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EXAMINING THE EFFECT OF CLIMATE CHANGE ON THE SUSCEPTIBILITY OF ROAD PAVEMENTS IN SOUTH-SOUTH NIGERIA USING THE DELPHI METHOD

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Abstract

Asphalt pavements constitute a high portion of Nigeria's roadways, which have high traffic volumes. The potential deterioration in the long-term performance of these pavements due to climate change has not been given much research attention. To this extent, the present study evaluated the pavement susceptibility of Federal roads in Edo state of South-South Nigeria. The study employed the Delphi technique to examine expert opinions. The standard deviation of the answers to two rounds of questionnaires was used to evaluate the consensus reached by the 10-person Delphi panel. The result showed that one of the four federal roads analyzed in the study was classified as having a high susceptibility, two were classified as having a medium susceptibility, and the remaining road was classified as having a low susceptibility. This research demonstrates that the Delphi technique, which incorporates both objective and subjective assessments, can comprehensively evaluate road pavements' vulnerability to climate change. Therefore, the government should employ adaptive maintenance plans for the roads' varying degrees of susceptibility.

Keywords: *climate change, Delphi technique, road pavements, susceptibility*

INTRODUCTION

Every country and culture relies heavily on its road system. It determines how quickly a country's economy and society progress. Without a reliable transportation network, no economy can succeed. However, improvements to transportation infrastructure can significantly impact GDP growth in any country. A country's economic development is positively correlated with the quality of its road network. Thus, roads are ubiquitous in human mobility, and pavement is an integral part of the road structure (Pasha et al., 2020). A country road network's intended social, cultural, and economic benefits should be maximized through careful planning, design, and construction of road pavements (Ighodaro, 2010).

Road pavement structures constitute multiple layers of processed and compacted materials in varying thicknesses, including bound and unbound forms, which together form a structure that primarily supports vehicle loads and provides a consistent usage quality (Lopez-Uceda et al., 2018). Accordingly, Onyebuchi et al. (2019) described road pavement as a structure composed of structural elements that protect the natural subgrade and carry traffic. Arguably, the quality of road pavements influences noise and vibration emissions caused by tire-road interactions (Hauwermeiren et al., 2019), thus affecting the road user's experience, including the well-being of nearby residents. Notably, road pavement quality is considered one of the most important indicators of economic competitiveness (Zumrawi, 2021), indicating the need to consider sustainability conditions in road construction consistently.

Environmental conditions are a key component determining the design life and maintenance required for road pavements (Taylor & Philp, 2015). Undoubtedly, one of the factors that shorten the life of the road pavement and cause premature damage is the increased moisture content in the pavement structure, particularly in unbound granular layers (Rokitowski et al., 2021). Indeed, numerous studies have underscored the conditions of pavement cracks, potholes, and other defects in Nigerian roads (Alhaji et al., 2022; Attahiru et al., 2016; Chibuzor et al., 2020; Falowo & Akintorinwa, 2015; Ikeagwuani et al., 2016; Jegede, 2005; Omowumi, 2018; Onyelowe, 2015; Osadebe & Quadri, 2021; Oyedepo et al., 2017; Thompson et al., 2015; Tijani & Olawale, 2020). Nevertheless, pavement-related failures in the country have nearly made it impossible to go more than a kilometer in Nigeria without encountering long cracks and potholes (Emmanuel et al., 2021). Indeed, road pavement unevenness, cracks, potholes, and other surface defects can make riding uncomfortable and potentially hazardous (Cafiso et al., 2022). Notably, road traffic accidents have increased, and the country's economic growth is negatively impacted due to road pavement failures. It is common knowledge that every road has a specified design life. However, roads frequently fail before the planned, expected date, while some roads fail immediately after construction, others fail after flooding, and some roads last their entire life expectancy with proper maintenance (Emmanuel et al., 2021)

There is an increasing awareness regarding the impact of climate change on the performance and durability of pavements (Mallick et al., 2018). Thus, the deterioration of road pavements as a result of climate change has received considerable research attention across the globe (Blaauw et al., 2022; Hemed et al., 2020; Ibeje, 2021; Maadani et al., 2021; Mahpour & El-Diraby, 2021; Oyediji et al., 2021; Qiao et al., 2019; Qiao, Santos, et al., 2020; Qiao, Zhang, et al., 2020; Shao et al., 2017; Stoner et al., 2019). Engineers often consult extensive historical records of climatic data for reference when designing road infrastructures. Road pavements can withstand the local weather and climate when constructed using standard practices. Unfortunately, climate change has distorted the trend in the global climate. As a result, the use of historical climate data in the design of road infrastructure has become unreliable as a result of this. Because of the increasingly significant impacts it has on road infrastructure, road administrators all over the world are concerned about the change in climate that has occurred over the past few decades. The unusual and frequent submergence of roads by severe flood events is one indication that climate change affects road infrastructure.

The susceptibility of road pavements describes its response to environmental conditions occasioned by climate activities. Accordingly, Patrick and Soliman (2019) state that the susceptibility of pavement to various types of surface distress is affected by many factors, including climatic conditions. Notably, increases in temperature, variable rainfall, rising sea levels and flooding, drought and desertification, land degradation, an increase in the frequency of extreme weather events, a decline in freshwater resources, and a loss of biodiversity are all signs that Nigeria's climate is changing. Rainfall has become more frequent and intense, resulting in large runoffs and flooding in many parts of Nigeria. Previous research has reported the impact of climate conditions on Nigerian roads, although the impacts are non-uniformly experienced across the country. For instance, extreme rainfall primarily impacts road infrastructure in the country's south-south region. Soil type, topographical features, type and previous pavement conditions exacerbate the severity of climate impacts. Road pavement susceptibility to climate change entails the extent it can withhold the adverse effects of climatic variations. Accordingly, the present paper underscores the susceptibility of road pavement in relation to its robustness and degree of protection from exposure to changes in temperature, precipitation, sea level, and extreme weather events.

The Delphi Technique

The Delphi method is a consensus method that aims to find general agreement among an expert panel on a specific research topic (Galanis, 2018). It describes a method of using questionnaires with controlled opinion feedback to elicit distilled knowledge from a group of experts. The Delphi Technique entails assembling geographically unconstrained groups of experts who then respond via email to a series of questions. There have been reports of the Delphi technique used in planning, environmental impact assessments, and other fields. It is new to determine road vulnerability using Delphi techniques. By identifying the climate change vulnerability of roads, future climate changes would be acknowledged, and

mitigating measures would be taken. The results of vulnerability assessments can be used to design resilient road infrastructure that can withstand climate change and extreme weather. Thus, utilizing a consensus method relative to problem-solving, idea generation, or determining priorities in road pavement becomes imperative due to diversity in ideas. Therefore, the present study aims to ascertain the susceptibility of road pavements to climate change using the Delphi method

Method

The study area is the Edo state in the south-south region of Nigeria. The various formations in the geology of Edo State are the Benin, Bende Ameki, Ogwashi-Asaba, Imo, and Nsukka formations (Alile et al., 2007). The geology is generally marked by top reddish earth composed of ferruginized or literalized clay sand (Ikhile, 2016)

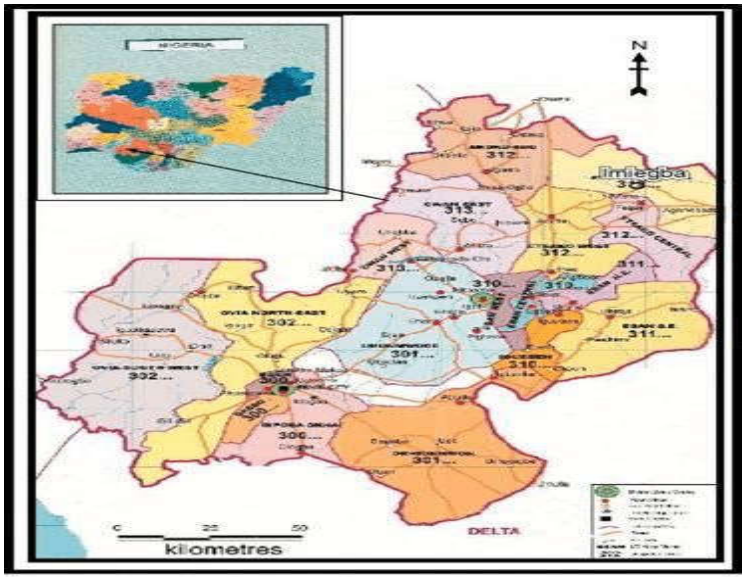
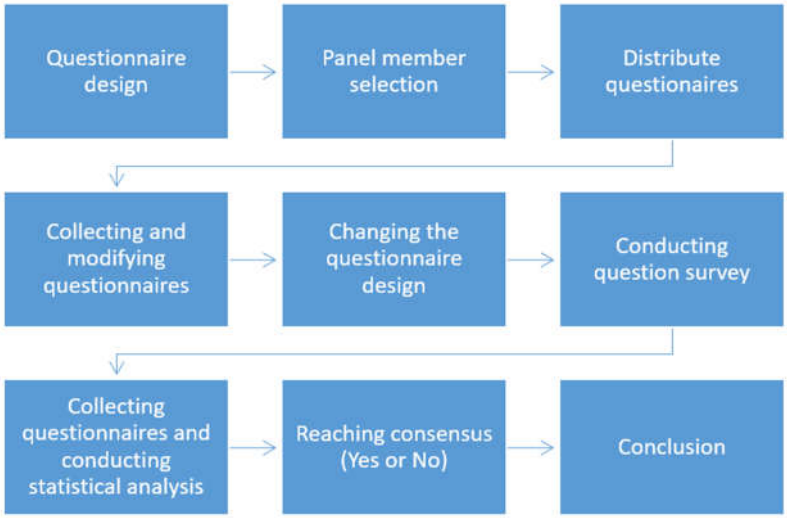


Figure 1: Location Map of the Study Areas

The Delphi process

The present study aims to examine the susceptibility of road pavements in Edo state using expert opinion. The selected panelists were conveniently drawn from academia, government works departments, and construction companies. The panel members were selected based on their experience in the road construction sector. The age distribution of the respondents ranged from 20 to 60 years, with a majority of 84% falling between 30 and 49 years. In addition, 92% of the respondents acquired postgraduate degrees. In the beginning, rounds of questions were emailed to the Delphi panel members. As a means of providing feedback to the participants, points of agreement that were found in the responses to each round of questions were shared. The rounds of questioning continued until all of the participants provided responses that were consistent with one another. The participants' responses were kept secret from one another to prevent undue influence from being exerted on the opinions of the other participants. When everyone's questions were answered satisfactorily, we stopped having rounds of questions. The Delphi technique aims to achieve this level of consistency in group and individual responses to the point where they do not change from one round to the next.



The Delphi flowchart

Statistical analysis for stability and consensus

The degree to which panelists' responses in a Delphi method remain consistent across multiple iterations of questioning is referred to as stability. Stability is frequently employed as a criterion when determining whether or not to terminate a Delphi process. Using standard deviation allowed for the identification of shifts in the variation of responses across the several rounds of questioning. In this investigation, the threshold for stability was determined to be a value of 0.10 for the standard deviation of responses to questions. This threshold was determined after two rounds of questioning. Similarly, consensus describes the overall agreement reached by the Delphi experts. In this investigation, the average number of responses was chosen as a measure of consensus, and the threshold for consensus was 0.20.

Determining exposure of road pavement to climate change

In order to estimate road exposure to climate change, the roads and their locations were initially identified. And to demonstrate the rating scale for estimating exposure, the scoring matrix in Table 1 was adopted. Dephi experts selected climate variables appropriate to the location based on historical experience and events. In addition, an asset that is getting close to the end of its design life may be more susceptible to the effects of the climate.

Table 1: Rating scales for assessing exposure

	Extreme heat	Mean heat	Drought	Mean rainfall	Extreme rainfall	Sea level rise /storm surge
Road 1						
Road 2						
Road 3						
Road 4						

Exposure can be scored as follows: 0 = No or negligible exposure now and/or in the future; 1 = Low exposure now and/or in the future; 2 = Medium exposure now and/or in the future; 3 = High exposure now and/or in the future.

Susceptibility estimation

When the exposure and sensitivity ratings were put together, it became clear whether or not the asset was vulnerable, to what extent, and due to which climatic factors. Vulnerability to the climate variable was increased for assets with high exposure and sensitivity compared to those with low exposure and low sensitivity. Those already relatively well-protected from the effects of climate change were less likely to benefit from additional adaptation strategies. Table 2 displays the vulnerability matrix used to determine the overall vulnerability level based on exposure and sensitivity. Thus, a low vulnerability score means the asset is less susceptible to risk and would benefit from adaptation and mitigation efforts. For an asset to have a low susceptibility rating, it must be highly resistant to risk, adaptable, or unavoidable.

Result/Discussion

Table 2 shows the summary of the Delphi survey results. Out of 4 federal roads considered in the study, one road had high susceptibility status, two had medium susceptibility status, and one was This represented 30% high susceptibility, 40% medium susceptibility, and 30% low susceptibility of federal roads to climate change in the Edo state of south-south Nigeria. There is only one highly vulnerable road in the state.

Road Section	susceptibility rate	susceptibility
Benin – Lagos Road	1	Low
Benin – Ekpoma – Okene Road	2	Medium
Benin – Sapele Road	3	High
Ewu – Uromi – Agbor Road	2	Medium

In Edo State, SR1, the result of the susceptibility survey is shown in the table above. Benin-Sapele road was the most susceptible, with a high rating of 3, indicating a high susceptibility. Benin-Ekpoma and Ewu-Uromi-Agbor roads were rated 2, thus, showing that the two roads scored a medium susceptibility exposure rating. Benin- Lagos road scored the lowest rating of 1, indicating that the road is less exposed to climate change.

Survey Results for Road Exposure to Climate Change

In survey round 1 (SR1), Benin- Sapele Road was the most exposed with an average rating of 1.5, with the highest rating of 3 by groups 3 and 4 participants and the lowest rating of 0 by groups 1 and 5 Survey participants (SPs). Benin – Lagos Road scored an average of 1.2 and was the least exposed. Its highest rating was 3, and its lowest rating was 0. This road was rated high by groups 3 and 4 SPs. In Survey round 2 (SR2), each road's average, lowest, highest, and overall rating was obtained and provided to SPs from SR1.

Table 3: standard deviations of responses

Federal Roads	R^1 (SD)	R^2 (SD)
Benin – Lagos Road	1.1	1.45
Benin – Ekpoma – Okene Road	1.2	1.35
Benin – Sapele Road	1.15	1.25
Ewu – Uromi – Agbor Road	1.5	1.32

R^1 = Round 1; R^2 = Round 2; SD = Standard deviation

Standard deviations of responses for each road were compared SR1 and SR2, as shown in Fig. 3.
The standard deviation of the exposure ratings of all the roads studied increased from R^1 to R^2. This was because some SPs decreased their rating of the roads while other SPs kept their rating the same. Standard deviations of group responses for each road ranged between 1.25 – 1.45.

Conclusion

The present study examined the susceptibility of road pavement to climate change. Critical indicators of exposure of 4 federal roads in Edo states of Nigeria were explored through repetitive rounds of questioning called the Delphi technique. After two rounds of questioning, the participants' responses were consistent and unanimous. These federal roads were found to be exposed to climate change to a greater extent due to non-climatic factors like land use, governance, and policy groups. The study found that the federal roads in the state of Edo were susceptible to climate change to varying degrees—high, medium, and low. It means that climate change may exacerbate or alleviate road deterioration depending on location (Piryonesi & El-Diraby, 2021). Stakeholders need to be more aware of climate-related risks and opportunities. They also need more information and dialogues to do so. The study recommend that to help with the formulation of sound policies, more community-based case studies involving a more comprehensive range of stakeholders be conducted.

References

[1]. Alhaji, M. M., Alhassan, M., Adejumo, T. W., & Abdulkadir, H. (2022). Road pavement collapse from overloaded trucks due to traffic diversion: A case study of Minna-Kateregi-Bida Road, Nigeria. Engineering Failure Analysis, 131. https://doi.org/10.1016/j.engfailanal.2021.105829
[2]. Alile, O. M., Molindo, W. A., & Nwachokor, M. A. (2007). Evaluation of Soil Profile on Aquifer Layer of Three Locations in Edo State. International Journal of Physical Sciences, 2(9).
[3]. Attahiru, Y. B., Yauri, R. A., & Abdulrahaman, S. (2016). An Investigation of Highway Structural Pavement Failures (A Case Study of Dayi-Kano Road, Nigeria). International Journal of Scientific & Engineering Research, 7(1).
[4]. Blaauw, S. A., Maina, J. W., Mturi, G. A. J., & Visser, A. T. (2022). Flexible pavement performance and life cycle assessment incorporating climate change impacts. Transportation Research Part D: Transport and Environment, 104. https://doi.org/10.1016/j.trd.2022.103203
[5]. Cafiso, S., Di Graziano, A., Marchetta, V., & Pappalardo, G. (2022). Urban road pavements monitoring and assessment using bikes and e-scooter as probe vehicles. Case Studies in Construction Materials, 16. https://doi.org/10.1016/j.cscm.2022.e00889
[6]. Chibuzor, O. N., Onwuka, ;, Echezona, F., Mbaoma, ;, Chinaedu, S., Wokocha, ;, & Okechukwu, I. (2020). Causes of Failure of Flexible Pavement (a Case Study of Awka-Ugwuoba Section of the Old Enugu-Onitsha Expressway). International Journal of Innovation and Sustainability, 3.
[7]. Emmanuel, U. O., Ogbonnaya, I., & Uche, U. B. (2021). An investigation into the cause of road failure along Sagamu-Papalanto highway in southwestern Nigeria. Geoenvironmental Disasters, 8(1). https://doi.org/10.1186/s40677-020-00174-8
[8]. Falowo, O. O., & Akintorinwa, O. J. (2015). Geophysical Investigations of a Pavement Failure Along Akure-Ijare Road, Southwestern Nigeria. IOSR Journal of Applied Geology and Geophysics, 3(6). https://doi.org/10.9790/0990-03624554
[9]. Galanis, P. (2018). The Delphi method. Archives of Hellenic Medicine, 35(4). https://doi.org/10.4324/9781315728513-10
[10]. Hauwermeiren, W. Van, David, J., Dekoninck, L., De Pessemier, T., Joseph, W., Botteldooren, D., Martens, L., Filipan, K., & De Coensel, B. (2019). Assessing road pavement quality based on opportunistic in-car sound and vibration monitoring. Proceedings of the 26th International Congress on Sound and Vibration, ICSV 2019.
[11]. Hemed, A., Ouadif, L., Bahi, L., & Lahmili, A. (2020). Impact of climate change on pavements. E3S Web of Conferences, 150. https://doi.org/10.1051/e3sconf/202015001008
[12]. Ibeje, A. O. (2021). Vulnerability of Road Pavements to Climate Change in Abia and Imo States of Nigeria. Nigerian Journal of Technology, 40(1). https://doi.org/10.4314/njt.v40i1.2
[13]. Ighodaro, C. (2010). Transport infrastructure and economic growth in Nigeria. Journal of Research in National Development, 7(2). https://doi.org/10.4314/jorind.v7i2.50973
[14]. Ikeagwuani, Christopher, C., & Chioma, I. (2016). Pavement Failures in Southern and South Eastern Nigeria, Causes, Effect, and Remedies. International Journal of Engineering and Management Research (IJEMR), 6(2).
[15]. Ikhile, C. I. (2016). Geomorphology and Hydrology of the Benin Region, Edo State, Nigeria. International Journal of Geosciences, 07(02). https://doi.org/10.4236/ijg.2016.72012
[16]. Jegede, G. (2005). Highway pavement failure induced by poor soil geotechnical properties at a section along the

F209 Okitipupa-Igbokoda highway, southwestern Nigeria. Ife Journal of Science, 6(1). https://doi.org/10.4314/ijs.v6i1.32121
[17]. Lopez-Uceda, A., Agrela, F., Cabrera, M., Ayuso, J., & López, M. (2018). Mechanical performance of roller compacted concrete with recycled concrete aggregates. Road Materials and Pavement Design, 19(1). https://doi.org/10.1080/14680629.2016.1232659
[18]. Maadani, O., Shafiee, M., & Egorov, I. (2021). Climate Change Challenges for Flexible Pavement in Canada: An Overview. Journal of Cold Regions Engineering, 35(4). https://doi.org/10.1061/(ASCE)cr.1943-5495.0000262
[19]. Mahpour, A., & El-Diraby, T. (2021). Incorporating Climate Change in Pavement Maintenance Policies: Application to Temperature Rise in the Isfahan County, Iran. Sustainable Cities and Society, 71. https://doi.org/10.1016/j.scs.2021.102960
[20]. Mallick, R. B., Jacobs, J. M., Miller, B. J., Daniel, J. S., & Kirshen, P. (2018). Understanding the impact of climate change on pavements with CMIP5, system dynamics, and simulation. International Journal of Pavement Engineering, 19(8). https://doi.org/10.1080/10298436.2016.1199880
[21]. Omowumi, A. (2018). Geotechnical influence of underlying soils to pavement failure in the southwestern part of Nigeria. Malaysian Journal of Sustainable Environment, 4(1). https://doi.org/10.24191/myse.v4i1.5604
[22]. Onyebuchi, M. N., Michael, T. T., & Peter, S. S. (2019). Pavement deterioration predictive models for a section of ijokodo-apete road Ibadan, Nigeria. International Journal of Engineering and Advanced Technology, 8(6). https://doi.org/10.35940/ijeat.E7214.088619
[23]. Onyelowe, K. C. (2015). Index Study of the Perception of Contractors and Consultants on the Causes of Road Pavement Failure in South-Eastern Nigeria. Umudike Journal of Engineering and Technology, 1(2).
[24]. Osadebe, C. C., & Quadri, H. A. (2021). Comparative Analysis of Effects of Heavy Vehicles on Roads in Southern and Northern Nigeria. LAUTECH Journal of Civil and Environmental Studies, 7(1). https://doi.org/10.36108/laujoces/1202.70.0120
[25]. Oyedepo, J. O., Dada, T., Aladegboye, S., & Adeniji, A. (2017). Crack Mechanism of Different Concrete Grades under Compressive Loading: Application in Rigid Pavement. FUOYE Journal of Engineering and Technology, 2(1). https://doi.org/10.46792/fuoyejet.v2i1.33
[26]. Oyediji, R., Lu, D., & Tighe, S. L. (2021). Impact of flooding and inundation on concrete pavement performance. International Journal of Pavement Engineering, 22(11). https://doi.org/10.1080/10298436.2019.1685671
[27]. Pasha, A., Mansourian, A., & Ravanshadnia, M. (2020). A hybrid fuzzy multi-attribute decision-making model to select road pavement type. Soft Computing, 24(21). https://doi.org/10.1007/s00500-020-04928-2
[28]. Patrick, G., & Soliman, H. (2019). Roughness prediction models using pavement surface distresses in different Canadian climatic regions. Canadian Journal of Civil Engineering, 46(10). https://doi.org/10.1139/cjce-2018-0697
[29]. Piryonesi, S. M., & El-Diraby, T. (2021). Climate change impact on infrastructure: A machine learning solution for predicting pavement condition index. Construction and Building Materials, 306. https://doi.org/10.1016/j.conbuildmat.2021.124905
[30]. Qiao, Y., Dawson, A., Parry, T., & Flintsch, G. (2019). Life cycle cost of flexible pavements and climate variability: case studies from Virginia. Structure and Infrastructure Engineering, 15(12). https://doi.org/10.1080/15732479.2019.1642364
[31]. Qiao, Y., Santos, J., Stoner, A. M. K., & Flinstch, G. (2020). Climate change impacts on asphalt road pavement construction and maintenance: An economic life cycle assessment of adaptation measures in the State of Virginia, United States. Journal of Industrial Ecology, 24(2). https://doi.org/10.1111/jiec.12936
[32]. Qiao, Y., Zhang, Y., Zhu, Y., Lemkus, T., Stoner, A. M. K., Zhang, J., & Cui, Y. (2020). Assessing impacts of climate change on flexible pavement service life based on Falling Weight Deflectometer measurements. Physics and Chemistry of the Earth, 120. https://doi.org/10.1016/j.pce.2020.102908
[33]. Rokitowski, P., Bzówka, J., & Grygierek, M. (2021). Influence of high moisture content on road pavement structure: A Polish case study. Case Studies in Construction Materials, 15. https://doi.org/10.1016/j.cscm.2021.e00594
[34]. Shao, Z., Jenkins, G., & Oh, E. (2017). Assessing the impacts of climate change on road infrastructure. International Journal of GEOMATE, 13(38). https://doi.org/10.21660/2017.38.72099
[35]. Stoner, A. M. K., Daniel, J. S., Jacobs, J. M., Hayhoe, K., & Scott-Fleming, I. (2019). Quantifying the Impact of Climate Change on Flexible Pavement Performance and Lifetime in the United States. Transportation Research Record, 2673(1). https://doi.org/10.1177/0361198118821877
[36]. Taylor, M. A. P., & Philp, M. L. (2015). Investigating the impact of maintenance regimes on the design life of road pavements in a changing climate and the implications for transport policy. Transport Policy, 41. https://doi.org/10.1016/j.tranpol.2015.01.005
[37]. Thompson, O. T. H., Zaid, M. M., & Raymond, A. A. (2015). Effect of Engineering Properties of Soil on Pavement Failures in Ogbagi -Akoko Area, Southwestern, Nigeria. Journal of Environment and Earth Science, 5(4).
[38]. Tijani, M. ., & Olawale, S. O. . (2020). Investigation of Flexible Pavement Failure along Ede – Akoda Road, Osun State, Southwestern Nigeria. LAUTECH Journal of Civil and Environmental Studies, 4(1). https://doi.org/10.36108/laujoces/0202/40(0110)
[39]. Zumrawi, M. M. E. (2021). Assessing the Pavement Quality of National Roads in Sudan. University of Khartoum Engineering Journal, 11(1). https://doi.org/10.53332/kuej.v11i1.151