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Environmental Sustainability of Pile Construction Activities in Nigeria; Strategies and Best Practices

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Abstract: *Pile construction activities is a multifaceted activity among the construction activities that are performed by heavy machines, materials and energy sources generating environmental impacts associated with pilling activities such as carbon emissions, noise, heavy vibration, soil instability and groundwater pollution. Sustainable piling construction guarantees that the whole piling process meets environmental sustainability and ultimately human health and wellbeing. Data were gathered through a questionnaire survey administered to construction professionals including engineers, project managers, surveyors, and builders. Out of the 50 questionnaires distributed, 41 responses were analyzed. The study employed the Relative Importance Index (RII) to rank the effectiveness of various strategies in mitigating environmental impacts. The findings underscore the critical role of introducing low-emission machinery and optimizing operational hours in reducing carbon emissions. Noise management was most effectively achieved through alternative pile installation methods combined with regular equipment maintenance. Maintaining adequate setbacks from structures and employing controlled installation techniques were identified as essential strategies to mitigate vibration. Addressing soil instability was found to rely heavily on thorough site investigations and the implementation of effective ground stabilization* *techniques and preventing groundwater pollution requires the proper use of drilling fluids and diligent site management. These findings contributed to the development of environmentally sustainable practices in pile construction, emphasizing the importance of comprehensive strategies to mitigate the adverse environmental impacts of such activities in Nigeria.*

Keywords: environmental sustainability, pile construction, stabilization techniques.

INTRODUCTION

The rapid economic and industrial growth in the past few years has brought about diverse environmental problems, which are fast-degrading the environment (Islam & Shuwei, 2023). Rising emerging nations have a greater prevalence of environmental challenges ranging from noise, soil, radioactive, chemical, waste, and water pollution. Industrial and commercial activities are the leading cause of environmental degradation. As part of industrial activity, construction projects have also been a contributing factor. The activities involved in construction such as piling operation, excavation, demolition, vibration can have devastating effects on the environment if not managed sustainably. Measures that will ensure the use of the best practicable means to reduce public nuisance effects should be instituted to address the concerns of nearby residents and the general public (Ayarkwa et al., 2014). These activities require specialized equipment that produces noise, carbon dioxide, and heavy vibrations. The role construction projects play in the nation's economic growth cannot be ignored. However, Environmental sustainability and resource efficiency must be given priority in technologies that are promoted by nations to encourage eco-friendly inventions while mitigating their detrimental effects on the environment, this involves supporting clean technologies, sustainable practices, and policies.

In Modern times, environmental Sustainability has been a primary concern in the construction industry. Statistics have clearly shown that every nation is experiencing some negative consequences as a result of construction-related side effects (Ojo *et al*., 2015). Li *et al*., (2018) stated that sustainable construction operates on three pillars in terms of industry performance: economy, society, and environment. For piling, sustainable construction concentrates on minimizing material use, energy use, waste production, noise, and ground impact (Ametepey *et al.*, 2015). Sustainability practices in piling construction must be taken seriously (Liu, et al., 2022; Basu & Lee, 2022)..

Pile foundation is an important part of a construction project. A large number of buildings worldwide are supported by pile foundations due to the immense load or low bearing capacity or both (Ayeldeen & Negm, 2015). Pile foundations can be classified into displacement and non-displacement piles. Displacement piles are also called driven piles, they are usually pre-casted and driven into the soil with special equipment which tends to displace the soil as it moves down the strata while non-displacement piles use the method of drilling or boring, the soil in the drilled path

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are excavated out during operation which causes little or no displacement in the soil. Although the method of installing these piles might differ, it is not possible to decide which design method is superior to the other. However, the site condition and applied load determine the selection of the methods to use but when both methods are feasible it depends on the designer's preference (Lee & Basu, 2018). Studies have shown that the choice of selecting a specific type of pile has environmental consequences.

Based on the method used (i.e. driven or bored) and the overall quantity of materials which is dependent on the pile depth and diameter, the amount of energy and raw materials used, and the amount of pollutants released throughout a single pile operation may differ. Bentonite slurry is a necessary material in bored pile foundations. If not properly managed on-site, it makes the construction site look messy and untidy. Improper mixing of bentonite can affect groundwater during operation and it has also been studied by Masoudi *et al*., (2020), that increased concentration and long-term exposure to bentonite nano-particles can cause damage to lung tissue using rats as a model. Another environmental impact is the vibration generated by pile machinery during operation. It propagates through the ground and interacts with the surrounding structures which may cause further settlement or cracks in buildings. It often disturbs occupants and causes unease in nearby aquatic life (Turkel, 2023; Cones et al., 2022; Yi et al., 2020). Noise pollution is a general occurrence during pile operation. However, the intensity differs depending on the method being used. Driven piles create more noise during operation than bored piles and can affect surrounding occupants. According to Sandanayake *et al*. (2015), pile construction requires the use of large machinery, energy, and materials that generate a high rate of CO_2. Studies on these environmental issues are important to mitigate the consumption of natural resources and energy and to increase awareness of the relationship between design safety and environmental impact (Lee & Basu, 2018). Integrating environmental sustainability, a necessity for sustainable development, decreases negative environmental effects associated with construction projects.

Pile Construction Practices

Pile foundation is a series of columns inserted into the ground to sustain and transfer loads from superstructures to deep soil, in either case, the load from the superstructure is very high or the soil at shallow depth is too weak (Alebachew & Gui, 2021). It is mostly used when the bearing capacity of the topsoil is weak to carry the design load of a superstructure. Pile construction projects are usually executed in three steps: pre-piling operations, piling operations, and post-piling operations. Pre-piling operations are the first stage in executing piling projects. They are carried out when the contract has been awarded, and the program of works has been approved. It involves the approval of the building footprint and perimeter survey, soil test and soil analysis, pile point set out, mobilization of equipment, installation, and testing of the trial pile. Piling operations start immediately after the pre-piling works have been confirmed and have met the necessary requirements. This is the stage where the actual piling activities are being done with the approved method of installation. The duration of construction depends on the number of piles to be installed.

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The post-piling operation is the last phase of pile construction. They are carried out to ensure that the installed piles satisfy the necessary specifications and are ready to support the superstructure. The activities during post-piling operations include a Pile integrity test, pile load test, and as-built survey. Quality assurance results and documentation are also being issued during this phase. All these stages in pile construction are necessary to ensure a stable, durable, and safe foundation for structures. Each execution stage plays a critical role in the overall success of the pile installation and contributes to the structural integrity of the final construction (Elizaveta *et al.,* 2020).

Causes and effects of environmental impact due to pile construction practices

Carbon emission

CO_2 emissions during construction happen to be one of the major problems in developing countries, which influences climate and environment. Considering the causes of these emissions, it is important to investigate their effects on climate and then provide tactical solutions to alleviate possible detrimental consequences. The increase in CO_2 has become the agreed level above which the consequences of climate change will become dangerous. The impact of these actions on humankind will be pervasive and lead to disruptive weather disasters, agricultural production instability, and public health challenges (Labaran *et al.*, 2021).

Increasing construction activities will expose CO_2 emissions, which could alter various natural events like changes in sea levels. The production of various construction materials, such as cement, steel, and other significant materials, has carbon footprints due to the processes involved. According to a report by the UN Environment Programme (UNEP, 2023), the buildings and construction sector are the widest emitter of all greenhouse gases, accounting for a staggering 37% of global emissions. (Dyson *et al.,* 2023). The use of different heavy machinery during pile construction impacts the production of CO_2 emissions. Emission rates from pile construction using piling rigs and concrete pumping trucks are the highest although excavator emission rates are higher for carbon monoxide and particulate matter (Sandanayake *et al.*, 2015).

Vibration

Bored piles, especially CFA, are the most popular method of pile installation, particularly in urban environments like Lagos, Nigeria, where soil conditions require deep foundations. However, their installation can generate significant vibrations that may cause further settlement or cracks in surrounding structures and soil (Liu et al., 2020; Wang et al., 2019; Chen et al., 2017). Below are some of the causes of vibration during the construction of bored piles, which can better be explained in Fig 1;

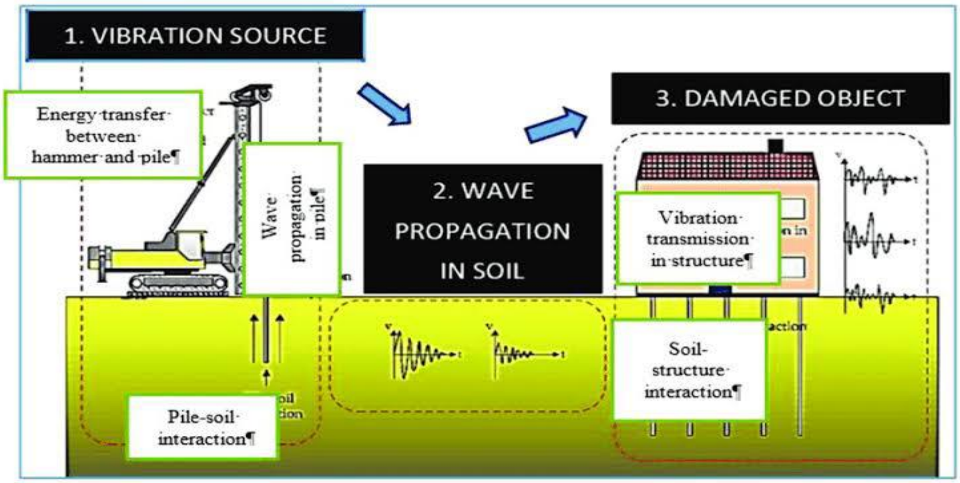

Fig 1: *Schematic illustration of vibration transfer during pile installation (Rahman et al., 2017)*

Noise Pollution

Any unwanted sound that is loud, unpleasant, and disturbing is referred to as noise. Continuous operation and exposure to drilling and excavation machinery equipments can significantly affect the machine operators (Zaiton et al., 2014), movement of construction materials and equipments such as handling trucks, cranes, and other heavy machinery create additional noise, particularly in the early morning or late at night, which can disturb the peace of nearby residents (Yi *et al.,* 2020).

Soil Instability

Soil instability threatens to weaken the foundation quality, resulting in environmental deterioration and ultimately culminating in structural failure (Dastpak et al., 2023; Roy et al., 2023). Soil instability is a vital part of any construction project and is essential to understand for developing mitigation strategies so that construction remains standing such as different types of soils (clay, silt, and sand) responding differently from the activities performed during construction. Instabilities often in saturated or elastic soils collapsed (Lalicata, 2021), the installation of driven piles, a large amount of soil is displaced laterally and vertically. This displacement may result in increased soil lateral pressures and instability of nearby regions (Yan et al., 2021), stress redistribution which can cause settlement or heave in the adjacent soils (Abdel-Rahman, 2021), soil loosening also occurs during pile drilling, it lowers the soil's stability and bearing power.

Groundwater Pollution

Wastewater from construction sites creates severity to the environment as it can harm or even disrupt the entire ecosystem (Joshi et al., 2021), understanding the primary factors contributing to groundwater pollution is crucial for developing sustainable construction practices (Abanyie *et al.*, 2023).

One of the primary sources of groundwater contamination in pile construction is the use of drilling fluids. According to Hemadasa *et al.*, (2022), these fluids, typically composed of bentonite, are essential for lubricating the drill bit, stabilizing the borehole, and carrying cuttings to the surface. Hence, if not adequately contained, these fluids can infiltrate groundwater aquifers, introducing harmful substances such as heavy metals and organic compounds. Construction debris, including soil, concrete, and other materials, can contribute to groundwater pollution (Kong & Ma, 2020). When mixed with rainwater, these materials can produce leachate containing various contaminants and the infiltration of this polluted runoff into the ground can degrade groundwater quality as studied by Powell *et al.,* 2015.

Environmental sustainability of pile construction

Environmental sustainability is essential for enabling human development while protecting our natural resources. The sustainability of construction projects has become increasingly important, especially since the depreciation of our natural habitats. Implementing sustainable development in the construction industry brings about sustainable construction. (Shan *et al.*, 2017). According to Saravanan (2011), during the 2008 construction industry recession in the United Arab Emirates (UAE), sustainable methods in piling construction were crucial in achieving competitive advantage through cost-effectiveness, performance efficiency, and sustainability. Several best practices and strategies can be employed to mitigate the effects of environmental impact on the built environment during pile construction. These include pre-construction surveys and monitoring, selection of appropriate drilling methods and equipment, regular equipment maintenance and inspection, and implementation of green technologies. The use of low-energy electric machinery manages and controls the amount of carbon emissions during pile construction. Noise levels can be considerably lowered by investing in contemporary construction equipment that runs more silently. Manufacturers provide equipment with vibration dampers, acoustic enclosures, and mufflers to reduce noise. In urban locations where construction activities are taking place near sensitive receptors, noise reduction measures and vibration-isolating materials or systems should be implemented.

As the construction industry is tremendously growing, it is clear that embracing environmental sustainability during pile construction activities plays a crucial role in promoting a healthy relationship between human development and the environment. Environmental sustainability helps create conditions for a more sustainable future.

Problem Statement

Nigeria as a developing country is experiencing rapid infrastructural development. The country is investing heavily in infrastructure such as bridges, high-rise buildings, roads, and other utilities to support economic growth. In all of these, pile foundation is a crucial element to execute these projects. Pile construction activities have become a major contributor to environmental problems when it comes to construction projects. The activities involved in pile construction cause environmental problems ranging from noise, vibration, waste, and air pollution. The absence of sustainable practices during pile installation not only harm the environment and the communities but also undermines the economic and operational efficiency of construction projects in the long run. Therefore, there is a need to implement sustainable piling construction practices for different environmental conditions to minimize environmental impact in Nigeria.

METHODOLOGY

Data Acquisition

This study gathered data using a quantitative research methodology, which entails obtaining, transforming, and analyzing data into numerical form to draw statistical findings. The literature review was used as a secondary source to state some factors that might impact the environment during piling activities. These factors were considered in the questionnaire survey administered directly to professionals across construction industries to provide the strategies and best practices to enable environmental sustainability during pile construction. This data source is considered a primary source since the information was collected from a direct source. The professionals administered the questionnaires included engineers, project managers, surveyors, and builders with relevant knowledge of pile construction in Nigeria's construction field. As Ikart (2019) stated, a questionnaire survey facilitates data collection from many respondents dispersed over an extensive geographic area briefly regarding a predetermined research problem. The survey had closed-ended and open-ended questions to gather direct and quick responses and encourage the respondents to give free responses (Antwi & Kasim, 2015). Fifty questionnaires were distributed among respondents, and forty-one responses were received and analyzed. Their years of experience and academic qualifications were also considered, as illustrated in Table 1.

Table 1: Respondent background table

Respondent	**Percentage**
Professionals	
Engineer	53%
Project Manager	20%
Builder	17%
Surveyor	10%
Academic Qualification	
B.SC/B.TECH	51%
M.SC/M.TECH	20%
HND	15%
PH.D	12%
ND	2%
Years of Experience	
11 to 15 years	27%
16 to 20 years	12%
5 to 10 year	27%
Less than 5 years	34%

A relative importance index (RII) was used to rank respondents' responses and determine the importance of the question asked. According to Wilfred and Sharafudeen (2015), RII is a well-known statistical method used to rank and evaluate the relative relevance of various attributes. The best strategies and practices to ensure environmental sustainability during pile construction in Nigeria were determined according to the RII calculated using Equation 01.

$$RII = \frac{\sum \quad Z.n}{Q.N} \qquad (01)$$

Where;
Z= response weight ranging from 1-5
n = Frequency of response for a factor
Q = highest weight
N = total number of responses

ANALYSIS AND DISCUSSION

Respondent's View on The Causes and Effects of Environmental Impact During Pile Construction

A descriptive analysis was conducted on the respondent's perceptions regarding the causes and effects of environmental impact during pile construction. The causes and effects highlighted in Figure 2 and Figure 3 were identified in the literature review survey. In addition, respondents were also encouraged to cite additional factors contributing to the environmental impact that they have experienced.

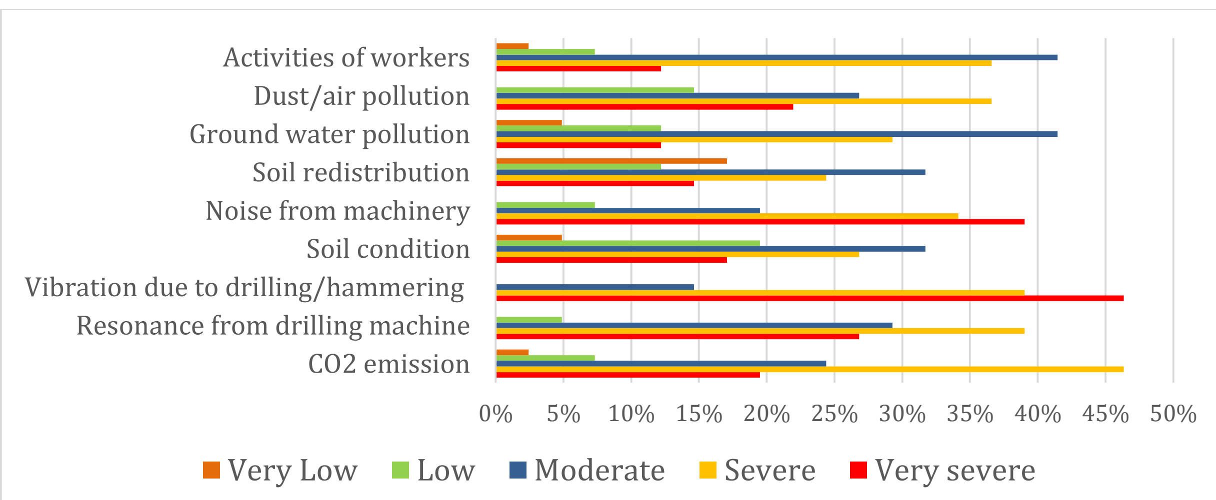

***Figure 2**: Respondent's view on the causes of environmental impact during pile construction in Nigeria*

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From Figure 2, it was observed that the respondents mostly identified 3 major factors that are highly responsible for the environmental impact during pile construction, namely, vibration due to drilling/hammering, Noise from machines, and carbon emission having about 46% very severe, 39% very severe and 45% severe respectively. Workers ' activities, groundwater pollution, and soil redistribution are considerably moderate. Also, dust/ air pollution and resonance from drilling machines are almost equal in severity and moderate, possibly due to some respondents' neutrality.

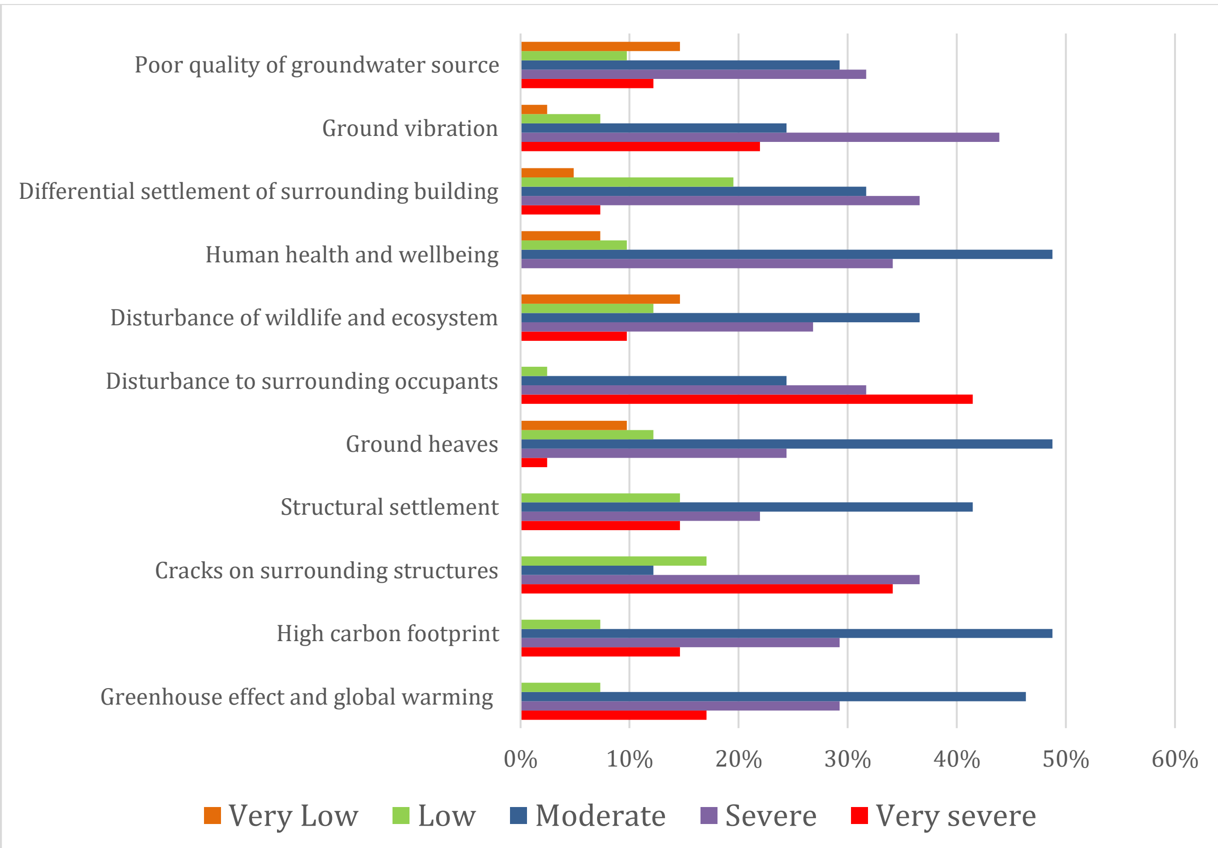

Figure 3: Respondent's view on the effect of environmental impact as a result of pile construction activities in Nigeria

Figure 3 above shows the respondents' views on the environmental impact of pile construction activities in Nigeria. According to the respondent's response, disturbance to surrounding occupants, ground vibration, cracks on surrounding structures, and differential settlement of surrounding buildings are most likely to occur due to pile activities. Other factors like the greenhouse effect, high carbon footprint, ground heaves, human health, disturbance of wildlife and ecosystem, and poor quality of groundwater sources will be moderately affected.

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Strategies and best Practices in ensuring Environmental Sustainability during Pile Construction in Nigeria

The questionnaire identified five major factors that impact the environment during pile construction. These factors were determined from the literature review survey. Based on the factors, possible strategies and practices in ensuring environmental sustainability during pile construction were highlighted, and respondents were asked to rank the relevancy of each practice using the Likert scale of 1 to 5, and the results are presented in ***Table 2, Table 3, Table 4, Table 5, and Table 6.***

Table 2: Ranking of best strategies/practices to mitigate carbon emission in ensuring environmental sustainability during pile construction.

CARBON EMISSION	**Importance factor**					**RII**	**Rank**
	5	**4**	**3**	**2**	**1**		
Regular assessment of the environmental impact of CO_2 emission	16	11	7	3	3	0.751	**2**
Optimization of operation hours of machines	10	20	5	2	4	0.746	**3**
Introducing low-emission machinery	19	10	8	2	2	0.805	**1**
Collection of CO_2 data for review and continuous improvement	11	18	5	2	5	0.737	**4**
Government policy and restrictions on high carbon emitting machine	10	20	5	3	3	0.751	**2**

Strongly Agree-5; Agree-4; Moderately Agree-3; Disagree-2; Strongly Disagree-1

According to **Table 2**, the introduction of low-emission machinery was identified as the most effective strategy for mitigating carbon emissions in pile construction, with a high Relative Importance Index (RII) of 0.805. This strong ranking reflects the growing emphasis on green energy within the construction industry. As the sector increasingly prioritizes environmental sustainability, adopting low-emission technologies is crucial in reducing carbon emissions, significantly contributing to global warming. If the piling industry in Nigeria embraces green energy solutions, there is potential for a substantial decrease in carbon emissions, contributing positively to local and global environmental goals.

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Government policy and restrictions on high carbon-emitting machines and regular assessment of the environmental impact of CO_2 were ranked second according to respondents with an overall RII of 0.751 each. Having the right policies on high-emitting machines aims to regulate the use of machines and set limits on emissions on construction equipment. Proper assessment of the environmental impact of CO_2 evaluates how the processes, equipment, and materials used in pile construction contribute to carbon emissions and how these impacts can be mitigated. Also, the optimization of machine hours and collection of CO_2 data for review and continuous improvement was ranked third and fourth, respectively, with an RII of 0.746 and 0.737.

Table 3: Ranking of best strategies/practices to mitigate Noise in ensuring environmental sustainability during pile construction.

NOISE	Importance factor					RII	Rank
	5	**4**	**3**	**2**	**1**		
Turning off equipment when not in use	25	10	3	1	2	0.868	3
Use of other forms of pile installation method with less noise	17	16	8	0	0	0.878	1
Regular servicing and maintenance of machines and equipment	22	14	3	2	0	0.873	2
Planning construction activities during less sensitive times of the day	21	13	4	0	3	0.839	5
Use of PPE(ear muff/earplug) and implementing noise barrier	24	12	2	3	0	0.844	4

Strongly Agree-5; Agree-4; Moderately Agree-3; Disagree-2; Strongly

With a relative importance index of 0.878, the use of other forms of piling installation methods with less noise was ranked first in **Table 3**. The high RII indicates that respondents view this factor as very important. Other installation methods are preferable if they are available, especially in densely populated areas. Shao *et al*. (2023) state that noise generated during driven pile operation is more intense than the bore pile installation method. This is because driven piles involve hammering pre-casted piles into the ground, and this activity can cause immense noise, unlike the bore pile operation. Regular servicing and maintenance of machines and equipment was ranked second with a RII of 0.873. it is necessary to put engineering control in place, which includes machine maintenance. Doing so increases the machine's efficiency and minimizes noise from the machine. Also, turning off equipment when not in use, ranked third with RII 0.868, is important not just to mitigate noise alone but also to save the cost of fueling and optimizing the operation hours of machines. The use of PPE and implementing noise barriers was ranked fourth with an RII of 0.844 while planning construction activities during less sensitive times of the day was ranked

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fifth with an RII of 0.839, which is also vital in ensuring environmental sustainability during the construction of the pile.

Table 4: Ranking of best strategies/practices to mitigate vibration in ensuring environmental sustainability during pile construction.

VIBRATION	Importance factor					RII	Rank
	5	4	3	2	1		
Considering enough set back from surrounding structures	27	9	4	2	0	0.912	1
Adopting other form of pile installation methods with less vibration	22	11	7	0	1	0.859	4
Implementation of vibration-dampening material	18	14	9	0	0	0.844	5
Controlled installation techniques	27	8	6	0	0	0.902	2
Adopting effective ground stabilization techniques before piling	24	12	5	0	0	0.893	3

Strongly Agree-5; Agree-4; Moderately Agree-3; Disagree-2; Strongly Disagree-1

According to the respondents, considering enough setback from the surrounding structure was ranked first and with almost equal relative importance index, controlled installation techniques came second with an overall RII of 0.912 and 0.902, respectively, as shown in **Table 4**. This implies that the two practices are crucial strategies in mitigating the effect of vibration on surrounding structures during pile installation. Research carried out by Karim *et al.* (2021) on the effect of vibration impact from piling works on the surrounding buildings shows that vibration has more effect on surrounding buildings based on how near or far the piles are to the surrounding structures, and it was concluded that there should be enough set back between existing buildings and piles. It was also found that the effect of vibration is higher at the bottom of a building than at the top. As a result, controlled installation techniques should be adopted by knowing the techniques applicable in a certain condition. Adopting effective ground stabilization techniques before piling and other forms of pile installation methods with less vibration were ranked third and fourth, respectively, with an RII of 0.893 and 0.859. These are necessary in order to mitigate the effect of vibration and ensure environmental sustainability during pile construction. Also, the Implementation of vibration-dampening material was given the least attention, with an RII of 0.844, ranked 5th.

Table 5: Ranking of best strategies/practices to mitigate soil instability in ensuring environmental sustainability during pile construction

SOIL INSTABILITY	Importance factor					RII	Rank
	5	4	3	2	1		
Conducting thorough site investigation to understand soil condition	29	8	4	0	0	0.922	1
Compulsory use of casing	10	16	12	2	1	0.756	5
Controlled installation techniques	19	17	2	3	0	0.854	2
Adopting effective ground stabilization techniques.	17	17	4	3	0	0.834	3
Avoiding unnecessary movement of heavy machines	16	17	4	2	2	0.810	4

Strongly Agree-5; Agree-4; Moderately Agree-3; Disagree-2; Strongly Disagree-1

To mitigate the effect of soil instability during pile construction, conducting a thorough site investigation to understand soil condition was ranked first with an RII of 0.922, as shown in **Table 5**. Understanding the soil condition of the site area is very important when construction work is about to commence. Site investigation, especially subsoil investigation, provides essential information about soil's geological, physical, and geotechnical properties, which are essential to understanding the condition of the soil (Elreedy, 2018). According to the respondents, the controlled installation technique was ranked second with an RII of 0.834. This depends on the personnel operating the pile rig or machine, so it is essential always to allow well-trained operators to handle the pile installation. With an RII of 0.834, adopting effective ground stabilization techniques was ranked third. Improving the properties and gradation of soil can be achieved by mechanical stabilization techniques, which include soil compaction and densification by application of mechanical energy using various sorts of rollers, rammers, and vibration techniques. Also, if the soil materials on site cannot bear the load from pile equipment, it is advisable to stabilize the soil by blending and mixing other materials (Afrin, 2017). Avoiding unnecessary movement of heavy machines was ranked fourth with an RII of 0.810, and compulsory use of casing was ranked the lowest with an RII of 0.756.

Table 6: Ranking of best strategies/practices to mitigate ground water pollution in ensuring environmental sustainability during pile construction

GROUND WATER POLLUTION	Importance factor					RII	Rank
	5	4	3	2	1		
Proper use of drilling fluid (e.g. bentonite)	21	14	3	3	0	0.859	1
proper disposal of hydrocarbons (e.g. fuel/oil spillage	19	12	8	2	0	0.834	2
Site keeping & proper wastewater channel	23	10	5	3	0	0.859	1
Regulation and guidelines for preventing groundwater pollution during piling activities	18	16	4	1	2	0.829	3

Strongly Agree-5; Agree-4; Moderately Agree-3; Disagree-2; Strongly Disagree-1

From **Table 6**, Proper use of drilling fluid and Site keeping and proper wastewater channel both have an RII of 0.859, making them the highest-ranked factors. This implies that respondents strongly believe these aspects are crucial in preventing groundwater pollution. Drilling fluids are essential because improper management can contaminate groundwater sources. Similarly, site management and proper wastewater channels are critical to ensure that wastewater does not leach into groundwater. Proper disposal of hydrocarbons has an RII of 0.834, making it the second most important factor. Hydrocarbons are hazardous pollutants, and their improper disposal can contaminate groundwater. Regulation and guidelines for preventing groundwater pollution during piling activities have the lowest RII of 0.829 among the factors listed, yet they are still considered important. Regulations and guidelines help ensure that all necessary precautions are taken during construction activities, including piling, which can impact groundwater. Although it ranks lower than the other factors, it is still essential in managing and mitigating groundwater pollution.

CONCLUSION

The synthesis of this study focuses on five primary factors contributing to the environmental impact during pile construction activities in Nigeria and provides the strategies and best practices in ensuring environmental sustainability. According to the data collected from professionals in the construction industry, it was revealed that vibration, noise, and carbon emission are the main factors contributing to environmental impact during pile construction. Also, the study revealed numerous suggested practices for mitigating these effects. The most effective technique for reducing carbon emissions is implementing low-emission machinery, enforcing government emission rules, and conducting frequent environmental assessments. Noise reduction efforts included using quieter pile installation methods and equipment. To address vibration, adequate setbacks from structures and controlled installation techniques were deemed necessary. Thorough site inspections and controlled installation techniques were prioritized to address soil instability. Properly use of drilling fluid and effective site management were deemed critical to avoid groundwater pollution.

The strategies and practices proposed in this study provide a strong basis for ensuring environmental sustainability during pile construction in Nigeria. Continued research and the use of these techniques will be critical to building an environmentally responsible construction industry in Nigeria and beyond.

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