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Determining Suitable Sites for Large-Scale Petrochemical Industry in South Eastern Nigeria Using GIS-Based Multicriteria Analysis

Igbokwe, J. I. [a*], Iwuanyanwu P. E. [a] and Oliha, A. O. [a]

[a] *Department of Surveying and Geoinformatics, Nnamdi Azikiwe University Awka, Nigeria.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Site selection is one of the most important choices in the start-up, expansion, or relocation of any business. Construction of a new industrial system is a significant long-term investment, and identifying the site is a vital step on the path to the success or failure of the industrial system. Site suitability assessment in Southeast Nigeria, like elsewhere, is influenced by inherent conflicts and a complex network of socioeconomic and ecological constraints, necessitating the use of a flexible decision-making support tool capable of incorporating multiple evaluation criteria, including the perspectives of various decision-makers. In this study, a GIS-based multi-criteria approach was used for site suitability evaluation for the large-scale petrochemical industry in Southeast Nigeria. The objectives of the study include reviewing planning concepts and existing planning guidelines for the siting petrochemical industry, defining important factors and criteria needed for the establishment of the industry in the area, determining potential locations for the proposed industry through the combination of these factors, while considering constraints, using multi-criteria analysis and produce maps showing suitable sites. Datasets used for the study comprised satellite images

**Corresponding author: Email: igbokweesom@gmail.com;*

for land use, SRTM, climate data, geology, soil, rainfall and disaster risk. The methodological approach enabled the evaluation of relative priorities of locating sites for the petrochemical industry, based on a set of criteria such as physiography, land slope, distance to river, soil type, rainfall, climate, land use land cover, distance to geological structures, land systems and geomorphology, distance from settlement, accessibility, distance from Central Business District (CBD), and disaster risk. Analytical Hierarchical Processes (AHP) were used in comparing criteria through matrix comparison and derive relative weights of the criteria. The weighted overlay was used to integrate suitability criteria maps to derive the final suitability map. An iterative post-aggregation constraint was applied ·to identify potential sites as a basis for delineating potential areas for the petrochemical industry. The final suitability map showed that 31% of the region was unsuitable for such industries due to the presence of developed areas such as built-ups, and residential and commercial areas. However, 35% of the region had less suitability while about 9% was highly suitable. In general, all the states in the southeastern region had high potential for large-scale petrochemical industries as 37 out of 95 local government areas in the region had highly suitable locations. It was recommended that demographic and environmental impact assessment be implemented in order to ensure suitable or potential sites would be effective and resourceful for the people, communities, and the region at large. In this way, industries can exist with less harmful impact on the environment while promoting economic growth and sustainability.

Keywords: Site selection; EIA; GIS; AHP; suitability assessment; petrochemical industry.

1. INTRODUCTION

Natural resources are the lifeblood of socioeconomic development, serving as the foundation upon which human societies thrive and flourish. These invaluable resources, whether they fall within the realm of renewability or non-renewability, play a pivotal role in fostering human well-being and underpin local and international trade networks [1,2].

Undoubtedly, the global landscape reverberates with the profound significance of the oil and gas industry, an industrial juggernaut that fuels transportation systems and exerts a formidable influence on the Gross Domestic Product (GDP) of nations [3,4]. Within this colossal sector, the petrochemical industry emerges as a vital subset, responsible for harnessing precious chemicals from petroleum and natural gas, thus bolstering a myriad of sectors and fortifying economic interconnections on a grand scale (IEA, 2019), [5].

However, the petrochemical industry, while undoubtedly a potent driver of employment opportunities and economic growth, does not come without its share of environmental challenges that must be addressed [6,7]. The strategic selection of sites for these industrial behemoths becomes an essential conundrum, necessitating a delicate balance between economic prosperity and environmental sustainability [8,9]. In this intricate dance, decision-makers turn to the arsenal of Geographic Information Systems (GIS) and the sophisticated Multi-Criteria Decision Analysis (MCDA) to chart their course, effectively optimizing objectives and deftly navigating the labyrinth of complex decision factors (Carver, 1991), [10].

This research undertaking stands as a testament to the powerful synergy between the realm of computing sciences and the pursuit of better, more sustainable industrial site choices [11,12]. Specifically, it leverages the formidable capabilities of Geographic Information Systems (GIS) to offer invaluable assistance to planners embarking on the intricate journey of petrochemical industrial site suitability analysis [13,14]. At its core, this innovative system functions as an oracle, providing expert guidance to decision-makers and offering recommendations for the most suitable selection criteria values [15,16]. It accomplishes this feat by meticulously analyzing a wide array of data, spanning the domains of physical attributes, environmental factors, geographical parameters, and other pivotal aspects, all working in harmony to facilitate a well-informed and judicious approach to site selection [17,18].

As the journey unfolds, it's imperative to appreciate the myriad facets of this research, and to do so, we must delve into the body of knowledge surrounding natural resource management [19,20], the complex intricacies of the petrochemical industry [21,22], the environmental challenges it presents [23,24], the role of Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA) in

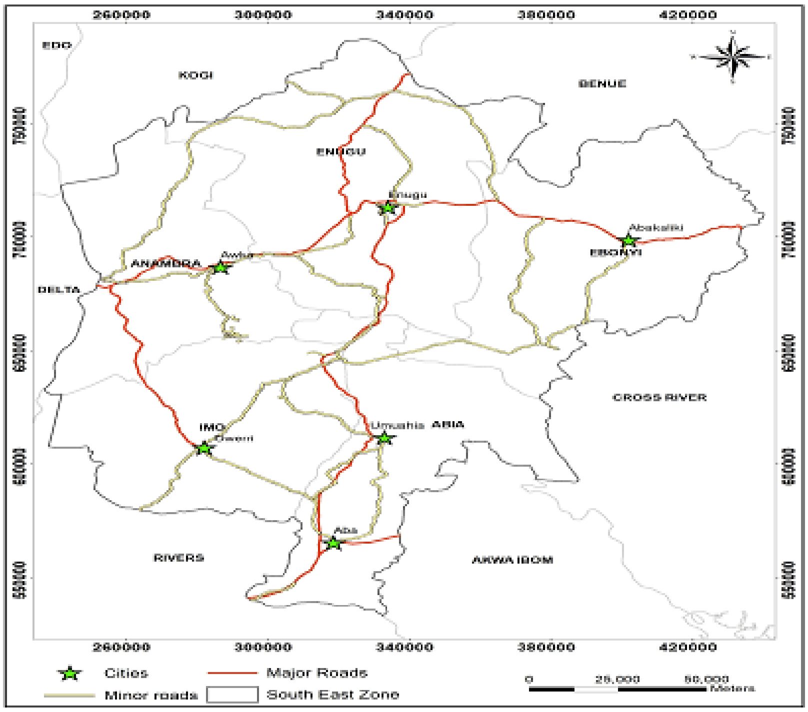

Fig. 1. Map Showing South Eastern States

decision-making [13,10], and the innovative contributions of computing sciences in this field [25,26].

Study Area: The study area encompasses Nigeria's Southeast region, including Abia, Anambra, Enugu, Ebonyi, and Imo states. With a population of over 30 million, primarily of Igbo ethnicity, the region covers 22,525 square kilometers within Nigeria's total land area of 923,768 square kilometers. It is bordered by Benue, Kogi, Rivers, Cross River, and Delta states, with major cities such as Aba, Enugu, and Onitsha among the most populous, contributing significantly to the area's economic vitality.

2. MATERIALS AND METHODS

2.1 Methodology

The methodology adopted in achieving the desired goal included:

a. Research Design
b. MCE Procedure
c. Data Analysis
d. Analytical Hierarchy Process

2.2 Research Design

The investigation employed a combination of survey and experimental design methodologies. A survey was used to assess the economic suitability of specific land use for the petrochemical sector, while an experimental design was employed to evaluate the physical compatibility of the property. The methodology included data collection from primary and secondary sources, encompassing field observations, satellite imagery, documentation, GPS data, and the use of questionnaires to gather essential information. These methods were utilized to process and analyze the data, ultimately leading to the study's results and conclusions.

2.3 MCE Procedure

In the Multi-Criteria Evaluation (MCE) approach, there are three primary hierarchies: decision, objectives, and criteria. The decision involves making a choice among different objectives. Objectives, as defined by J. Ronald Eastman (1995), represent perspectives that guide the formulation of decision rules. Criteria, also defined by J. Ronald Eastman (1995), serve as the basis for measurement and evaluation. Criteria can be categorized into two types: factors and constraints. Fig. 2 illustrates the structure of the Multi-Criteria Decision Analysis (MCE) framework used for identifying suitable industrial sites.

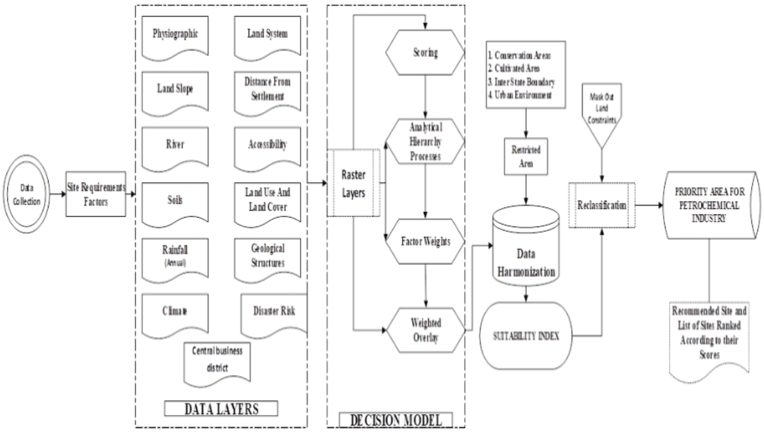

Fig. 2. Flowchart summarizing the methodology for the evaluation of site suitability for the development of the petrochemical industry

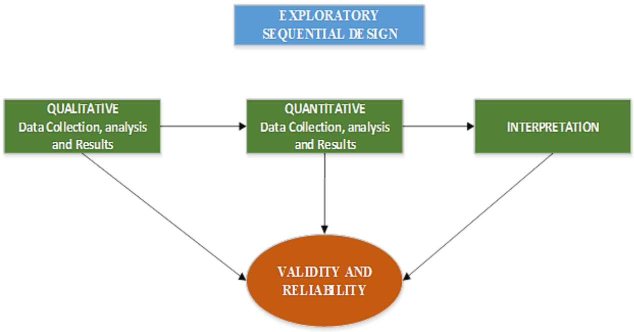

Fig. 3. Explorative sequential mixed methods design

2.4 Data Analysis

The analysis of the processed data employed both quantitative and qualitative methods. The quantitative approach aimed to validate the criteria weights, while the qualitative method sought evidence supporting a specific hypothesis related to a particular event. Empirical theory underpinned this analysis. Criterion suitability maps were used to discern trends, which, in turn, informed the identification of potential petrochemical industry locations through qualitative analysis. The study employed an explorative sequential mixed methods design, as depicted in Fig 3.

2.6 Analytical Hierarchy Process

The Analytical Hierarchical Process (AHP) is recognized as a robust mathematical method for addressing intricate decision-making problems. It calculates criteria weights by systematically comparing their relative importance through a pairwise comparison matrix. In this study, 13 parameters were employed to identify suitable sites for the Petrochemical Industry. These parameters encompassed 9 bio-geophysical, 3 socio-economic, and 1 disaster-related aspects, all of which needed to be represented in geospatial data for seamless integration.

3. RESULTS AND DISCUSSION

Highly suitable areas for the petrochemical industry in the Southeast region are primarily located in the northwest and northeast regions, particularly in Anambra, Enugu, and Ebonyi. These locations are chosen for their consideration of both economic and environmental factors. Conversely, central areas in the region, characterized by built-up, commercial, and industrial zones, are mostly unsuitable or moderately suitable due to their proximity to sensitive structures. Such areas may have a viability of around 50%. Extremely suitable sites are concentrated in the Enugu-Anambra axis and north of Abakaliki, offering high viability due to their minimal environmental impact and potential for economic growth. Only about 3% of the region exhibits very high suitability for petrochemical industries, while 31% is unsuitable due to various constraints.

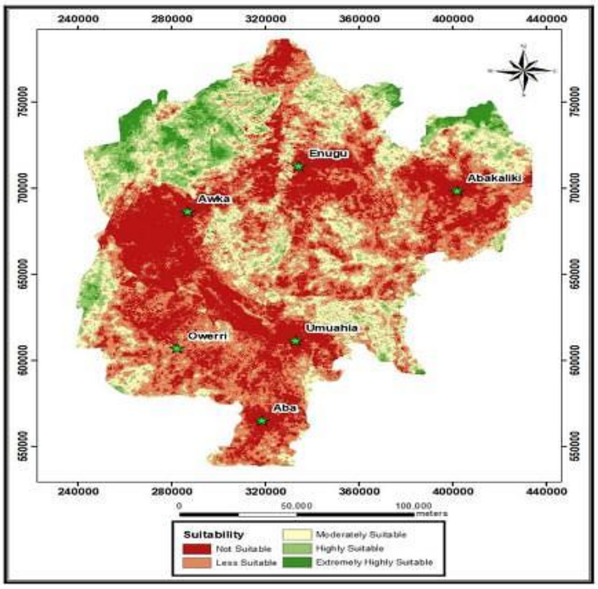

Fig. 4. Site suitability for petrochemical industry in Southeast Nigeria

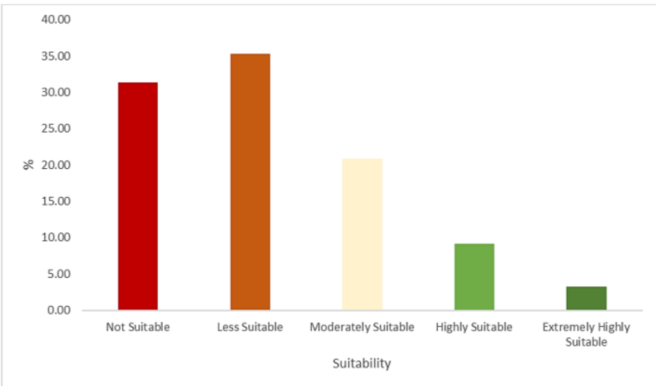

Fig. 5. Site Suitability Extent for each class

In the Southeast region, potential sites for the petrochemical industry are distributed across different local governments within each state. Some states exhibit higher potential than others in terms of area coverage.

Notably, in Abia, four local governments (Bende, Ohafia, Arochukwu, and Umu-Nneochi) have the most suitable sites for the petrochemical industry. Arochukwu, with its large suitable areas, stands out as a highly preferred location. Anambra State has a higher potential for a large-scale petrochemical industry than Abia State. Local governments with the highest potential include Anambra West, Awka, Anyamelum, and Ogbaru. This is due to the large areas of suitable sites within these local government areas. Areas in Ebonyi State, such as Izzi, Ebonyi, and Ohaukwu local government areas, feature large-scale suitable sites, suggesting the industry's capacity to exist in the state's fringes. Enugu State boasts seven local governments with suitable sites, primarily in the northwestern areas. These areas are characterized by their distance from steep slopes and urban centers. Although Enugu has more local governments with suitable sites compared to Anambra, the latter offers more extensive suitable locations. Imo State has the lowest number of areas with high suitability. Local government areas like Ohaji/Egbema, Okigwe, Ngor-Okpala, and Oguta show the highest potential for petrochemical industry sites. These areas are home to easily exploitable natural resources, and the presence of industry could contribute to more sustainable resource utilization, reducing environmental issues.

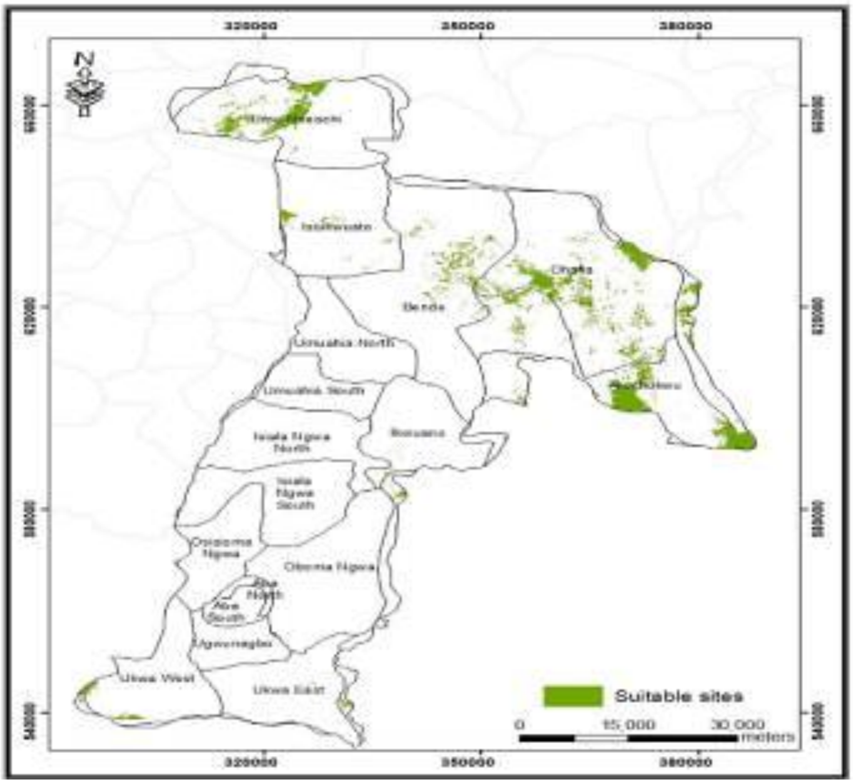

Fig. 6. Suitable sites in Abia State

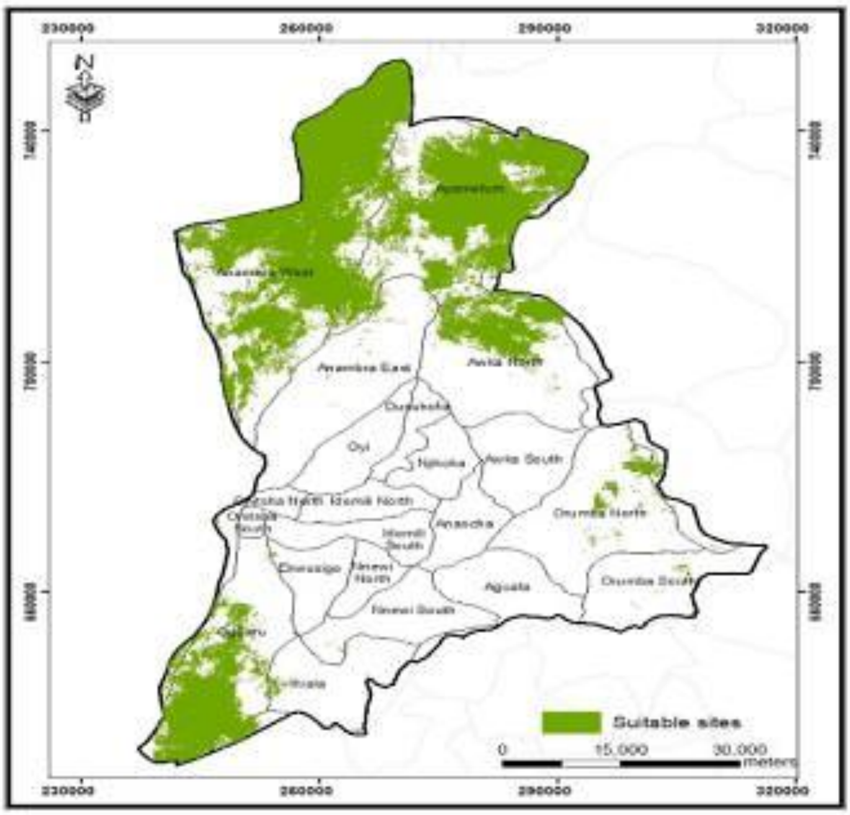

Fig. 7. Suitable sites in Anambra State

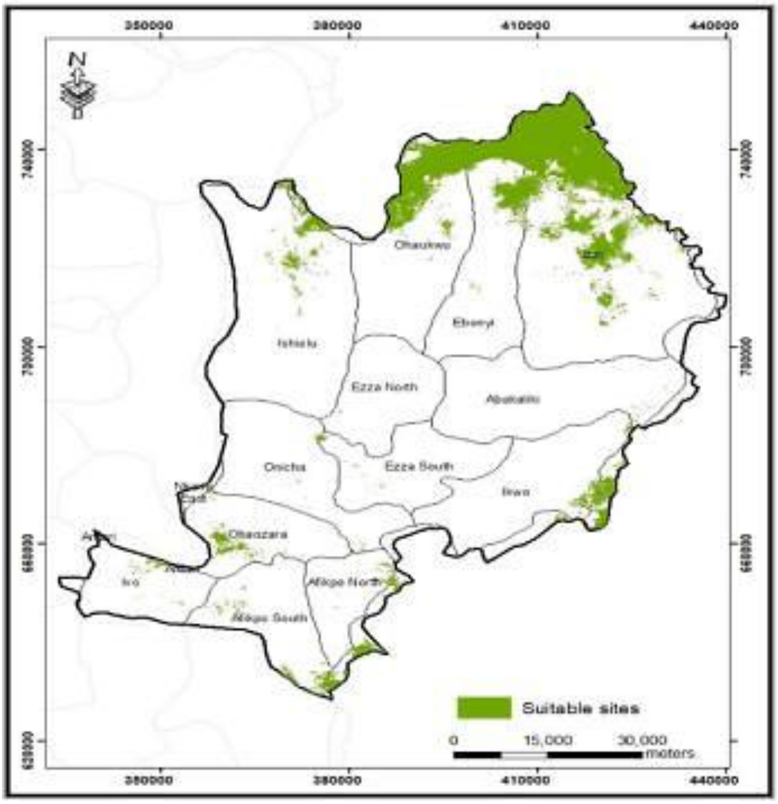

Fig. 8. Suitable sites in Ebonyi State

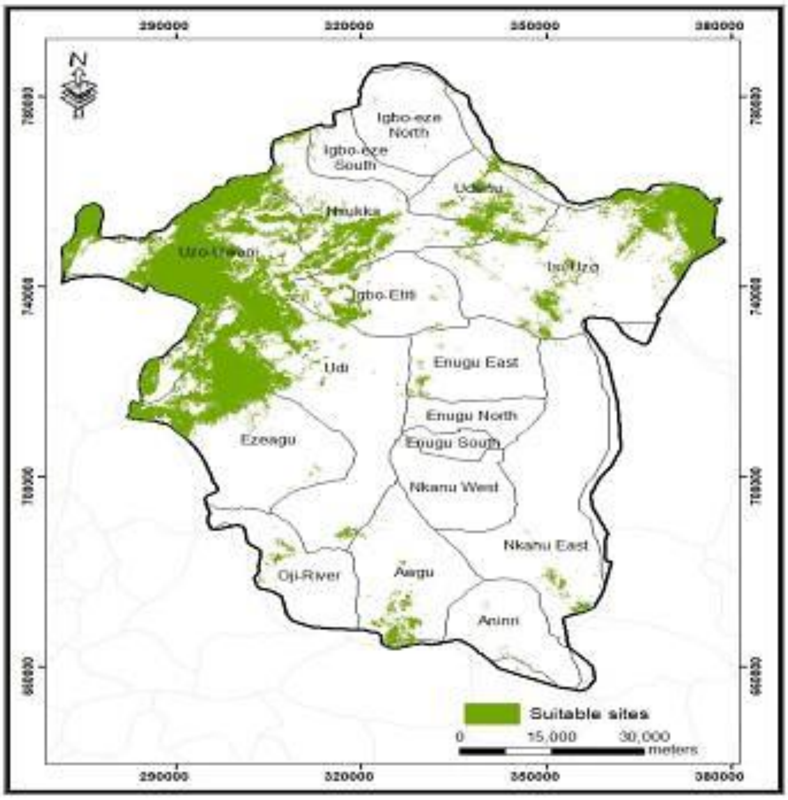

Fig. 9. Suitable sites in Enugu State

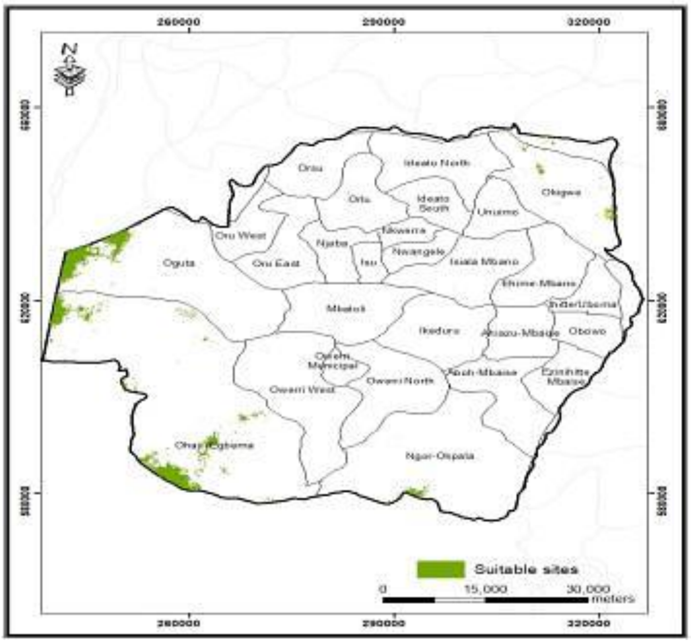

Fig. 10. Suitable sites in Imo State

4. CONCLUSION

In conclusion, this study used GIS-based multi-criteria analysis to identify suitable locations for a large-scale petrochemical industry in Southeast Nigeria. It considered various factors, excluding developed and central business areas, to pinpoint fringe areas as more suitable sites. The findings highlight the region's high potential for such an industry, promoting economic opportunities, resource management, and reduced environmental harm.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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