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Geospatial Multi-Criteria Suitability Analysis Of Proposed Lagos State Airport Site Selection

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Abstract— **The Federal Government of Nigeria recently announced the plan for new airports across the country in order to ease the air transportation system across the country and its connectedness to other parts of the world. However, the adequacies of the declared sites were not empirically supported through a carefully designed suitability assessment; that assured their appropriateness environmentally and geospatially. Thus, this paper examines the geospatial suitability evaluation of the proposed Airport in the Eti-Osa Local Government Area in Lagos State. A multi-criteria suitability analysis (MCSA) concept in a geospatial environment was adopted, using the analytic network process (ANP)del based on reviewed criteria for the airports' site suitability selection. Different thematic layers of the land cover for the assessment were achieved through the geospatial capabilities of Geographic Information System and Remote Sensing, with the various factors' priorities from the ANP model in the final analysis of alternative suitability sites for this proposed airport. The final suitability model revealed different levels of this suitability for consideration by relevant decision-makers for better-informed decisions about the project.**

Keywords— Multi-criteria evaluation; Geoinformation; Analytic Network Process model; Suitability Analysis; Airport Site Selection.

I. Introduction

In conjunction with the recently announced plan for new airports across the country by the Federal Government of Nigeria, aimed to ease the air transportation system across the country, her connectedness to other parts of the world and increased gross national product (GDP) [1, 2], the Lagos State Government has also been intensifying her commitment to the works on the development of a 3,500 hectares of land for Lekki-Epe International Airport to complement activities at the zone. It is designed to handle about five million passengers annually, and with modularly terminal expansion in the future; inclusive of all necessary and phased compensations to respective owners, farmers and necessary stakeholders [3, 4]. Airports are one of the major parastatals in any location within a country, where they are cited that contribute to their economic growth. Generally, airports help mass transportation of goods and services over different destinations locally, regionally, nationally, and internationally, thereby promoting economics transactions for such regions. [5]. As such, there is need for proper airport planning strategy and evaluation of the various conflicting factors and searching for the best among them that will ensure future expansibility and development of existing facilities for sustainability. Furthermore, there are many requirements, such as expansive land areas, large capital, proximities to the existing basic infrastructure, increased volumes on road networks and transportation systems and buffers from the urban and residential areas due to noise and other health hazards to host communities. Thus, there lies the need to carefully study the sites for the proposed airport, with proper evaluation of competing factors that affect the land used potentials of the areas for their suitability.

Land-use suitability is one of the critical challenges in land use planning, which according to Mendoza [6] is generally associated with both the arrangement of factors and the assessment of their effects with respect to probable land uses. On the one hand, suitability [7] is the degree to which a landed property meets the specific types of different land-use patterns, whereas land numerous factors are peculiar to suitability analysis and is considered to be a decision problem; since, according to Rossiter [8], the use to which any land is designated for must be properly documented and suitably planned. On the other hand, assessment of landed areas for a specific function is therefore considered as multi-criteria and multi-stakeholder problem [6]; thus, the need for their multi-criteria decision making (MCDM) evaluations. Meanwhile, MCDM problems are generally geospatial in nature and are generally associated with

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some competing factors. This, necessitates the need for likely trade-offs among these factors and the quest for a thorough and careful scientific and hybrid approach that link GIS capabilities to that of MCDM methodology [9-11].

In this respect, geospatial/spatial multi-criteria decision-making (MCDM) according to Malczewski and Rinner [10], Malczewski [12] is a complex technique that involves geographical datasets from multiple sources with the ultimate goal of transforming them into decisions by stakeholders, and according to Yildirim, et al. [13], these problems are even getting complicated. Therefore, geospatial/spatial MCDM involves the transformation and combinations of geospatial data and criteria weights obtained from the expert judgement for the evaluation of different alternative stakeholders' decisions, so that their complementary benefits could be adequately utilized in arriving at a better and informed decisions by stakeholders [9, 10]. Despite, the current trends and the importance attached to airports site selection cases, there is a dearth of adequate MCDM geospatial consideration in use, particularly with respect to the study area.

From the MCDM literature, the factors were sourced from relevant previous studies from where these quantitative and qualitative factors were reviewed and proved to be satisfactory through experts' opinions. One of the well-known, robust, and most effective decision-making MCDM method is the analytic hierarchy process (AHP) [14-17] as well as advanced type – analytic network process (ANP) model commonly used due to computational simplicity in handling complex multi-criteria decision problems [11, 14-18].

In addition, among the features of the geospatial method is the extraction of viable thematic features from the LANDSAT 8 imagery of the study areas, these are land-use/land-cover (LULC), settlement, slope, drainage, streams and rivers patterns, as well as town and road networks around the project site/location.

This paper therefore critically analyzes the factors for the suitability siting of Lekki-Epe International Airport using the geospatial MCDM approach that incorporates Remote sensing (RS) and GIS with the AHP/ANP model. This ensures the assessment of the experts' judgment of the criteria, and it is written as a supermatrices in the ANP models [19] based on Saaty's fundamental scale of absolute judgment. Thereafter, the most prioritized criteria weights were generated for suitability analysis of siting the airport, and in the context of existing FAO regulations.

The rest of this paper is subsequently arranged as follows: literature, materials, and methods are covered in Sections 2, while in Section 3, the methodology is presented. The results and discussion are respectively made known in Section 4, while Section 5 covers the conclusions.

II. Review of Literature

The planning process in the siting and building of airports has been considered to be complex due to many phases that must be accomplished in the face of many militating and pertinent factors. Interestingly, an hybrid MCDA and GIS based analysis are extremely beneficial in this planning phases [20]. Though, airports and their locations are built not on safety and security concerns only but with the social, economic, environmental, market dynamics, and political implications on where they are located [21].

A. Multi-criteria decision making (MCDM)

The MCDM has over the years been one of the approaches used in decisions support systems and analysis. These methods incorporate experts' views and judgment in the form of weights for the prioritization of the earlier reviewed factors for this study. Previous studies established a number of MCDM in literature, such as the analytic hierarchy process (AHP) [11, 13-15, 17, 22, 23]; Analytic Network Process (ANP) [24, 25]; simple additive weighting (SAW) [13, 26]; Data envelopment analysis (DEA) [27, 28]; Elimination and Choice Expressing Reality (ELECTRE) [29], for evaluation and the subsequent rankings of the factors previous reviewed [30, 31].

B. Analytic Network Process (ANP)

The ANP represents the advanced type of AHP, both developed by Saaty [19], and used in this study. The AHP was conceptualized by Saaty in the mid-1970s and later developed in the 1980s [19]. It is the most widely used method for criteria weights' assessments in MCDM and in spatial MCDM [13, 32, 33]. AHP-based spatial MCDM has the benefit of handling different decision-making problems due to its capability in integrating a vast amount of varied information with a relatively large number of factors, as well as for land suitability analysis [13, 34, 35].

The basic steps involved in the AHP methodology from previous studies [36-39] are adapted in this study as follow:

i. Identify the issues at hand;
ii. Expand the objectives behind these issues and identify the necessary factors that affect them to have the desired outcomes.
iii. Identify all the militating factors for the problems identified to solve;
iv. Express the issues to be addressed in different hierarchies/levels, consisting the goal, criteria, sub-criteria, and alternatives.
v. Arrange the factors hierarchically, based on tree-like structure envisioned in Saaty's AHP model. Thereafter, comparisons of the respective components must be made using the Saaty's Fundamental and numerical scale that ranged from 1 - 9. This requires $n(n-1)/2$ comparisons, n represents these respective components with their corresponding diagonal components, and must be equal or equal to 1, while other components will be represented by the inverse of the previous comparisons. Thus, a pairwise comparison matrix (D) is generated; it consists of elements $\{x_{ij}\}$ of the criteria; where the *ith* criterion represents degrees of its preference to that of *jth* criterion or vice versa, based on Eqn 1.

$$\text{Comparison matrix} \quad D = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ \vdots \\ C_n \end{array} \overset{\begin{array}{ccccc} C_1 & C_2 & C_3 & \cdots & C_n \end{array}}{\begin{bmatrix} x_{11} & x_{12} & x_{13} & \cdots & x_{1n} \\ x_{21} & x_{22} & x_{23} & \cdots & x_{2n} \\ x_{31} & x_{32} & x_{33} & \cdots & x_{3n} \\ \vdots & \vdots & \cdots & \cdots & \vdots \\ x_{n1} & x_{n2} & x_{n3} & \cdots & x_{nn} \end{bmatrix}} \quad (1)$$

Next, and using Eqn 2, compute the Normalized Comparison matrix (R).

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \quad (2)$$

vi. Compute the Eigenvalue, consistency index (CI), and the consistency ratio represented as (μ) using Eqn 3, and those obtained from Eqn 2.

$$\mu = \frac{\lambda_{max} - n}{n-1}, \quad (3)$$

where λmax is the principal eigenvalue for the decision matrix D of n order. The consistency is achieved if this equality $(a_{ij}a_{jk} = a_{ik}, \forall i, j, k)$ condition is true.

The Consistency Ratio (CR) is an important criterion used to established the validity of the survey, and must be <= 0.10 [38, 40]. In addition, CR and CI are linked by Eq 4, through the random index (RI) that represents the consistency index of a randomly produced inverse matrix [11, 41], an example of which is shown in Table 1.

$$\text{CR} = \frac{\text{CI}}{RI} \quad (4)$$

Thereafter, decisions are made on the based on Eqn 4 once the values obtained and those from the normalizations are within the threshold; otherwise, the process must be re-evaluated till it becomes satisfactory.

C. Criteria considered for the proposed Lekki Epe airport

Airports are the gateway to cities; they are important assets to any country that has them for the movements of citizens and their diverse infrastructures, and economics. This ensures the required connectivity of these vibrant industries with other transportation nodes, as well as the management and regulation of air traffic operations [3]. Based on extensive literature reviewed in the study and in line with AHP and ANP models, there were five main criteria identified: Economic, Engineering, Social, Environmental and Cultural, an extract of this review is shown in Table 2. In addition, reviews were also conducted for the sub-criteria identified: Cost, Drainage, Future Development, Grading, Revenue and Employment, Topography, Accessibility, Proximity, Security, and Tourism.

D. GIS data models for site selection

GIS is a means of collecting, storing, as well as the retrieval of spatial data which could be further manipulated and analyzed in order to have necessary spatial output information. It is a decision support tools with great capabilities of combining different geospatial features of interest and the wide attributes [42]. To achieve the desire capability, GIS has many facilities that must be integrated with database systems to ensure the representation of different spatial information. In this respect, GIS provides tools integrating and analyzing land related features for suitability analysis and land-use classes [42].

It is no doubt that the conventional approach of land use planning and site selection is laborious, ineffective and has gradually been replaced by more supple and strategic methods involving hardware, software, data, numerical modeling techniques, and organization procedures. Campbell and Masser [43] focused on the shift in site selection and land use management style in terms of spatial information requirements and their potential usage.

In the studies of Worrall [44], Wang [45] found that 80% of spatially related information are handled by land managers and planners. However, there are still challenges with data accessibility, since most database management systems, especially in developing countries are manually operated. Furthermore, Keech [46] posited that; there are many approaches (such as surveying, photogrammetry, remote sensing, GIS and numerical modeling) that are well suited for land-use management for better planning and outcomes.

A GIS suitability analysis is used to assess ideal locations for establishing any facility. There are different factors identified for such purpose and manipulated within a GIS environment using either a vector or raster data – particularly, with respect to weight site selection [47]. Equations 5 and 6 show the suitability equation [39].

$$\text{Suitability}(S) = \sum_{i=1}^{n} w_i C_i * \prod_{j=1}^{m} r_j \quad (5)$$

Where:
w_i = weights assigned to factors *i*
S = suitability for the airport location
C_i = criteria score of factors *i* for suitability
r_j = constraint *j*

Also, the restriction model is given by:

$$\prod_{j=1}^{m} r_j = (r_{rivers}; r_{proximity}; r_{security} \ \cdots) \quad (6)$$

where:
r_{river} : Restriction related to river location e.t.c.

The raster cells are eventually ranked as suitability surfaces using a scale that ranged from 1 to 5, where 1 represents the least suitable sites and 5 – the most suitable, and based on their respective weights obtained [47]. Moreover, according to FAO [48], there are five-level scales for suitability analysis that was also used in this study: three Suitable (Class S1: Highly Suitable; Class S2: Moderately Suitable; Class S3: Marginally Suitable) and two Not Suitable (Class N1: Currently not Suitable; and Class N2: Permanently not Suitable).

III. MATERIAL AND METHODS

This methodological process for airport site selection can be achieved by a decision model that examines many criteria, and sub-criteria and assigning them relative levels of importance [49, 50]. Based on the adopted G-MCDM, different suitability maps and composite land use for the airport site could be generated [49, 51]. Experts expressed their views by assigning weights to the identified factors and sub-factors using the AHP fundamental scale of 1-9, where 1-Equally important, 3-Moderately important, 5-Strongly important, 7-Very Strongly important, and 9-Extremely important. Subsequently, a suitability score is obtained by multiplying the weights by the rank; it is thereafter used to identify the most suitable locations for the airport development, [49, 52], as shown by Equations 5 and 6.

A. Study Area

The site considered in this research is the Lekki Epe Free trade zone (LEFTZ) area of the Lagos State, Nigeria. The zone is roughly 60 km to the east of the city center of Lagos and has an area of 16500 hectares, and is located in the Lekki Peninsula (6°35'9"N and 3°52'38"E). The site for the new Lagos International Airport is within 10km from LFTZ, the LEFTZ has a flat topography with attractive scenery. It is bounded by the Atlantic Ocean in the south, and Lekki lagoon in the north [53].

B. Instrumentation and software

The following software was used in this study:

i. Microsoft Office package
ii. SuperDecision software
iii. LANDSAT – 7 TM Imageries (30m Spatial Resolution)
iv. ASTER-DEM (30m Spatial Resolution)
v. Topographic sheet
vi. Digital map of Eti-Osa Local Government Area
vii. ArcGIS 10 suite
viii. ERDAS Imaging

C. *Questionnaire design*

Based on the outcome of the literature reviewed, a AHP/ANP structured questionnaire was designed, after it has gone through four rounds of Delph process for reviews till a consensus was reached among them concerning the full criteria for this study. Thereafter, the structured questionnaire was later administered to selected experts. Their responses were entered into the SuperDecision software environment.

D. GIS data layer and modelling

The data in the Table 3 shows the various data layers, and sources of data used in carrying out the suitability analysis of the proposed airport. These layers were used to process the satellite image of the Eti-Osa Local Government Area.

A sequence of geoprocessing tools in ArcGIS Model Builder was implemented for the workflow’s models.

IV. RESULTS AND DISCUSSION

A. Results from the SuperDecision analysis

Figure 1 shows the implementation of the responses received from the experts in the SuperDecision software environment with their respective priorities from the factors earlier reviewed were obtained. The priorities of the factors, and the alternatives from the SuperDecision software were analyzed by ensuring that each normalized cluster is equal to 1, while the normalized limiting values indicate their respective priorities; an example is shown in Table 4 for sub-criteria for the first main criteria – Engineering criterion.

Analyses of the priorities shown reveal that project management is given more priority having 44.221% then followed by Topography (25.591%), Airport Type (15.721%), Geological Characteristics (8.1%), and Drainage (6.367%) with the least priority. Whereas, for Environmental factor, Land use/ Land cover is given more priority having (43.074%) then followed by Security (25.257%), Accessibility (17.857%), Weather/ Climate (9.477%), and Environmental impact (4.334%) with the least priority. The priorities were later used for GIS suitability analysis.

B. Results from the SuperDecision analysis

The final result from the modeling workflows of thematic layers is shown in the Figure 2. The analytic capability and power of GIS through the creation, visualization, and management of geospatial and non-spatial data and their interrelationships were well demonstrated in previous studies [49] that the outcomes of this study supported.

C. Modelling of the suitability

Among the goals of this study is to determine the suitability of the new Lagos airport site via multi-criteria analysis of the studied factors within a GIS environment. This was done using the Weighted Overlay toolbox in ArcGIS to model the thematic layers of different thematic areas such as proximity, the drainage network, land-use/land-cover, the road network, water, elevation, and geology. The factors earlier identified are multi-criteria in nature and are well suited for overlay analysis based on the priorities obtained from these factors. Figure 3 shows the suitability map of Eti-Osa with Legends 1 to 5 (N2= Permanently not Suitable; N1 = Currently not Suitable; S3 = Marginally Suitable; S2 = Moderately Suitable; and S1 = Highly suitable) for Airport citing.

TABLE 1.
THE EXAMPLE OF GENERATED RI VALUES

n	*1-2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
R.I.	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

TABLE 2.
THE REVIEWED LITERATURE FOR THE MAIN CRITERIA USED IN THIS STUDY

Factors	**Literature Review**
Social	**[54-63]**
Environmental	**[55, 57-60, 62-74]**
Economic	**[54, 57, 62, 63, 65, 67, 68, 73, 75-78]**
Engineering	**[68, 79-81]**
Cultural	**[73, 82]**

TABLE 3.
DATA: TYPES, LAYERS, AND THEIR VARIOUS SOURCES

S/N	**SEGMENT**	**DATA**	**DATA LAYERS**	**SOURCE**
1	Secondary Data	Google Earth Imagery	Imagery	Google Earth (Digital Globe)
2	Primary Data	Digitized map of Study Area	Base Map	Authors
			Settlements & Relocation maps	
3	Secondary Data	Digitized Road	Road Network	Open Street Map
4	Secondary Data	Digitized River & Drainage	River & Drainage Network	Open Street Map
5	Secondary Data	LANDSAT 8 satellite imagery of the Study Area	Multispectral Image	USGS official website (www.earthexplorer.usgs.gov)
			Land Use /Land Cover	Authors
6	Secondary Data	SRTM	Elevation Map	USGS official website (www.earthexplorer.usgs.gov)
			The Slope Map	Authors
7	Secondary Data	Population Data	Demographic Map	Lagos State Lands Bureau and Surveyor General Office
8	Primary Data	GPS coordinates of points within the study area	Points of Interest (POI)	Authors' GPS receiver
9	Primary Data	Questionnaire data	Priorities	Authors

TABLE 4.
EXAMPLE OF GENERATED RI VALUES

Name	**Normalized**	
	By Cluster	**Limiting**
A1 Project management	0.44221	0.03735
A2 Topography	0.25591	0.021615
A3 Airport type	0.15721	0.013278
A4 Geological characteristics	0.081	0.006841
A5 Drainage	**0.06367**	**0.005378**

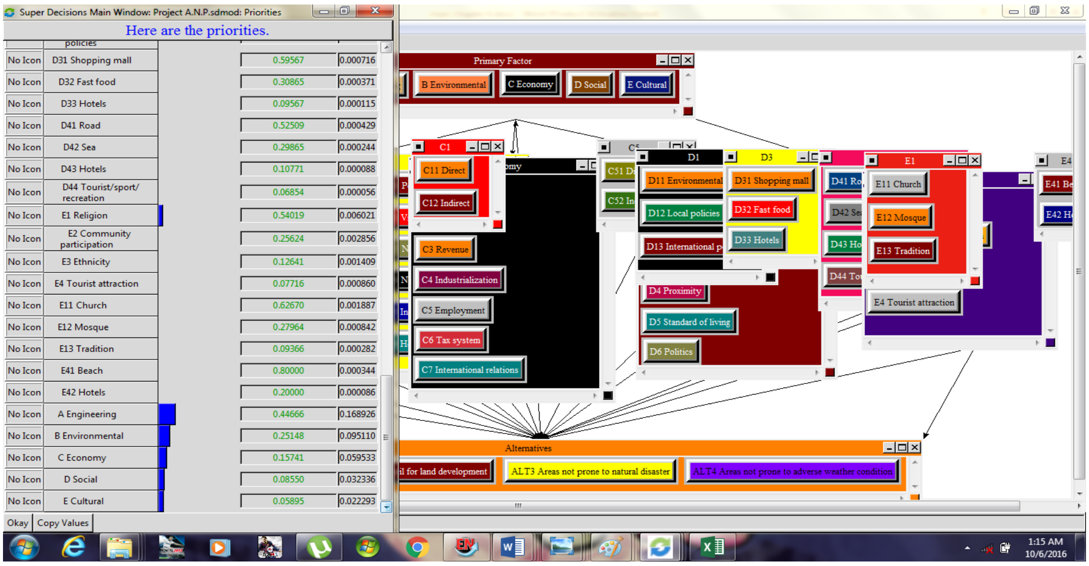

Figure. 1. ANP Model with criteria weights in SuperDecision software

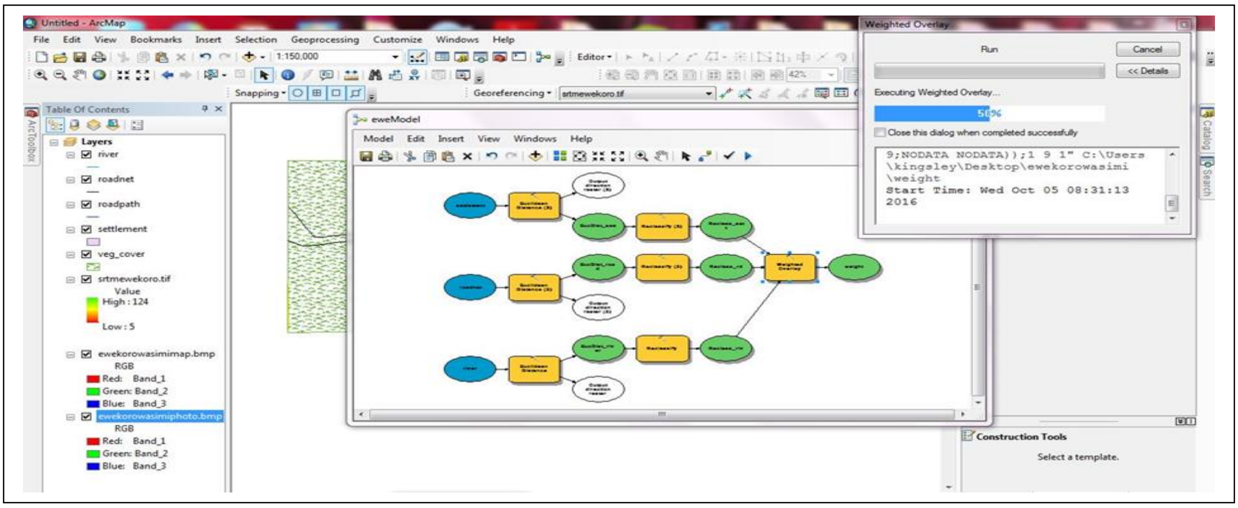

Figure. 2. Final modeled workflow for Lagos International Airport Suitability

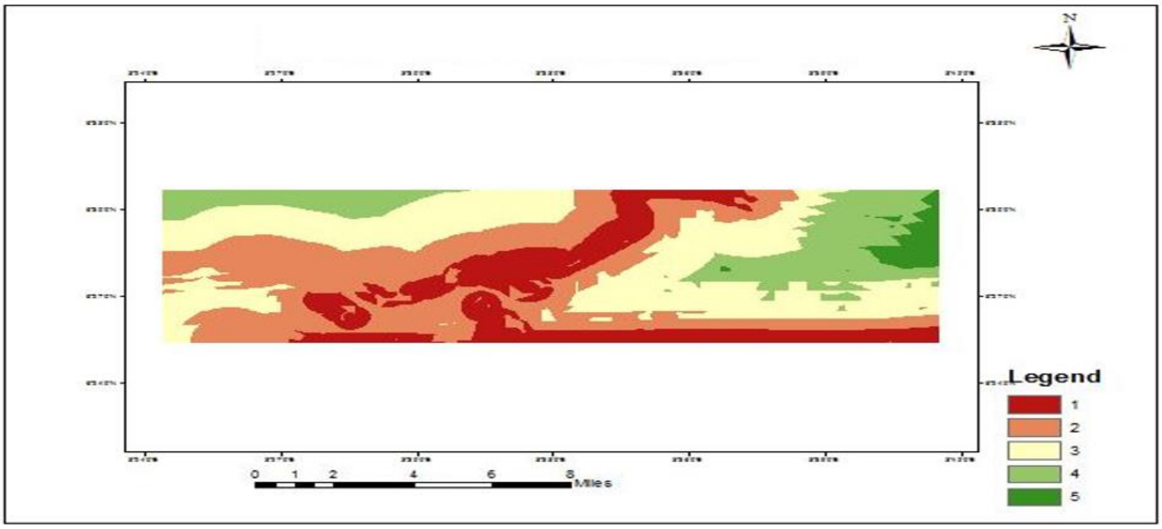

Figure. 3. Suitability map of Eti-Osa

V. CONCLUSION

In this paper, site suitability and selection for Lagos International Airport Lekki, Lagos, Nigeria was investigated based on geospatial MCDM methods that incorporate an AHP/ANP structure for the identified criteria for this study and implemented in the ArcGIS environment. The applications of GIS as an effective tool cannot be over-emphasized as demonstrated in this study for airport site selection, planning and decision-making. The processes involved in the selection of airport sites, such as the formation of the suitability criteria through the AHP/ANP structure, screening of the sites, and site evaluation are generally multifaceted and significantly impact investments that are put into their planning. This could be achieved on the one hand, through a combined system that enables analysts to find optimum airports locations. On the other hand, the combined GIS and ANP system helps in determining the accurate suitability criteria and values for their selections; thus, this integration is particularly imperative to the various stakeholders and decision-makers. Moreover, Landsat Thematic Mapper images (Landsat TM) were used for spatial analysis to detect and classify the various land cover types of that area. Moreover, other datasets used are those through the DEM including network delineation, slope, and boundaries were obtained from ASTER images. Thereafter, these datasets were further analyzed in order to choose the best airport site location around Lagos Eti-Osa Local Government Area. Future studies using other soft computing methods could also be used in carrying out further analyses.

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Author Contributions

Isa Adekunle Hamid-Mosaku: Supervision, Conceptualization, Methodology, Data analysis, Reviewing, Editing, Validation, and Coordination of research. Paul Ugochukwu Ngadi, David Oluwafemi Osoba, Abdulkareem, Ademola Idris, Peter Akpabio, Kehinde Morenike Oseni, Adewale Anthony Ademuyiwa, Solomon Adetayo Adegoke: Data Curation, Satellite data analysis & Validation, Visualization, Methodology, Manuscript writing, and Editing.

Conflict of Interest

There is no financial conflict of interest or personal relationship that could influence the outcome of this manuscript.

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