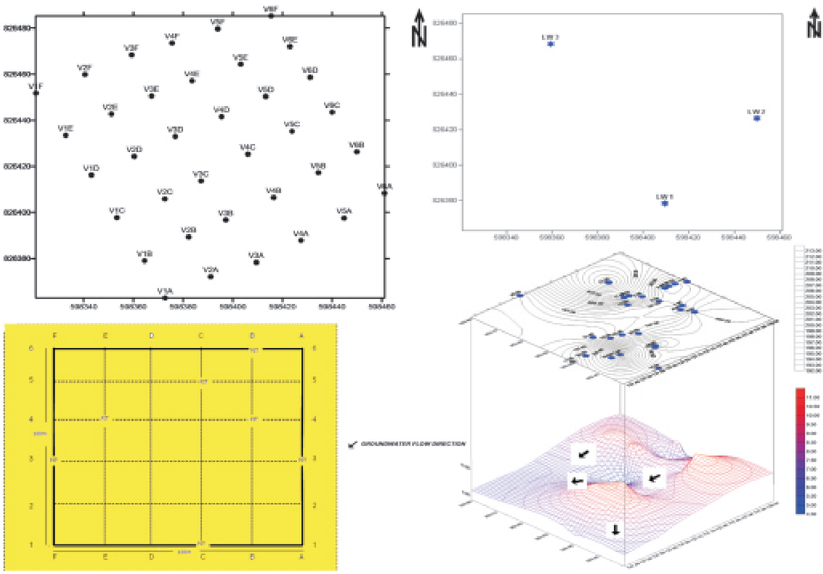
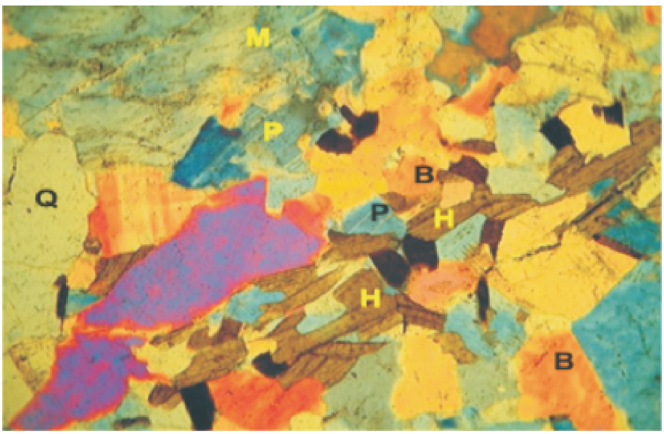
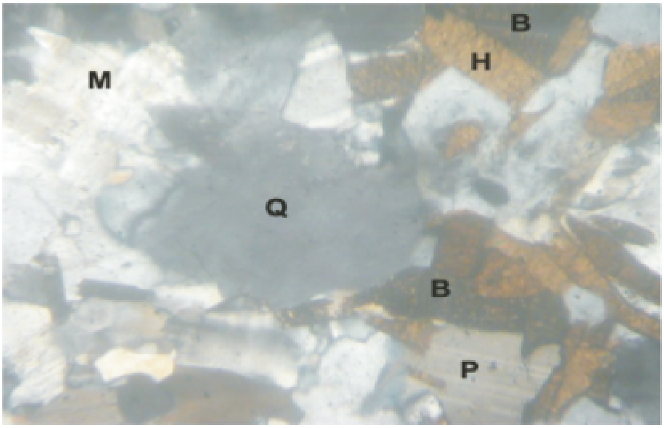


Fig. 6: VES points, Test pits, Wells and Groundwater flow direction Oyediran and Adeyemi (2011a and b).



Q = Quartz,
B = Biotite,
H = Hornblende,
M = Microcline,
P = Plagioclase

Plate 1: Photomicrograph of Granite Gneiss in transmitted light showing quartz, biotite, microcline, plagioclase, hornblende and other minerals (magnification x40)



Q = Quartz,
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M = Microcline,
P = Plagioclase

Plate 2: Photomicrograph of Granite Gneiss in transmitted light showing quartz, biotite, microcline, plagioclase, hornblende and other minerals (magnification x40)

microcline also showed cross hatches. Few opaques were observed.

The VLF-EM survey yielded no linear features, such as fractures or faults, but the electrical resistivity survey using the VES method revealed the presence of a clay layer in all of the established traverses, with a thickness ranging from 3.10 to 12.20 meters. The layer's role is to act as a seal, preventing any kind of contamination from reaching the underlying aquifer. In the study area as a whole, the depth to bedrock ranges from 3.80 to 13.60 meters, while the three wells dug on the site show varying depths to the water table, ranging from 8.00 to 9.25 meters. Moreover, the site has suitable geology because the bedrock is not chemically active. A proposed landfill model based on the results obtained from the integrated investigations is presented (Fig. 7.).

In summary, the site assessment revealed that the research area is safe for waste disposal due to its geological stability and geotechnical stability. It would be disastrous to site a landfill or a dam on a chemically active rock owing to the interaction that may occur between leachate and underlying groundwater in the case of a landfill or the significant loss of water leading to pressure loss and eventual collapse in the case of a dam.

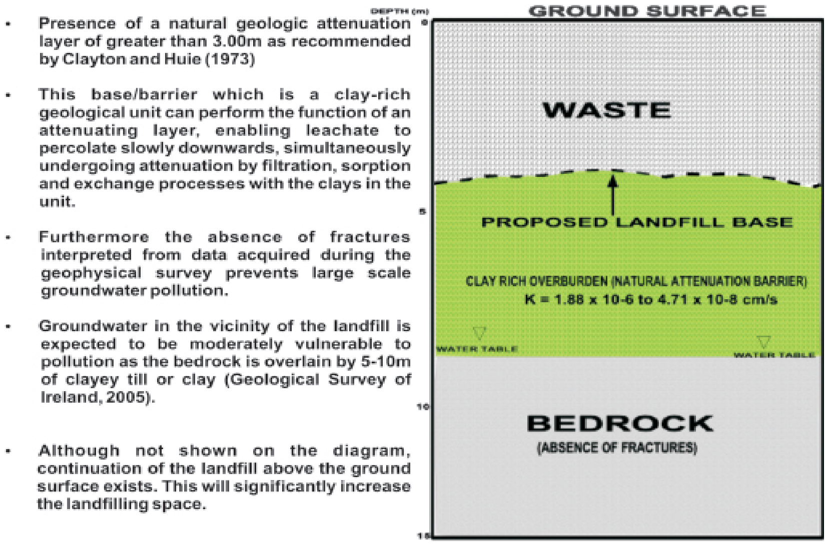

Fig. 7: Proposed Landfill Model (Oyediran and Adeyemi, 2011a and b)

Material Selection and Testing

The choice of construction materials, such as aggregate for concrete or stone for building, is influenced by geological studies. Engineering geologists conduct detailed investigations to determine the physical and mechanical properties of subsurface materials. They help identify suitable material sources and ensure they meet the necessary specifications for strength and durability. The overall aim is to choose appropriate construction materials based on geological properties. Knowledge of local geological materials helps in choosing appropriate suitable construction materials and methods which in turn translates to reduction of transportation costs (and associated carbon footprint) and energy consumption, contributing to the sustainability of the project. Aggregates, cement, subbase, basecourse and other materials are tested for strength, durability, and suitability. This is done to achieve the use of high-quality materials that meet engineering standards and contribute to the longevity of the infrastructure. Efficient use of materials and resources based on geological assessments reduces overall project costs and enhances durability.

Adeyemi and Osamor (2001) performed standard penetration tests (SPT) on soils in twenty boreholes sunk around Lagos and Port Harcourt in southern Nigeria Cone resistance and friction ratios from almost a thousand cone penetration tests were compared to the test findings. The purpose of this was to see if there were any quantitative relationships between penetrometer and standard penetration data. Cone penetration tests were conducted 1.50 meters away from neighboring boreholes. The SPT N-values (blows per 3000mm) and cone resistance on the soils of Lagos and Port Harcourt were found to have correlation coefficients of 0.85 and 0.64, respectively. For the soils in the two locations, linear regression equations were also developed. It was also discovered that every soil that was tested for penetration had distinct friction ratios (the ratios of the sleeve to cone resistance). For example, the lowest friction ratios were reported for sandy gravels and sands, at 0.11 and 1.20, respectively, while the highest ratios were recorded for clayed peat and peaty clays, at 13.00 and 16.75, respectively. Sands, silts, clays, and soil mixtures exhibited intermediate friction ratios.

Moreover, Adeyemi (2013) indicated that many standard geotechnical specifications established for temperate zone soils have been found not to be applicable to tropical soils. For instance, laboratory tests of tropical soils require special approaches that are different from those of temperate zone soils. Malomo (1977) noticed significant degradation of grains of tropical soils from Brazil when the level of mechanical energy is slightly increased (increase in the time of mechanical sieving). The property which he called "mechanical instability characteristics" has been noticed in many lateritic soils from southwestern Nigeria (Adeyemi, 1992). Mechanical instability characteristics is attributable to weak induration of particles caused by coating by oxides (especially iron). This often gives the impression that lateritic soil is rich in coarse fraction when it is not. Meanwhile, coarse grained and well graded soils have been found very suitable for road construction. Grains of many lateritic soils are susceptible to degradation upon application of axle load or when in contact with water on highways. A supposedly 'coarse' grained soil used for road construction may actually be fine grained and this may lead to road failure. Therefore, the adopted approach over the years is that any lateritic soil meant for road construction must thus be soaked in weak Calgon solution for a period of 24 hours after it has been air dried for days or weeks. Calgon (Sodium hexametaphosphate) is a dispersing agent that has the capacity to remove oxides that bind particles together and can also prevent coagulation of fine particles. The wet sieving that follows guarantee correct assessment of the grain size distribution of the soil. This is what the Edunabon manuscripts has made obvious over the years.

Environmental Impact Assessment and Auditing

Engineering Geologists assess the potential environmental impact of engineering projects and propose measures to minimize adverse effects (evaluates and mitigates the environmental impact of construction projects). The assessment is a bid to minimize adverse environmental impacts and promoting conservation of natural resources, ecosystems, and sustainable development practices. This involves conducting detailed environmental impact assessment (EIA) to identify potential negative effects on the geological environment, assessing how infrastructure development might alter natural geological conditions and identifying and proposing measures to minimize adverse effects. Looking at potential changes in erosion patterns, groundwater levels, and soil stability helps to ultimately minimize environmental impact eventually promoting sustainable development. For example, ways to manage erosion or prevent contamination of groundwater resources may be recommended. Waltham and Waltham (2009) noted how Engineering Geology contributes to environmental protection through careful site assessments and sustainable construction practices. Adeyemi (1994) opined that EIA are often executed in five main stages (Fig. 8.).

On the other hand, Environmental auditing (EA) measures the effects and or impacts of a structure that's already in place on the environment. EA is used to, investigate, understand, and identify.

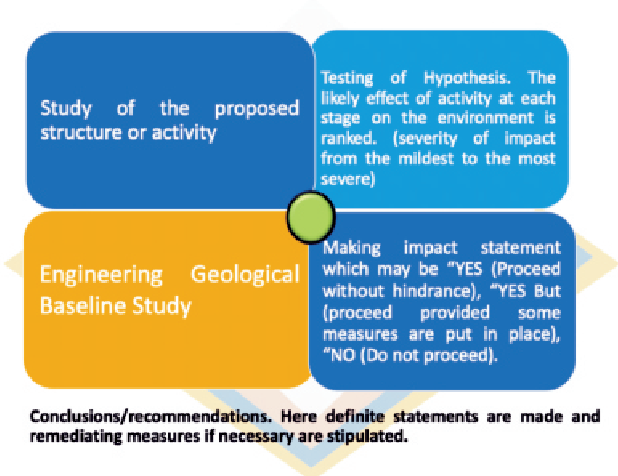

Fig. 8: Stages of Execution of EIA (Adeyemi, 1994)

These are used to help improve existing human activities, with the aim of reducing the adverse effects of these activities on the environment. EA should not be confused with EIA. EIA is an anticipatory tool, that is, it takes place before an action is carried out (*ex ante*). EIA therefore attempts to predict the impact on the environment of a future action, and to provide this information to those who make the decision on whether the project should be authorised. However, EA is carried out when a development is already in place, and is used to check on existing practices, assessing the environmental effects of current activities (*ex post*). EA therefore provides a 'snap-shot' of looking at what is happening at the point in time. This is compared to an established baseline information which existed before the project was executed.

Professor Adeyemi has over the years been involved in EIA and EA for many organizations in many parts of southwestern Nigeria. On Friday, 1 February, 2013, he was in the witness box in a High Court of Oyo Sate as an expert witness for about 30 minutes before he was discharged (Adeyemi 2013). Members of a community in Moniya area of Ibadan southwestern Nigeria, took a quarry operator to court after they had suffered negative impacts on their structures which they linked with the quarrying operation.

Adeyemi and Oyediran (2005) carried out investigation at Aba-Kulodi along Ibadan-Ife highway for location of a landfill. The electrical resistivity survey conducted did not reveal the presence of fractures and confirmed appreciable depth to bedrock and hence availability of large volume for disposal of wastes. Moreover, the results of geotechnical tests which include grain size distribution and plasticity tests revealed that soils are well graded non-plastic soils, a possible indication of no compressibility thereby meeting the standard specification for landfill seals. The soils showed no significant variation in compressibility with no likelihood of differential settlement. However, the fairly high permeability of the soils at the base called for effective in-situ compaction and lining if the site is to be used as a sanitary landfill.

In terms of auditing, Akintola, Adeyemi and Ariyo (2018) assessed the impact of waste dump on the groundwater quality with special reference to heavy metal contamination. Composite groundwater samples were collected from upslope and downslope locations within and some distances from the vicinity of dumpsite. Water samples from downslope location revealed high metal concentrations in comparison to upslope location. Heavy metal concentrations showed reductions with increase in distances from the waste dumpsite. The Contamination Factors of heavy metal concentration and Degree of Contamination in water gave indications that groundwater in study area was moderately contaminated. The study showed that toxic contaminants from waste materials in the dumpsite had analytically contaminated the groundwater.

The consequence of such contamination as determined from the study decreased away from the anthropogenic source (dumpsite). The implication of this was that the contamination of the groundwater was more dependent on the closeness to the dump sites. Lesser dependence has been attributed to topography and hydrogeology of the area, type, state, and age of dumpsite. The moderate degree of contamination of heavy metal in the water further suggests anthropogenic influence of dumpsite on the surrounding groundwater, which course for concern. There is a future risk to the people living in the study area. Therefore, re-designing of the dumpsite to sanitary landfill with clay or plastic liners to prevent future risk and adoption of clean technology for heavy metals are recommended.

Water Management

Management of both groundwater and surface water effectively, preventing structural damage and promoting environmental sustainability are essential aspects of the intervention by Engineering geologists. They begin by evaluating hydrogeological conditions to design effective drainage and dewatering systems, waterproofing measures, and groundwater management strategies. Very practical examples include the siting of waste dumpsites, prevention of water-related issues such as flooding, erosion, and foundation weakening, thereby ensuring the long-term stability and sustainability of structures.

Oloruntola and Adeyemi et al. (2019) used gamma ray logs, lithologic, resistivity, and vertical electrical sounding (VES) to conduct hydro-geophysical studies of the groundwater resource in the Ikorodu area of southeast Lagos. This was done in order to assess the lithologic sequence's lateral and vertical variations and to identify the aquifers that are located in the subsurface. To illustrate the degree of continuity of various strata and assess their hydrogeological relevance in the study area, a total of fifty-three (53) VES were chosen, out of which six (6) traverse lines were chosen. The geo-electric logs along these profiles were then correlated. The alternating underlying layers of clay, sandy clay, "upper" sand, "lower" sand, and ferrugenized sand were visible in both the simulated VES curves and the drill logs. The presence of confined/semi-confined and unconfined/semi-unconfined aquifers, which correlate to the lower and upper sands, was discovered by lithologic, geo-electric, and gamma ray records. The top and lower sands of two aquiferous layers provide the majority of the water needed for domestic use. The lower sand supplies groundwater in the landward area, while the top sand only supports shallow hand-dug wells exclusively around the coastline area. For the purpose of managing groundwater, the study offered some insightful information about the local groundwater resource.

Furthermore, Adeyemi (1991), used remote sensing techniques which are cheap and rapid methods often employed to isolate promising locations for groundwater before subsequent detailed exploration are conducted. He interpreted lineaments and photo-lineaments on radar imagery and air photographs respectively that covered part of the Basement Complex terrain of southwestern Nigeria and established weak but positive correlation ($r = 0.20$) between lengths of lineaments (majority of which are known to represent subsurface fracture) and well yields. However, locations where long lineaments criss-crossed were found to be more promising for groundwater accumulation.

Monitoring and Maintenance of Existing Structures

Once infrastructure is built, Engineering Geologists play a role in ongoing maintenance and monitoring. This is to ensure long-term stability, performance, and safety of structures through continuous monitoring and maintenance of infrastructure. They help identify early signs of geological issues that could affect structural integrity, such as ground subsidence or slope instability. This is done by implementing geotechnical monitoring systems to track ground movement, regular geological assessments and inspections, structural health monitoring technologies, and inspecting structural integrity. This continuous monitoring and timely interventions can prevent minor problems from becoming major failures as early detection and mitigation of potential issues, allows for timely interventions and repairs that extend the lifespan of structures and reduce the need for extensive overhauls.

Adeyemi et al. (2014) investigated the subgrade soils beneath sections of the Ibadan-Ife highway in an effort to determine the component or factors that contributed to the expressway's stability or failure in certain areas. Bulk soil samples from both stable and unstable spots on the Ife bound road and the Ibadan bound carriageway were collected. The soils compacted at West African and Modified American Association of State Highway and

Transportation Officials (AASHTO) levels had their specific gravity, grain size distribution, liquid limit, plastic limit, linear shrinkage, California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS) determined. The amounts of fines in the subgrades varied significantly depending on the soils' degree of laterization. The majority of the soils in the stable sites have medium plasticity, whereas the soils in the unstable sections have higher plasticity. Compared to the West African level, the modified AASHTO compaction characteristics of the examined soils were better. When the soils compacted at both degrees of compaction were soaked, the strength, as expressed in terms of CBR, decreased by more than 60%. Curing significantly increased UCS at both compaction levels, however UCS values were normally higher at the Modified AASHTO level. Groundwater levels are typically higher in the vicinity of unstable sections than they are near stable ones, according to field observations. Thus, the primary cause of the pavement's observed characteristics is groundwater's diminishing influence on subgrade soils.

Adeyemi and Wahab (2008) reported significant variations in the grading, plasticity and CBR characteristics of samples of subgrade soils from Awosun on the Ife/Ibadan highway. Shallow depth to water table was found to be responsible for the failure of the highway. Continuous inundation of subbase and subgrade soils by groundwater can increase its plasticity and weaken its strength. Studies by Adeyemi on many lateritic soils have confirmed that even when the amount of absorbed water is low, lateritic soils often suffer great loss in strength in terms of CBR. Appropriate drainage must therefore be provided if the soils are to be used for road construction.

Informing Land Use Planning

Engineering geologists provide valuable information for land use planning and development. Their assessments help determine the most suitable locations for various types of infrastructure, considering factors like soil stability, water table levels, and proximity to fault lines. This informed decision-making leads to more effective and safer land use.

Geological transition zones are known to be difficult for groundwater potential and development because of their unpredictable and complicated nature, which is also a feature of the underlying lithologies, according to Ariyo and Adeyemi (2016). Due to a dearth of data that could be used as a database to research the groundwater potential of these zones in Nigeria, there have been multiple reports of dry wells and borehole failures. In order to provide baseline data on groundwater potential and to identify different subsurface lithologies that are present for land use planning, their study was meant to produce hydrogeophysical data. Using the vertical electrical sounding (VES) technique, an electrical resistivity survey was conducted for a geophysical study. Using a Schlumberger electrode array, 150 VES stations were purposefully examined (Fig. 9.).

The interpreted data were utilized to create subsurface geoelectric lithologies and to create a geological section that covered the whole region (Fig. 10.). The Basement Complex (BC), Transition Zone (TZ), and Sedimentary Terrain (ST) were identified based on the resistivities of various subsurface lithologies. Topsoil, weathered zone, and fresh bedrock were distinguished in BC. Topsoil, lateritic and sandy clay, dry sand, sandstone, and new bedrock were identified in the ST, whereas topsoil, sandy, laterite/clay, dry sand, and sandstone were identified in the TZ. In summary, the Abeokuta Group's nature and composition, which underlie the sedimentary portion of the research region, as well as the existence of thick laterite/clay unit in the basement complex portion of the area, all have a significant impact on the groundwater potential of the area.

In 2014, Oloruntola and Adeyemi conducted a hydrogeological evaluation of the groundwater resources in a portion of the Abeokuta area. The purpose of the assessment was to identify the origin, chemical properties, and potential for the aquifers to supply portable water. A total of 75 Vertical Electrical Soundings (VES) were dispersed among regions with varying rock compositions. In addition, fifty groundwater samples that were taken from wells and examined for main ions and seventy-two minor elements were included (Fig. 11).

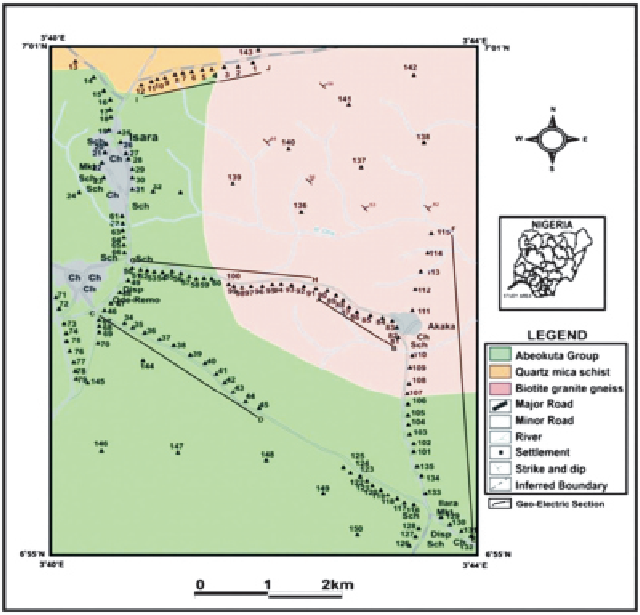

Fig. 9: Geological map showing VES stations and geoelectric sections lines Ariyo and Adeyemi (2016).

From the VES, three to five subsurface geo-electric layers were identified. Lower reflection coefficients (0.82), greater lineament frequencies, higher regolith resistivity (av. 119-167 m), and relatively thick regolith (av. 9.2- 13.76m) were observed in areas underlain by porphyritic granite and porphyroblastic gneiss. High groundwater output and potential were linked (Fig. 12).

Guiding Construction Practices and Safety Assurance

During the construction phase, Engineering geologists monitor geological conditions to ensure compliance with design specifications with the aim of protecting human lives. They ensure that infrastructure is safe for use as they can identify unforeseen geological issues and recommend adjustments to construction methods, delivering that projects are completed safely and on schedule (Kehew, 2006). Engineering projects must meet local and international safety standards and regulations. Proper geological

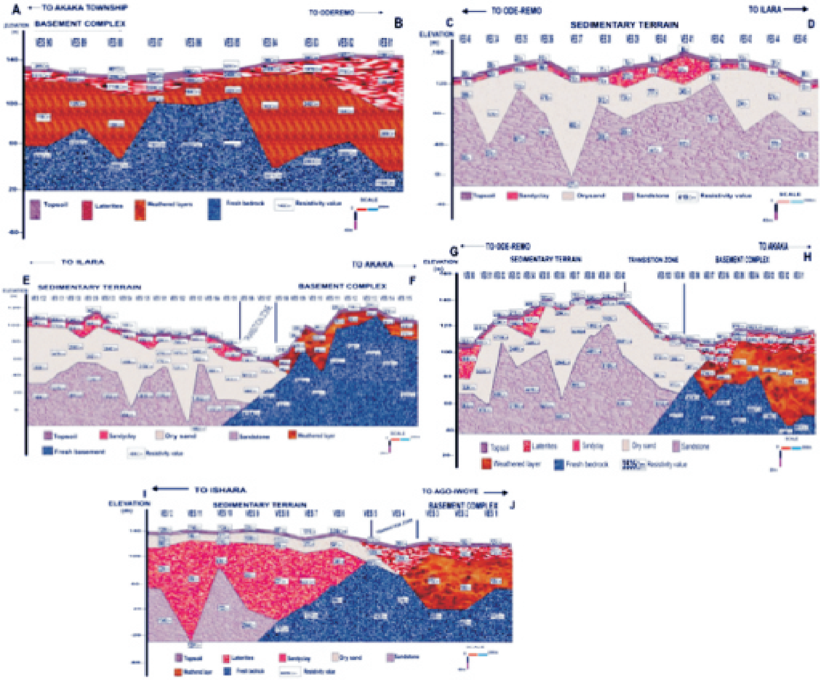

Fig. 10: Geoelectric Section across the study area and transition zone (Ariyo and Adeyemi (2016))

assessments prevent construction failures and natural disaster impacts, safeguarding the lives of workers and future occupants. A good example of provision of guidance for construction is regarding the California Bearing Ratio often used by highway geotechnical engineers to recommend thickness of sub-base. Any CBR test that is not extended to soaked compacted samples is not complete (Adeyemi, 2013). Soaking of compacted samples prior to CBR test would help in determining the amount of water the sample would absorb and how much strength reduction it would suffer if there was ingress of water to the sub-base on highways.

The effects of the Coastal Plain Sand (CPS) and Meander Belt (MB) on the geotechnical characteristics of foundation soils have not been discussed in engineering geological literature, according to Adebisi, Osammor, and Adeyemi (2019). The study used clay

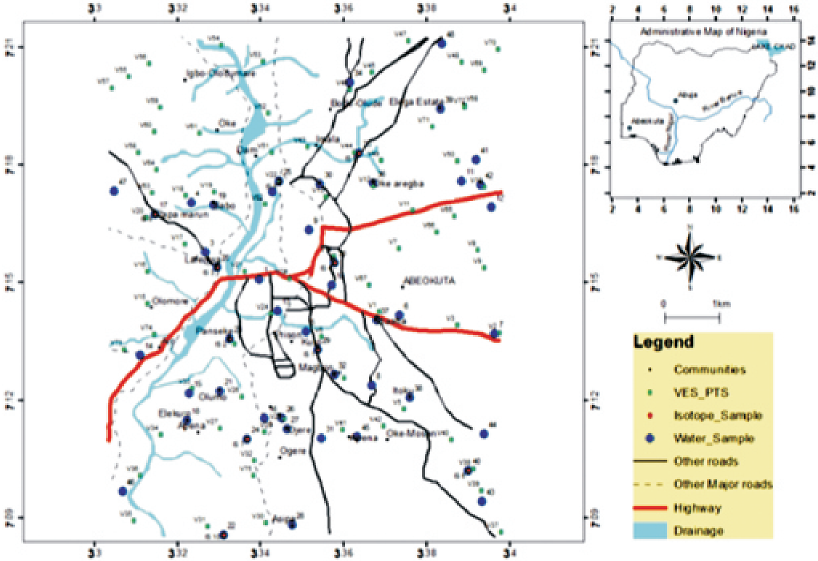

Fig. 11: Study area showing VES and groundwater sampling points (Oloruntola and Adeyemi, 2014).

mineralogy, chemistry, cohesive strength, and moisture content of foundation soils in the two main subenvironments of the southern Nigerian Niger Delta. Lithium elaborate and atomic absorption spectrophotometry (AAS) were used to analyze major oxides, X-ray diffraction (XRD) was used to analyze clay minerals, and scanning electron microscopy (SEM) signals were used to create images for grain interpretation. Cohesive strength and consistency limits of undisturbed and disturbed samples were examined respectively. The foundation materials in the region are the deltaic sediments that underlie the Coastal Plain Sand (CPS) and Meander Belt (MB) regions of southern Nigeria. According to geology, the Miocene – Recent Benin Formation is the oldest and highest type of soil. Soils from the MB area have higher levels of $Fe2O3$ and $Al2O3$ in their kaolinite than soils from the CPS area. In contrast, the CPS soils had significantly more $SiO2$ than than those from the MB regions. The cohesive strength and plasticity index of the CPS soils are considerably impacted by the differences in the amount of illite and

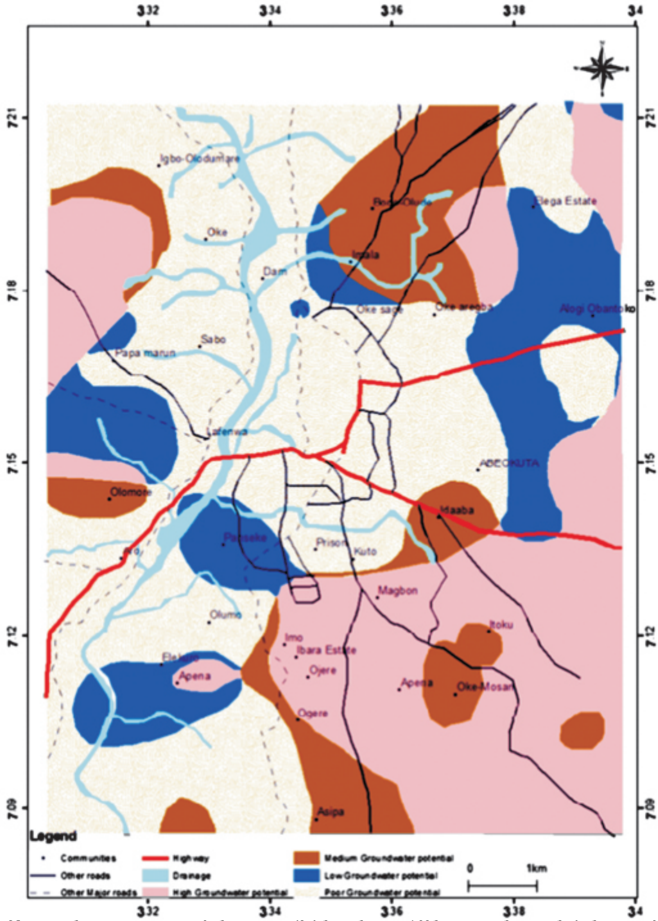

Fig. 12: Groundwater potential map of Abeokuta (Oloruntola and Adeyemi, 2014)

chlorite between the soils from the MB region and the CPS. Quartz grains from the MB range in size more widely than those from the CPS area, according to SEM analysis. Whereas the foundation soils from the CPS area are medium to high plasticity silty clay, those from MB are low to very high plasticity silty clay. In order to carry out problem-free design and construction in the Niger Delta region, it is necessary to be aware of the sub environments and clay properties that may affect the stability of the foundation.

Energy, Cost Efficiency and Geomaterials Modification

Identifying geological conditions and potential issues early in the planning stages can significantly reduce construction costs by avoiding expensive modifications during construction. By anticipating problems and addressing them before construction begins, engineering geologists help avoid costly misadventures and preventing cost overruns. Johnson and DeGraff (1988) outlined how early geological assessments can save costs by preventing unforeseen issues during construction. The whole essence is to enhance the energy efficiency of buildings and infrastructure. This is done by Incorporating geological data into the design of geothermal energy systems, optimizing building orientation, and utilizing natural insulation properties of geological materials. Furthermore, proper assessment of geomaterials helps determine optimal usage and modifications required for such materials. At the end of the day, we obtain reduced energy consumption and lower operational costs, contributing to the overall sustainability of structures.

Drilling mud which is very important in oil, gas, and water drilling operations to suspend rock cuttings, control well pressure, stabilize exposed rocks, provide buoyancy, lubricate and cool the drilling bit is very expensive to get. However, Oyedeji and Adeyemi (2019) evaluated shales around Dange, Northwestern Nigeria as a raw material for drilling mud using its physico-chemical and the rheological characteristics. This was in a bid to turn the hazardous and unwanted material which is noted for being responsible for cracks in buildings and several construction failures (Oyediran and Fadamoro, 2015a, b & c) to beneficial use while promoting cost reduction and energy efficiency. Shales are regarded as problematic, notoriously unpredictable materials because of their propensity for swelling and shrinking under varying moisture conditions and their quick-clay behaviour (Fadamoro and Oyediran, 2020). Oyedeji and Adeyemi (2019) observed the shales are composed of fine-grained materials (mainly clay and silt) which are made up of clay minerals rich in Smectites implying good expansive potential in addition to good sodium exchange potential. In the natural state, the studied shales do not meet the API/OCMA specifications. However, its rheological properties improved significantly on treatment with sodium carbonate thus confirming its suitability as raw material in drilling mud. The observation by the authors shows the potential for energy optimization and cost efficiency using readily available local materials.

Research on stabilization of geomaterials which is a process used to modify their properties to make them useful for a given purpose has been severally undertaken by Professor Adeyemi. Adeyemi (1992) observed that the energy level required to compact a soil to the maximum dry density at a given optimum moisture content increases with its grain size distribution, which in turn depends on the pedogenic factors of parent rock, topography, and climate. Adeyemi and Salami (2004) confirmed statistically significant improvement in geotechnical properties of termite-reworked soils from Ago-Iwoye over those of nearby lateritic soils from identical depths. Adeyemi et al. (2000) also stabilized samples of amphibolite derived soils from Ifewara road, Ile-Ife using varying amounts of lime under different energies of compaction. Addition of lime was found to cause significant reduction in both plasticity and linear shrinkage of the soils. Although both the amount of lime and energy of compaction showed fairly strong positive correlations with the strength of the soils, the influence of the energy of compaction was found to be stronger than that of the amount of lime. Additionally, Adeyemi (2013) indicated that using percentage by volume rather than by weight of stabilizers for stabilization is easier, cheaper and can be replicated even by men with little or no formal education.

Design and Construction of Tunnels and Underground Structures

Provision of infrastructure below the ground surface has become inevitable owing to increasing population and surface decongestion measures. Therefore, Engineering Geology plays a crucial role to safely construct tunnels and other underground facilities which have become major means of transport in the advanced countries. Processes involved include Geological mapping, rock mass characterization, and stability analysis. This is aimed at providing safe and efficient construction of underground structures that can withstand environmental and geological stresses over time. In other parts of the world, underground excavations, and tunnelling practice has been put to great use to ease transportation and other issues. Great examples exist around the world including the Channel Tunnel between the UK and France. The Channel Tunnel, (Fig. 13.) also known as the Chunnel, is the longest undersea tunnel in the world. Its section under the sea is 38km long. It is actually composed of three tunnels, each 50 km long, bored at an average 40m below the seabed. They link Folkestone, Kent) to Coquelles, Pas-de-Calais (GETLINK, 2024).

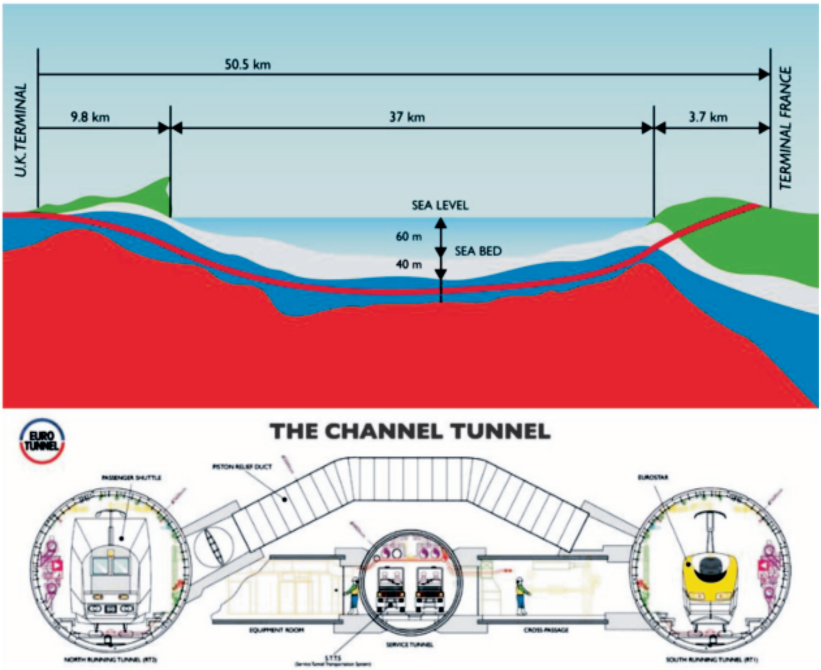

Fig. 13: Cross section of the Channel Tunnel, showing the three-tunnel design (GETLINK, 2024)

The tunnel is made up of three tunnels: two rail tunnels for freight and passenger trains, and a service tunnel for the Eurotunnel Le Shuttle, which carries road vehicles. Constructing a tunnel beneath the English Channel with varying geological conditions was initially seen as a challenge. However, detailed geological surveys and the use of advanced tunnelling machines capable of dealing with different rock types and groundwater conditions were deployed. This brought about a functional and safe underwater tunnel that connects the UK and France, facilitating transportation and commerce. In 2021, around 3.1 billion passengers were transported by subway or metro in the Chinese capital Beijing. The number of people using buses or trams in Beijing was 2.3 billion in that year. The Panama Canal Expansion where they had to deal with complex geological conditions, including soft clay and volcanic rock is another case in reference. Extensive geological investigations and innovative engineering solutions, such as the use of specialized dredging techniques were deployed. The outcome was the successful completion of the canal expansion, enhancing global trade routes. Unfortunately, we are still grappling with surface infrastructure and maintenance in Nigeria.

Supporting Sustainable Development

By understanding the geological environment, Engineering geologists can help minimize the environmental impact of construction projects. Incorporating principles of Engineering Geology promotes sustainable development by ensuring that infrastructure is built to last while minimizing its environmental footprint. This includes preserving natural landscapes, protecting water resources, selecting construction materials that are environmentally friendly and ensuring that these construction materials are sourced sustainably. Processes involved include geological assessment of local materials, such as aggregates for concrete, to ensure they meet engineering standards while minimizing transport distances and environmental impact. Sustainable practices in Engineering Geology contribute to long-term environmental health and resource conservation. It aids in the development of resilient infrastructure capable of withstanding natural hazards and changing environmental conditions. Furthermore, it helps with reduced carbon footprint through the use of locally sourced, sustainable materials that contribute to the durability and longevity of structures. Understanding geological resources aids in the sustainable extraction and use of materials.

Ojo and Adeyemi (2003) highlighted the need for geoscientists to show more interest not only in exploration but to invest and coordinate exploitation of construction materials such as lateritic soils, gravels, sands and rock aggregates. They discussed the investment opportunities attached to the construction materials found in abundance in southwestern Nigeria where they are found in commercial quantities and what they can be used for. Moreover, the authors revealed the cost effectiveness in terms of exploration and exploitation of these construction materials, mining rights and some environmental issues associated with mining to ensure that owner communities do not become victims of the endowed resources. They further reiterated that investment in solid minerals such as sands, gravels, laterites and quarry products will certainly lead to mining of export materials, establishment of local industries which can in turn transform into a more diversified and stable economy, employment opportunities and poverty alleviation.

Conclusion

I would like to copy copiously and highlight the findings of a mapping exercise conducted by scientists at Arup and the British Geological Survey (BGS) to systematically review all 169 UN Sustainable Development Goals (SDGs) targets and related indicators against typical Engineering Geology knowledge, skills, and activities in order to wrap up this presentation and better understand the contribution of Engineering geologists to the UN Sustainable Development Goals (Fig. 14). They came to the conclusion that 107 of the 169 targets (63%) may be connected (directly or indirectly) to Engineering Geology knowledge, skills, and activities.

Of the 17 SDGs, Engineering Geology contributes most

Fig. 14: The United Nations Sustainable Development Goals (United Nations 2022).

overall to five of them (Fig. 15.):

- SDG 7 (clean and cheap energy): connected to 100% of objectives
- Industry, innovation, and infrastructure (SDG 9): associated with 88% of targets
- SDG 12 (responsible production and consumption): associated with 82% of SDGs
- Sustainable cities and communities, (SDG 11), is associated with 80% of the targets.
- SDG 13 (action on climate change): associated with 80% of goals

According to the study, Engineering Geologists play a significant role in developing infrastructure, fostering resilience, lowering the risk of natural disasters, protecting the environment, creating equitable communities, and forming strong, cooperative partnerships—all of which are crucial to the realization of sustainable development on a worldwide scale.

To capture the role played and importance of this very special group of people, Marcus Dobbs, a Senior Engineering geologist at the British Geological Survey noted that:

> With their extensive domain understanding of natural systems and processes, engineering geologists and more broadly geoscientists are highly qualified to address environmental and socioeconomic issues. He went on to say that despite the special abilities and expertise held by geoscientists, they have historically been underrepresented in the international discourse on sustainable development.

Nigeria as a country has gotten to a stage where we cannot continue to pay lip service to the vital role played by Engineering Geologists albeit Geologists in the delivery of sustainable structures. Our roads keep failing, our buildings keep coming down, we refuse

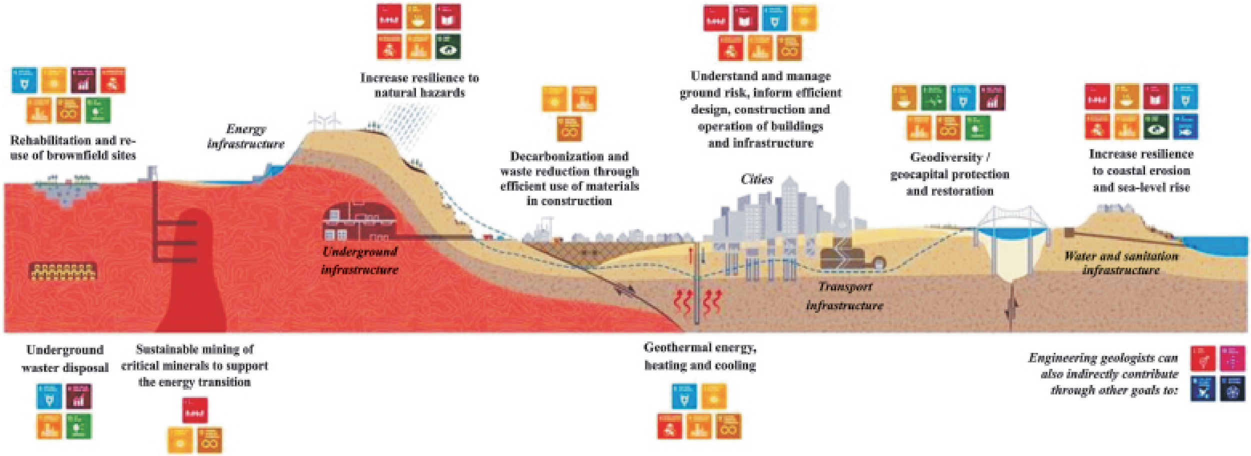

Fig. 15: Conceptual ground model showing the contributions of engineering geology to sustainable development (Lagesse *et al.*, 2022)

to consider the environment in emplacement of structures. We design beautiful structures without recourse to material suitability, bearing capacity, environmental impact, and sustainability. We obviously have no value for human life and place more premium on quantity rather than quality. How do we walk and move forward when we have refused to crawl and take care of the basics?

Summarily, Professor Adeyemi's course notes and instructional materials (which form an important part of the Edunabon manuscripts) which has over the years been passed from set to set and served as the main guide for students and cited in Adeyemi (2013) indicates the Importance of Engineering Geology to include the following:

1. Subsoil investigation for structures such as buildings, dams, roads/highways, bridges, and tunnels. Data generated from geological, geophysical, and geotechnical studies are often used for foundation design for stable structures (buildings, dams, roads and bridges and tunnels) some of which can be quake resistant.
2. Location and evaluation (qualitative and quantitative) of naturally occurring construction materials such as clays, lateritic soils, sands, gravels, and quarry products. Quarry products are used as foundation, dimension stones, ripraps for dams and railroad ballasts.
3. Open cast and deep mining of solid minerals such as gold, cassiterite, iron ore, coal, tar sand, marble, and limestone.
4. Drilling for water and hydrocarbons. An Engineering geologist can provide technical advice which can prevent caving of holes during drilling.
5. Environmental impact assessment involving engineering geological baseline studies can help in making impact statement for installation of a proposed structure or execution of a proposed activity in an area.
6. Environmental auditing involves assessment of the impact of a structure or activity on the environment.
7. Evaluation of proposed waste disposal site. Data generated

from engineering geological investigations can help in locating favorable sites for disposal of wastes.

8. Prevention of natural hazards such as landslides, subsidence, flood and erosion
9. Urban and Regional planning. Engineering Geological studies can help in demarcating where certain structures can be installed.

By ensuring that geological conditions and processes are fully considered, Engineering Geology helps to create structures that are safe, durable, resource-efficient, and environmentally responsible, contributing to the well-being, progress of society and a sustainable built environment. In essence, it is indispensable, and Its importance cannot be overstated in the realm of civil engineering and infrastructure development.

Acknowledgements

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Web Resources

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NIGERIAN ASSOCIATION FOR ENGINEERING GEOLOGY AND THE ENVIRONMENT

ABOUT US

NAEGE is a specialist group of Nigerian Mining and Geosciences Society (NMGS) established to promote the development and application of geosciences and related engineering roles, promote innovation and create enabling environment to foster the role of engineering geology in sustainable development and public safety, fellowship and cooperation between those working in, studying or otherwise being interested in these fields.

Mission

The primary mission of the Association is to promote the interest, development and application of geosciences and allied environmental geosciences, to promote innovation and technical progress and to foster the communication, fellowship and cooperation between those working in, studying or otherwise being interested in these fields.

Objectives

The objectives of the Association shall include the following:

1. To provide a platform for meeting of all Engineering Geologist and allied Environmental Geoscientists;
2. To prescribe a code of ethics for the practice of the profession;
3. To standardize the qualifications of practicing persons in the profession;
4. To encourage data collection, research and dissemination of information on Engineering Geology and the Environment;
5. To advise the government and the public on the need to control the engineering, geologic and environmental investigations;
6. To harness funds and support from government and other bodies in their involvement towards the growth of Engineering Geology and the environment;
7. To cooperate with other allied professional bodies connected with Geotechnical practice;
8. To nominate any member or members as arbitrators or investigators on geotechnical failures and or problems whenever necessary;
9. To establish for and or facilities for
   (i) Annual international conferences and AGMs of the society;

(ii) Organization of symposia, workshops and trainings on problems involving Geotechnical and Environmental Practice in Nigeria from time to time;
(iii) Publishing of journals, proceedings of annual conferences, symposia, workshops, seminars and engineering geologic and environmental papers;
(iv) Advising on curricular development on the training of Engineering Geologists in Nigerian Higher Institutions;
(v) Collaborating with the Council of Nigerian Mining Engineers and Geoscientists to monitor and enforce the adherence to codes, ethics, and regulations regarding the practice of engineering Geology;
(vi) Any other functions necessary for the growth of the profession.

HISTORY

NAEGE was founded in 1976 by a team of distinguished personalities headed by Late (Prof.) E.S. Meshida. Later, Prof. C.O. Okogbue became the second President and was succeeded Prof. S.C. Teme. These professionals worked tirelessly in conjunction with the team members to lay a solid foundation for the growth of the Association. NAEGE and its successor reached out first to engineering geologist / geotechnical engineers, and later broadened its platform to environmental scientists. There were watersheds for 25 years between 1987 – 2012. The repositioning and internationalization of NAEGE took place under the leadership of Prof. Gabriel O. Adeyemi as President between March 2013 and September 2017. The series of meetings held in various parts of Nigeria such as Abuja, Ibadan, Lagos, Port Harcourt, Enugu, etc. under his leadership eventually led to the first conference held at the Lagos Airport Hotel, Ikeja in 2016 and got the Association registered with the Corporate Affairs Commission of Nigeria.

The evolution of NAEGE, its growth and structure, perfectly reflects the emergence of geoscience and its inter-relationship between the academic, industry and international body. During the Nigerian Mining and Geoscience Society (NMGS) Annual Conference held in Ilorin in 2016, the then Vice President of IAEG Africa,Prof, Louis Van Rooy, interacted with members of NAEGE to solidify relationship with the international body. This resulted in the invitation of the then President, Prof. G.O. Adeyemi to the 1st IAEG Africa Regional Annual Meeting held in Cape Town, South Africa in 2016. The 2nd and 3rd IAEG

Africa Regional Congress were subsequently held in Nigeria (Abuja & Lagos) in 2019 and 2022 respectively.

The years between the first organized annual conference in Ikeja, Lagos in 2016 and the present have established phenomenal progress in geoscience practice which is always, very challenging. Nevertheless, we have always overcome by immense benefit to members, scholars and practitioners (professionals). Also, communiques produced after series of brainstorming sessions are always made available to relevant government agencies for consideration and implementation.

The table below recaps the locations of the Annual Conferences held and thePresidents leading the Association through the years.

2024	**2023**	**2022**
9th ANNUAL CONFERENCE PORT HARCOURT	8th ANNUAL CONFERENCE MINNA	7th ANNUAL CONFERENCE LAGOS
Engineering Geology for Sustainable Highway Pavements and Buildings in a Changing Global Climate	Sustainable Infrastructure and the Environment: The Role of Environmental and Engineering Geology	Engineering Geology: Imperative for Infrastructural Development and Sustainability of Cities in Africa
Dr. Waliu O. Adeolu	**Dr. Waliu O. Adeolu**	**Dr. Waliu O. Adeolu**
2021	**2020**	**2019**
6th ANNUAL CONFERENCE IBADAN	5th ANNUAL CONFERENCE VIRTUAL	4th ANNUAL CONFERENCE VIRTUAL
Geosciences for Sustainability of Structures and the Environment	Environmental & Engineering Geology as invaluable tools for Sustainable Infrastructural Development	Environmental and Engineering Geological Mapping for Sustainable Development
Prof. Moshood N. Tijani	**Prof. Moshood N. Tijani**	**Prof. Tamunoene K. S. Abam**
2018	**2017**	**2016**
3rd ANNUAL CONFERENCE PORT HARCOURT	2nd ANNUAL CONFERENCE LAGOS	1st ANNUAL CONFERENCE LAGOS
Engineering Geology for Sustainable Development	Sustainability of Building and the Environment	Sustainability of Infrastructure and the Environment
Prof. Tamunoene K. S. Abam	**Prof. Gabriel O. Adeyemi**	**Prof. Gabriel O. Adeyemi**

Today, NAEGE members are involved in diverse fields of geosciences such as:

- •Pre-construction foundation investigation for structures such as buildings, roads, bridges, dams, etc.;
- Ground investigation and rock works application;
- Environmental Impact Assessments;
- Safe disposal of waste especially with respect to geotechnical assessments of landfill sites;
- Evaluation and location of naturally occurring construction materials;
- •Prevention of Natural hazards such as assessment of slope stability design and landslide prevention;
- •Geoenvironmental mapping of landuse in infrastructural planning, among others.

The Association has given birth to seven Chapters such as Lagos, Ibadan, Port Harcourt, Abuja, Minna, Ilorin and Enugu. Plannings and consultationsare underway for the formation and inauguration of many more Chapters in other parts of the country.

The Association acknowledges the contributions of its founding members such as Late Prof. Ebenezer S. Meshida, Late Prof. Siyan Malomo, Emeritus Prof. Celestine Okogbue, Prof. So-ngo Teme, Prof. Gabriel Adeyemi, Prof. Tamunoene Abam, Prof. Moshood Tijani, Prof. Abel Olayinka, all past and present members of the Executive, all Fellows of NAEGE, Corporate members and all well-wishers that have generously supported the activities of NAEGE over the years.

Types of Membership

i. **Fellow Membership:** Conferred upon active members who are distinguished in service for the growth of the Association.

ii. **Corporate Membership:** For professionals involved in geoscience field.

iii. **Student Membership:** For undergraduate in geoscience field.

iv. **Honorary Membership:** Conferred upon those who have made significant and distinguished contribution to geoscience and engineering community. In addition, former presidents are to be awarded honorary membership in recognition of their service.

v. **Retired Membership:** Member of the Association who have been involved in geoscience and engineering for at least 30 years, older than 70 and retired.

Membership Benefits

By joining the **Nigerian Association for Engineering Geology and the Environment** you will become part of our international community. Membership of NAEGE comes with a variety of services and benefits. Furthermore, long term members gain additional perks through our **Recognition Programme** as their engagement with NAEGE grows.

i. **Discounts on All NAEGE Events:** Members can benefit from **special rates for all NAEGE's conferences, workshops and educational programmes**. Throughout the year, NAEGE offers an extensive range of events for members to engage in, both online as well as in person. These include our conferences such as the Annual Conference & Exhibition, chapter meetings and specialized workshops.

ii. **Free online journal subscription:** NAEGE members gain access to the online versions of all IAEG bulletins and electronic newsletters and opportunity to apply for IAEG summer school. Student also have access to the archive of the journal.

iii. **Learning Geoscience:** NAEGE members will gain access to online learning geoscience through e-courses, e-lectures and webinars. This is one thing to look forward to.

iv. **My NAEGE Members Only Platform:** All members will have access to the Members Only section (including Member search) on the NAEGE website. This section includes a member search that allows members to find each other and get in touch. Members will get a login name and can choose a password in order to access this part of the EAGE website.

v. **Mentoring Programme:** This is designed to allow for an informal engagement between the senior members with a well-established career and the next generation of leaders in the industry and academia. It is meant for any special interest communities.

vi. **NAEGE Membership Recognition Programme:** The NAEGE Membership Recognition Programme will be launched to recognize the loyalty of our members and the value they bring to the Association. The programme will offer a number of additional benefits based on the number of years you have been with the Association.

vii. **Eligibility for Financial Support:** NAEGE will offer support to members through Economic Hardship Programme.

SUPPORT

We offer a special support programme for those facing difficulties raising the regular fees: this includes the possibility to apply for a membership fee discount **for all types of membership**, as well as waivers and contributions to educational expenses for EAGE members. T & C apply.

Membership Recognition Programme

This programme recognize the loyalty of our members and the value they bring to the Association. The Programme offers a number of extra benefits to those renewing their membership based on the number of years they have been with the Association. The benefit begins after first year of membership.

Definition of NAEGE Membership Status

Green:	1 year of membership
Bronze:	2 - 4 years of membership
Silver:	5 - 9 years of membership
Gold:	10 - 14 years of membership
Platinum:	15+ years of membership.

NOTE:

- Honorary members and ex-Presidents are granted Platinum for Life membership.
- Green membership status has a discount on the non-member fee for each event registration.
- Bronze membership status can benefit from an even greater reduced member registration fee.
- Regular membership renewal increases a member's Membership Recognition Level.

NIGERIAN ASSOCIATION FOR ENGINEERING GEOLOGY AND THE ENVIRONMENT

www.naege.org

OVERVIEW

N**AEGE** is a specialist group of **Nigerian Mining and Geosciences Society (NMGS)** established to promote the development and application of geosciences and related engineering roles, promote innovation and create enabling environment to foster the role of engineering geology in sustainable development and public safety, fellowship and cooperation between those working in, studying or otherwise being interested in these fields. NAEGE is affiliated internationally to the **International Association of Engineering Geology (IAEG)**.

MISSION

The primary mission of the Association is to promote the interest, development and application of geosciences and allied environmental geosciences, to promote innovation and technical progress and to foster the communication, fellowship and cooperation between those working in, studying or otherwise being interested in these fields.

CORE OBJECTIVES

- **Provision** of platform for meeting of all Engineering Geologists and allied Environmetal Geoscientists;
- **Encouraging** data collection, research & dissemination of information on Engineering Geology and the Environment;
- **Advising** government & the public on the need to control the engineering, geologica and environmental investigations;
- **Prescribing** code of ethics and standardize the qualifications of persons for the practice of Engineering Geology & Environmental Geoscience.

MEMBERSHIP TYPES

Student | Graduate | Corporate | Fellows
Affiliate | Institutional | Honourary

BECOMING A MEMBER

Kindly Contact Us Via: ***website:*** www.naege.org
e-mail: secretariat@naege.org | naegesecretariat@gmail.com