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Spatio-temporal analysis of the impact of quarry material extraction on land surface temperature: a case study of Anambra East L.G.A

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KEYWORDS

Land Surface Temperature (LST), Quarrying, Anambra East LGA, Spatio-temporal Analysis, Remote Sensing, GIS, Urban Heat Island

ABSTRACT

Quarrying has emerged as a leading land-use in the Anambra East Local Government Area (LGA) following the massive urbanization and infrastructural development in the state of Anambra. Although economically important, the activities have caused serious ecological changes especially in terms of thermal environment of land surface. This research paper presents a spatio-temporal assessment of the effect of the quarrying on the Land Surface Temperature (LST) in Anambra East LGA. It will measure the increase in the size of the quarrying locations and determine the thermal reaction of the landscape that follows. The study makes use of multi-temporal satellite images of the Landsat 5 TM, 7 ETM+ and 8/9 OLI/TIRS sensors. The Maximum Likelihood Algorithm was applied to find the change between vegetation and quarrying/bare land by means of the Land Use Land Cover (LULC) classification. The Thermal Infrared (TIR) bands were used to retrieve LST and it was corrected by the land surface emissivity. The correlation analysis was done statistically to establish how the relationship existed between the Normalized Difference Vegetation Index (NDVI) and surface temperature. A preliminary survey shows that there is a substantial increase in the quarrying operations, which are mostly located in the Aguleri and Umueri axes. There is a high positive relationship between the transformation of land to quarrying locations and the appearance of the thermal hotspots. Statistics indicate that LST in quarrying areas is always greater (around 4 ºC to 8 ºC) than in the adjacent vegetation cover. The loss of the green lung in the LGA has resulted in the emergence of localized Surface Urban Heat Island (SUHI) effect, which is decreased evapotranspiration and high sensible heat flux. The paper shows that localized climate warming is mostly caused by unregulated quarrying in Anambra East. These results underscore sustainable mining and compulsory reclamation of land and inclusion of thermal environmental monitoring into the environmental impact assessment (EIA) systems of the states as the most appropriate action to curb the ecological degradation in the long term.

1. Introduction

This All over the world, there is a realization that quarrying activities have evolved into mining industry that has the potential to provide hitherto unparalleled services to management in their efforts to reduce the effects of quarrying risks to human beings and the surroundings. Quarries are generally used for extracting construction materials, such as dimension stones, ornamental stones, road, building, and industrial raw materials (Galin et al, 2026). A quarry is an open-pit surface mining from which rock or minerals are extracted. However, mining and quarrying are destructive enterprises and involve the destruction of the habitat. The destruction and fragmentation of habitat is the greatest threat to biodiversity and the primary cause of species extinction. In most African nations and other nations of the world, quarrying is not well managed for environmental sustainability (Bundi et al, 2026). The methods used are very poor and there is no order in resource exploitation. Most of the quarries do collapse and there are no measures taken to rehabilitate such quarries since most of them are left open.

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Therefore, the need for a detailed study on the significance of quarrying management in mining industries has become inevitable. One of the biggest negative impacts of quarrying on the environment is the damage to biodiversity. Quarrying carries the potential of destroying habitats and the species they support (Pochechun et al, 2025). Even if the habitats are not directly removed by excavation, they can be indirectly affected and damaged by environmental impacts such as changes to groundwater or surface water that cause some habitats to dry out or others to become flooded. Even noise pollution can have a significant effect on some species and affect their successful reproduction. Nevertheless, with careful planning and management, it is possible to minimize the effects on biodiversity.

Quarries can also provide a good opportunity to create new habitats or to restore existing ones. Again, like many other man-made activities, quarrying involves the production of significant amounts of waste. Some types of quarries do not produce large amounts of permanent waste, such as sand and gravel quarries, whereas others produce significant amounts of waste material such as clay and silt. However, there is still potential for damage to the environment particularly with water contamination and also damage to the plants and animal habitats. Plants are major components of the ecosystem a complex interaction between the biotic and abiotic entity of the environment. The plants help to rehabilitate the area. While quarries can have a significant impact on the environment, with the right planning and management, many of the negative effects can be minimized or controlled and, in many cases, there is a great opportunity to protect and enhance the environment, such as with the translocation of existing habitats or the creation of new ones (Arquié et al, 2026). To achieve the equilibrium between natural ecosystems, project planning, formulation, and implementation, there is a need to minimize the impact of stone quarry on the environment and living community. Based on the preceding, this study will attempt to assess the environmental effects of sandstone quarrying in Anambra East and its impacts on the environment.

Mining and processing of stone have a considerable impact on land, water, air, and biological resources if the operation and post-operation issues are not handled properly. Even though the impact is part of the price we bear for the benefits of mineral consumption, the unregulated destruction of the natural environment is not compatible with sustainable development. Previous research works done in Nigeria on the issues that relate to the impact of stone quarrying on the environment and community focus on a national level and create a gap for decision-making in different geographical locations (Christian, 2025a). In addition, the participation of the different stone unions on the site for the production of stone for road construction leads a given environment and society to be susceptible to damage. Quarrying negatively affects the environment and society in a variety of ways from exploration, blasting, transport, and disposal of waste rocks.

Major environmental effects are the destruction of vegetation, disruption of animal habitats, diversion and blockage of natural drainage systems, soil erosions, river siltation, noise, vibration, dust pollution, and health problems. The range of negative environmental and social impacts associated with extractive industries widely spread in the living environment (Iguocha, 2026; Christian, 2025b). This is especially true of opencast mining of the sort used in extracting construction materials. The greatest problem is the destruction of the habitat where the quarrying occurs. A study conducted on the host community of the Oba-ile quarry site in Oba-ile Nigeria revealed that quarrying causes various environmental and social impacts. The operation of land clearing led to the loss of vegetation cover, soil removal, spring eye spot extinction, scenic quality loss, formation of ugly scenery, and susceptible geomorphology for erosion. Land stability problems where the rock falls on the slope foot can be seen easily creation of deep wells and ponds. Land degradation and social challenges related to the increase in quarrying activities in general include: threats to health and safety, displacement of communities, and damage to cultural sites.

In Anambra East, demand for housing and physical infrastructure maintenance materials such as stone and sand are increasing. There are several individuals and unions involved in stone quarrying legally and illegally to generate income. However, some challenges have been observed over the past few years; stone quarrying in Anambra East has led to environmental degradation. In addition, overexploitation of the resources and poor methods of technology in quarrying have left the landscape rugged. The magnitude of the problems can be explained in terms of social conflict, vulnerability of soil to water and wind erosion, deforestation, and disposal of waste in open places. Hence, the extent of those problems and their effect on society and the environment needs the attention of the stakeholders.

The motivation for this study on the spatio-temporal analysis of the impact of quarrying on land surface temperature (LST) in Anambra East Local Government Area was driven by increasing environmental and developmental concerns within the region. Rapid human activities such as quarrying have significantly altered land surfaces, yet there remains a paucity of empirical studies examining their direct impact on environmental parameters such as temperature variations over time. This is an especially important gap in terms of the socio-cultural and developmental issues facing Nigeria in general (Molokwu et al., 2023; Okezie, 2021). The literature has mostly been concerned with socio-economic and governance challenges like insecurity, violence, and inefficiency in the public sector, which is still a setback towards sustainable development (Ezeogidi et al., 2020; Iwino and Uzor, 2025). Although these studies offer important information on development issues, they have a common tendency of not considering the environmental impacts of human actions. On the same note, other problems concerning social exclusion, human rights, and household issues (Okezie, 2022; Okezie et al., 2023) also indicate the existence of gaps in the society but fail to effectively handle environmental degradation caused by extractive industries.

Additionally, the literature on the organizational performance, innovation, and sustainability highlights the fact that it is essential to adopt environmentally responsible practices (Muogbo et al., 2025a; Muogbo et al., 2025b; Muogbo et al., 2025c), but it is difficult to implement these notions to the study of the processes of quarrying and their impact on the environment. The growing correlation between humans and their environment is also highlighted by philosophical and historical interpretations of society and development (Chukwu et al., 2025) but does not present any spatial fact of environmental alteration. Moreover, educational and technological research emphasizes the role of innovation, digital literacy, and capacity building in the process of managing current issues (Oguejiofor and Onyiorah, 2021; Oguejiofor et al., 2022; Onyiorah, 2021a; Onyiorah, 2021b; Onyiorah, 2022; On Although these developments have been made, there is still underutilization of the geospatial technologies including GIS and remote sensing to monitor the environment in local studies. This presents a great gap in knowledge on the spatial and temporal dynamics of the land surface temperature changes during quarrying.

Besides, the studies of governance and public administration (Chukwurah et al., 2020; Obikeze et al., 2022; Iwono, 2021) emphasize the necessity of a better policy implementation and monitoring system. Nevertheless, there is inadequate application of scientific and geospatial tools to assist in the decision-making process of the environment. The wider socio-economic research, such as the investigation of the issues of public service delivery, security challenges, and development strategies (Obi et al., 2026), also indicates the gaps in the implementation of environmental sustainability of the development planning. Hence this work was inspired by the fact that these multidisciplinary gaps need to be filled by using GIS and remote sensing methods to understand the effects of quarrying on the land surface temperature over time. In this way, the study will help in a deeper understanding of the process of environmental change and aid the sustainable land use planning and policy development in Anambra East. The core area of the study is to undertake a spatiotemporal analysis of stone quarrying in stone quarrying environment of Anambra East L.G.A, Anambra State to come up with information that would be required in planning and management of activities within the study area.

2. Method

The research was undertaken in the Anambra East Local Government Area of the state of Anambra, Nigeria, which is a collection of various communities including Aguleri, Igbariam, Nsugbe, and Nando. The geographical location of the area is in the tropical zone, and it has wet and dry climate with heavy rainfall and a clear dry season. The primary economic activity is agriculture where crops like yam, cassava, maize, and rice are grown on large scale as well as fishing can be found in the riverine regions. Both basement complex rocks and sedimentary rocks shape the physical environment of the area which has a well established drainage system that links to the Niger River and tributaries. It has a tropical vegetation that is well covered with forest cover given the high rainfall and humidity. The region is also susceptible to seasonal floods, although this floods the land and interferes with human activities despite having fertile land.

Primary and secondary data were used in the study. Primary data comprised of coordinates of stone quarrying sites and ground control points based on the fieldwork using hand-held GPS devices. Moreover, physical characteristics on the ground were also described. The secondary data consisted of satellite Landsat 8 images and administrative boundaries maps that were acquired in the corresponding organizations: the Department of Surveying and Geoinformatics and the USGS Earth Explorer platform. Different hardware and computer software were used to assist in processing and analyzing data. The hardware resources comprised a Garmin handheld GPS used in collecting field data, computer system used to process the data, and a printer used in presenting output. Image processing, land use and land cover classification and spatial analysis were done with software like ArcGIS version 10.7 and ERDAS Imagine. The statistical analysis and report writing were done using Microsoft Excel and Word.

Image pre-processing was applied to the set of images acquired. This was done in ArcGIS by conversion of digital numbers to radiance, and conversion of radiance to top-of-the-atmosphere reflectance. The processes followed are to estimate land surface temperature, the calculation was done by converting top-of-atmosphere (TOA) radiance. Using the radiance rescaling factor, thermal infrared digital numbers were converted to TOA spectral radiance using the formula:

$L\lambda = ML * Qcal + AL$

Where: $L\lambda$= TOA spectral radiance (watts/m2 *sr * um); ML= Radiance multiplicative Band (No.); AL= Radiance Add Band; Qcal=Quantized and calibrated standard product pixel values (DN)

Spectral radiance data was converted to top-of-atmosphere brightness temperature using the thermal constant values in the Metadata file.

$BT = K2 / In\,(K1/ L\lambda + 1) - 272.15$

Where: BT=Top of atmosphere brightness temperature (OC); $L\lambda$= TOA spectral radiance (Watts/m2 *sr * um); K1=KI Constant Band (No.); K2=K2 Constant Band (No.)

The Normalized Differential Vegetation Index (NDVI) is a standardized vegetation index that was calculated using Near Infra-red and Red bands.

$NDVI = (NIR - RED)/NIR + RED)$

Where: RED=DN valves from the RED band; NIR= DN valves from Near-infrared band

Land surface emissivity (LSE) is the average emissivity of an element on the surface of the earth; this was first calculated from NDVI values to get a proportion of vegetation value.

$PV = [(NDVI - NDVImin)/(NDVI\ max + NDVImin)]^2$

Where: PV= Proportion of Vegetation; NDVI=DN values from NDVI image; NDVImin =Minimum DN values from NDVI Image; NDVI max = Maximum DN values from NDVI Image

The Land Surface Emissivity is calculated by

E=0.004*PV+0.986

Where: E=Land Surface Emissivity; PV= Proportion of vegetation

The Land Surface Temperature (LST) is the radioactive temperature which was calculated using Top of atmosphere brightness temperature, Wavelength of emitted radiance, and Land Surface Emissivity.

LST= (BT/1) +W* (BT/14380)*In (E)

Where: BT=Top of atmosphere brightness temperature (OC); W= Wavelength of emitted radiance E Land Surface Emissivity.

The study adopted a supervised classification method for land use and land cover (LULC) analysis, which involved the use of training samples to guide the classification process. Landsat 8 OLI imagery was utilized, and training samples were created based on prior knowledge of the study area. These samples were generated by delineating polygons on the satellite imagery and assigning them to specific land cover classes within an Area of Interest (AoI) layer. A signature file was then developed to represent the spectral characteristics of each class. The maximum likelihood classifier (MLC) was employed as the classification algorithm due to its effectiveness in handling medium-resolution imagery. The classifier used a statistical approach, assuming that spectral values for each class followed a normal distribution. It computed the probability of each pixel belonging to a particular class and assigned it accordingly. To improve classification accuracy, spatial reclassification techniques, image interpretation, auxiliary data, and GIS functions were applied to reduce errors. An accuracy assessment was conducted using a confusion (error) matrix to evaluate the reliability of the classification results. Four metrics—user’s accuracy, producer’s accuracy, overall accuracy, and the kappa coefficient—were calculated. These metrics helped determine classification performance, with the kappa coefficient providing a measure of agreement beyond chance.

3. Results

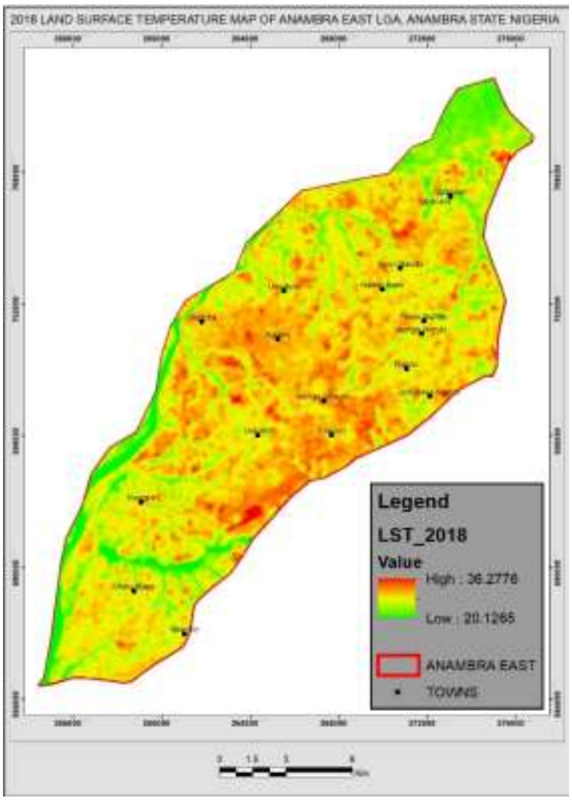

Figure 1: Land Surface Temperature (LST) Map of Anambra East LGA, Anambra State, Nigeria (2018)

Figure 1 map depicts the spatial distribution of land surface temperature of Anambra East with temperature values of about 21.4621C to 31.2682C which is higher in red and orange areas and lower in green areas. Its central and northern regions are comparatively warmer probably because of the more human activities, loss of vegetation cover or constructed surfaces. On the contrary, colder areas are seen along the western and southern sides, which might be related to water bodies and thick trees. This trend indicates that land use, density of vegetation and closeness to water had a great impact on the variation in temperature in the area.

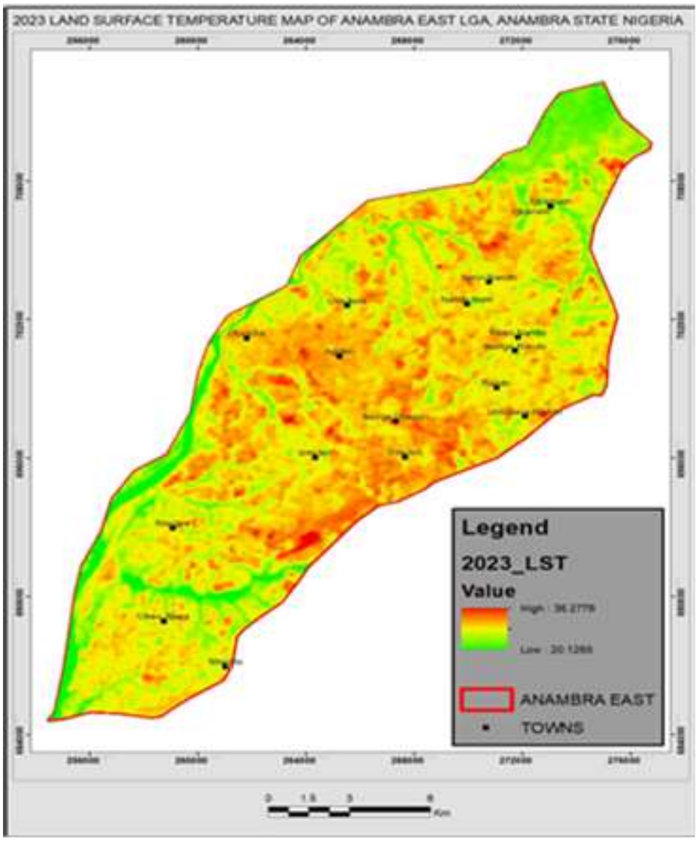

Figure 2: Map of Anambra East LGA, Anambra State, Nigeria Land Surface Temperature (LST) (2023)

The map in Figure 2 shows the spatial distribution of the land surface temperature in the year 2023 and the value of land surface temperature varies between 20.13C to 36.28C, with the areas of high temperatures (red and orange colors) being more prevalent in the central and southern areas, which implies the presence of more surface heating. This can be blamed on low vegetation cover, urbanization and increased human activities. The green depicts cooler areas which are majorly found along riverine and vegetated areas and in the western part. Unlike the previous trends it can be seen that there is a marginal increase in warmer areas which could be an indication of environmental changes like a change in land use or deforestation.

The spatial distribution of land surface temperature in the year 2013 in Anambra East is given in the map (Figure 3) and the values are between about 20.125 o C to 36.2776 o C with hotter regions (red/orange) being found in the central parts which may be ascribed to less vegetation cover and more activities. The green areas represent cooler regions which are more evident in the south and west, which may be the presence of water bodies and thick vegetation. The temperature distribution shows that there was average heating of the surface relative to later years and possible land cover changes and human activities might have got more intense with time thus adding to high temperatures in the later years.

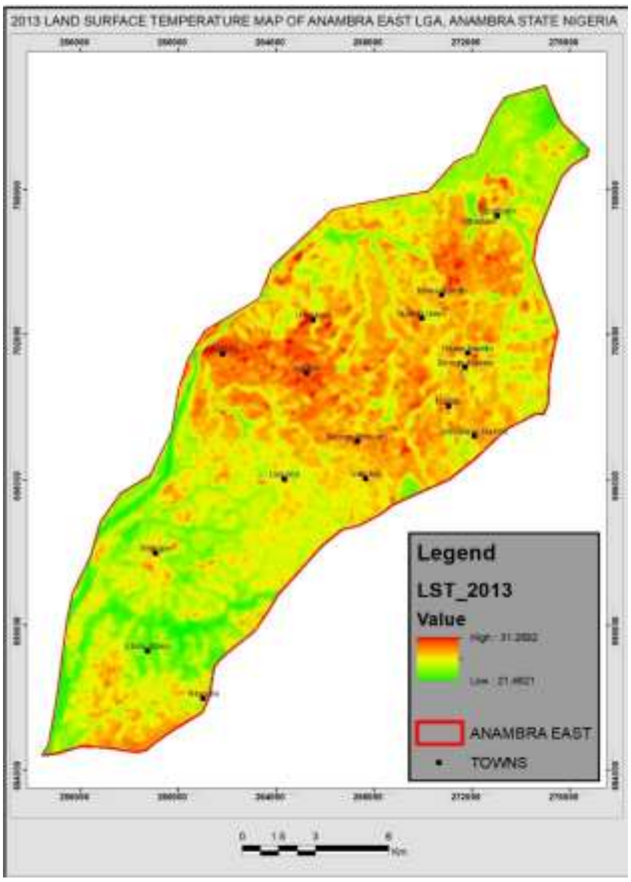

Figure 3: Land Surface Temperature (LST) Map of Anambra East LGA, Anambra State, Nigeria (2013)

From the results of land surface temperature analysis, it was observed that surface temperature was less in 2013 in Study area with 31.2682% while in 2018, it was observed to be 36.2776 and 36.2776 respectively. It was also noted that the mean potential soil loss was minimum in 2018 and 2023. This is thus in agreement with Brooks et al., (2013) who indicated that climate and weather conditions such as rainfall intensity and duration, temperature changes, soil strength, particle size distribution, clay content, infiltration capacity, soil drainage condition, porosity, depth, and stratification, slope steepness, slope length, and slope roughness explained increase in soil loss with a change in temperature. To study land use/land cover and land surface temperature, this paper applied the technology of remote sensing and geographic information system in the study. Various datasets have been gathered and these are field survey data of quarry site and satellite imageries. The ArcGIS 10.2 software was used for data analysis. Based on the analyses, the results obtained indicated that the activities of the quarry cause loss of a farmland, loss of soil fertility and destruction of the basic infrastructures within the study area. The land use categories of the area under study were categorized as built-up areas, quarries, water bodies and vegetation. Between 2013 and 2023, farmland and forest areas had reduced and built-up, quarry, and water were on the increase.

4. Conclusion

Based on the research results on spatiotemporal of stone quarrying in Anambra East Local Government Area of Anambra State, it was found out that the effect of quarrying activities has affected the environment negatively. These have led to land degradation, decline in agricultural output and destruction of properties and other important infrastructure like roads. The paper has also determined that Geographic Information Systems (GIS) and remote sensing methods were effective and reliable methods of examining changes in land use/land cover and land surface temperature over time. In addition, the results showed that there was a significant reduction in the amount of land to be used in agriculture because of the growth of quarry locations. On the basis of these observations, the study proposed the use of land reclamation strategies in order to reclaim degradable areas and enhance agricultural productivity. Moreover, afforestation should be promoted especially planting of trees including cashew and bamboo to minimize surface run-off and erosion of gullies caused by quarry activities.

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