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Spatial Multi-Criteria Analysis (MCA) for Airport with Air Traffic Control Tower Site Selection based on GIS Platform

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Spatial Multi-Criteria Analysis (MCA) for Airport with Air Traffic Control Tower Site Selection based on GIS Platform

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Spatial Multi-Criteria Analysis (MCA) for Airport with Air Traffic Control Tower Site Selection based on GIS Platform

ABSTRACT

Air transportation is fast growing, and safety is of paramount importance in order to protect lives of passengers and crew as well as the properties of commercial airlines and airports facilities providing services to air travelers. To maintain safety and minimize the risk of air traffic accident, it is necessary to put in place adequate infrastructures like the airports with air traffic control tower that will support air traffic and provide accessibility to passengers utilizing air as a medium of transportation to move from one location to the other. Choosing a location to site an airport can be a complex problem because of multiple factors such as maneuverability of aircraft, movement of passengers, location of warehouse and government authorities like security, immigration and customs which need to be considered and most times are influenced by personal interest, political interest or religious affiliations while neglecting safety. Furthermore, airport is a gigantic project that requires substantial allocation from the federal budget in order to fund it, and hence requires careful consideration and critical analysis to make sure that such a project will maximize its potential when completed. Geographic Information Science (GIScience) based approach which is devoid of human influence can be used in solving a complex problem like choosing a location for airport with air traffic control tower. In this study, GIScience based approach such as spatial multi-criteria analysis (MCA) which combines analytic hierarchy process (AHP) with experts' opinion is used to build a model which produced suitability map for site selection of airports with air traffic control tower in Nigeria. This study discovered that distance to road network (38%), distance to settlement (26%), and slope (12%) are the most contributing criteria in the suitability map. Comparative analysis also showed that 10.4% and 58.3% of existing airports with air traffic control tower are in areas classified as highly suitable and moderately suitable respectively.

KEYWORDS

Airports

Air Traffic Control Tower

Analytic Hierarchy Process (AHP)

Expert’s Opinion

Geographic Information Science

Safety

Spatial Multi-Criteria Analysis

Suitability Map

ACRONYMS

AHP – Analytic Hierarchy Process

AIM – Aeronautical Information Manual

ANP – Analytical Network Process

ATC – Air Traffic Control

CIA – Central Intelligence Agency

C.I – Consistency Index

C.R – Consistency Ratio

DEM – Digital Elevation Model

ESRI – Environmental System Research Institute

EVCARD – Electric Car

FAA – Federal Aviation Administration

FAAN – Federal Airport Authority of Nigeria

GIS – Geographic Information System

GIScience – Geographic Information Science

IATA – International Air Transport Association

ICAO – International Civil Aviation Organization

MAS – Multi Airport System

MCA – Multi-Criteria Analysis

MCDM – Multi-Criteria Decision Making

NCAA – Nigeria Civil Aviation Authority

OSM – Open Street Map

R.I – Random Consistency Index

S.I – Suitability Index

USGS – United States Geological Survey

WLC – Weighted Linear Combination

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1. INTRODUCTION

1.1 Theoretical Framework

Air transportation is one of the fastest growing industries in the world and has traversed many industries and technologies (Jiang Chunshui, 2012; Purwaningtyas, Trisetyarso, Abdurachman, & Suparta, 2020). Expansion in air traffic has equally resulted in expansion of airspace where air transportation is being conducted (Max Z. Li, 2018). To support the expansion of airspace in order to accommodate more aircrafts' movement and maintain air safety, infrastructure such as the airport with air traffic control tower need to be readily available. Airport is a defined area on land or water (including any buildings, installations and equipment) that meets certain guideline and intended to be used either wholly or in part for the arrival, departure and surface movement of aircraft (ICAO, 2016). A 20 year market outlook from 2005 to 2024 by Boeing airplane manufacturing company in Seattle Washington, USA has projected that worldwide passengers' traffic growth will average at the rate of 4.8% per year, cargo traffic growth will average at 6.2% per year, and the world fleet will grow to 35,300 passenger and cargo jets (Boeing, 2005). International Air Transport Association (IATA) which is the global trade association of 230 registered world airlines in 118 countries has projected that global air passengers' transportation will continue to grow in the range of 1.5% to 3.6% over the next 20 years post COVID19 (IATA, 2021). This means that airspace will experience an increase in volume of flight operations which will lead to expansion in the airspace or different approach in which airspace management is currently being conducted. Air traffic control towers are the equivalent of ground traffic lights that manage air transportation and separation of air traffic in a given air space so as to avoid any air traffic accidents or incidence (near misses) during flight operations (FAA, 2021). Therefore, airports with air traffic control towers provide air traffic control services thereby improving the safety measures in the airspace (Grishin & Timirgaleeva, 2017). Other services that airports with air traffic control tower provide include radio communication services for air operation, navigational aids, weather reporting services, airport lighting equipment for instrument arrival and departure, rescue and fire-fighting equipment for emergency services (ICAO, 2016).

Nigeria as a developing country is faced with perpetual air mishap that seriously retard the sustainable development of the nation and weakens her aviation sector from developing to its full potential which is a lot of concern to the policy makers and general public (Daramola, 2014). A 52 year analysis of civil aviation accidents in Nigeria from 1960 to 2012 revealed a recurring pattern which suggests the need to improve the safety of her airspace (Oluwakoya, 2020). Segregation of airports with air traffic control tower in a given airspace can be random instead of systematic especially in a developing country like Nigeria where major decisions are being influenced by political or personal interest and this may not adequately provide good coverage to the airspace for efficient management and safe conduct of air transportation. Secondly, siting of airport with air traffic control tower can be a complex task because of the different amenities and resources that need to be integrated together such as maneuverability of aircraft, movement of passengers, orientation of runway, taxiways, apron, terminal building, location of airport security, immigration, customs, parking areas for aircraft maintenance, cargo warehouse, office building for airlines, freight forwards, and other tenants of the airport. This lack of adequate coverage and management of the airspace can pose a risk to air transportation and severely impact the safety of air traffic in the region. To mitigate this risk, GIScience can be applied as a tool in selecting location of airports with air traffic control tower for good coverage and adequate management of airspace and to improve the safety of air transportation in the region. This can remove any bias or personal interest in siting an airport since it is based on scientific methods. The spatial multi-criteria analysis methodology used in this research project will involve applying analytic hierarchy process (AHP), (Jacek, 2007; Saaty, 1990) which incorporates experts' opinion in order to find suitable locations for airports with air traffic control (ATC) tower so as to improve the safety of air traffic and provide adequate coverage of airspace in Nigeria which will minimize the risk of aviation accidents.

The paper is structure in the following way. Chapter 1 presents the motivation and the context of airports that include air traffic control tower site selection. Chapter 2 provides literature review on related works and the research gap. Chapter 3 addresses the methodology that was applied and how the analytic hierarchy process (AHP) which incorporates experts' opinion was used to assign weights to each criterion. Chapter 4 displays the results. Finally, Chapter 5 discusses the results, limitations of the study, and prospects for future works; while Chapter 6 ends with conclusion.

1.2 Study Area

The study area of this research work is Nigeria which is located in the western part of the African continent as shown in figure 1 below. The geographic coordinates of Nigeria lies in 10 00 N, 8 00 E with a total area of 923, 768 square kilometers, a coastline of 853 kilometers (530 miles), and is bounded in the north by Niger Repulic, in the north-east by Chad Republic, in the east by Cameroon, in the south by Gulf of Guinea and Atlantic Ocean, and in the west by Benin Republic (CIA, 2020). The southern part of Nigerian physical geography is lowland that merge into the hills and plateaus of the central part of the country with the north being mostly plain land while the mountains can be found in the southeastern part of the country. The highest point in Nigeria is Chappal Waddi which stood at 2,419 meters above the sea level, and the lowest point is along the coast of Atlantic Ocean at 0 meter (CIA, 2020). Nigeria weather pattern alternates between the rainy and dry seasons around the year with three distinctive climatic conditions that range from equatorial type of climate in the south, tropical in the central and arid in the north. Nigeria with a human population of 206.1 million (World Bank, 2019) is endowed with a lot of natural resources among which are natural gas, petroleum, tin, iron ore, coal, limestone, niobium, lead and zinc (CIA, 2020). Some attractions such as landmarks and wildlife's reserves that can be found in the country include Chad Basin National Park, Yankari National Park, Cross River National Park, Zuma Rock, Gashaka Gumti National Park, Kainji Lake National Park, Kamuku National Park, Okomu National Park, Old Oyo National Park (Adekunle Anthony Ogunjinmi, 2013), thick rainforest, and rare primate habitat. The economy of Nigeria relies heavily on crude oil export as the main source of foreign exchange. The lucrative foreign exchange from crude oil export has positioned Nigeria as the largest economy in sub-Saharan Africa with emerging middle class (Timothy O.Olawumi, 2020) who dwells in large cities and urban centers such as Lagos the financial hub of the country and Abuja the capital city of the country. In addition to economic growth from crude oil export, air transportation has equally contributed substantially in socio-economic transformation of the country such as in the promotion of trade, facilitation of tourism, creation of jobs, and rapid movement of people, goods and services from one place to the other (Onyinye Ogonna Onwughalu, 2021). Despite all these, lack of adequate airport infrastructure and poor safety policy still remain a challenge in the country (Onyinye Ogonna Onwughalu, 2021). Although there has been expansion in the volume of air traffic, but deteriorating airport infrastructure and poor air safety practices have resulted in poor safety performance in the Nigerian aviation industry (Daramola, 2014). Statistics has shown that Nigeria has one of the poorest air safety records in the world with 45 accidents involving 781 fatalities between 1985 and 2010 (Daramola, 2014). Between the year 2011 and 2015, the administration of President Goodluck Jonathan embarked on an Aviation Roadmap initiative in order to transform the Nigerian airports and to pave way for reformation of Nigerian civil aviation industry to align with global standard (Salisu Paul Ojonemi, 2019). Consequent upon this, a viable scientific approach such as Geographic Information Science can be used to find suitable locations for airports with air traffic control tower in Nigeria in order to mitigate the risk of aviation accidents by providing adequate controlled air traffic services and improve the safety records of air transportation in the country.

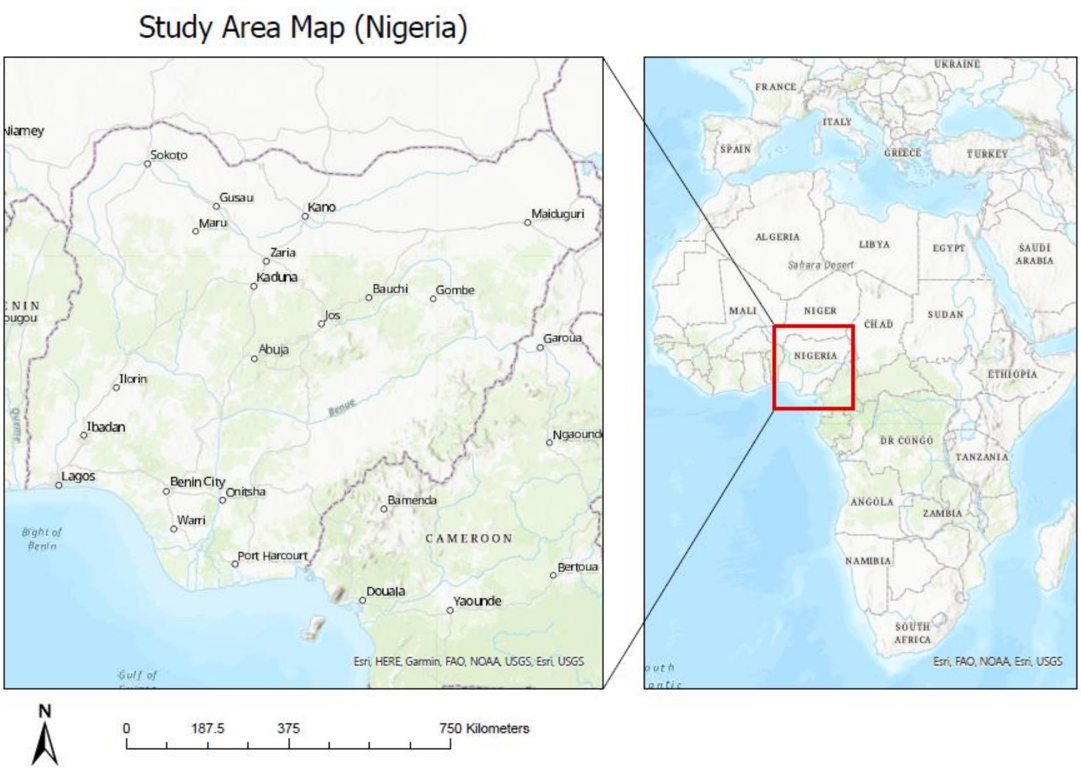

Figure 1. Study area

2. LITERATURE REVIEW

Geographic Information Science (GIScience) is a discipline and a tool that studies and performs wide range of spatial analysis on geographic objects and the relationships between them (Goodchild, 1992). The combination of GIScience and remote sensing enables time saving, reduce exposure to life threatening risks and enable projects to be carried out with limited material and human resources. This literature review will provide an overview on how Geographic Information Science (GIScience) has been applied in site selection of different projects at various locations such as in aviation, landfill, wind farm, multi energy farm, car sharing and much more.

To select a site for airport project, several criteria have to be taken into account which may be influenced by other factors such as the nature of the airport (whether the airport is for civilian or military purposes), type of operation (whether it will operate under instrument or visual flight rules), type of flight (whether it will accommodate heavy aircrafts or just light aircrafts) or nature of activities (whether it is both for passengers and cargo activities or separate for each). In their study (Cláudio Jorge Pinto Alves, 2020) proposed airport site selection methodology termed MESA. This method relies on analytic hierarchy process (AHP) and experts' judgment to score and rank each criterion. In the context of Brazil where this study was carried out, the authors nominated experts from various fields such as in airport construction, airlines, airport regulation, regional development, transportation, planning economics and the academy in their scoring criteria. They also recommended the need for public participation process for acceptance when using MESA to site an airport in a given region in order to fully realize the purpose of siting the airport in that region. The authors also carried out a sensitivity analysis in order to eliminate the subjectivity of experts' judgment, and to improve efficiency of the method. Choosing site to construct a new airport in order to promote tourism and attracts foreign investment or upgrade existing airport so as to accommodate air traffic expansion and maintain air safety can be done using Geographic Information Science (GIScience) approach. In (UCHE Eugene Onyebuchi, 2011), geospatial technique was used to investigate the proposed extension of existing airport's runway of Margaret Ekpo International Airport in Calabar, Nigeria. The criteria for consideration in the expansion of existing airport's runway include land use, ecosystem, settlement, economic benefits, cost, noise pollution, accessibility, safety and security. Their methods took into consideration the impact of extending the existing runway to settlements, roads, river, forest and low laying marshy land within the limit of the proposed extension. The authors carried out a land use classification of their study area using remote sensing to check the accuracy of their method. They went further to carry out geotechnical test as well as analysis of the study area in order to make recommendation for further investigation. Safety is an important factor when dealing with air traffic congestion at regional airports. Some of the reasons for using GIScience approach to site an airport is for air safety and accessibility by air travelers. In the study of Italian regional airports, (Maria Nadia Postorino, 2012) suggested using Multi-Criteria Decision-Making (MCDM) method to identify airports' locations and the role each airport plays within a given geographic locations. This will help to rank airports in a regional Multi-Airport System (MAS) over a period of time. The ranked airports will leverage on the advantages of their locations to provide an efficient and tailor-made air transport services to customers within the region. The siting of new airport is a complex task, hence the co-operation of scientists from various discipline is a necessity in order to achieve this purpose (Athanasios, 2003). The author opinioned that a thorough investigation of existing criteria such as land use, meteorology (wind), safety and security, accessibility, cost, construction, environmental and social impacts (noise and air pollution) have to be taken into consideration before choosing a site to erect an airport. In this study, scientists from different disciplines resorted to eliminatory alternatives based on their expert knowledge to rank each criterion and narrow down to the most important criteria for the proposed project. The proposed multi criteria method is combined with analytic hierarchy process (AHP) to produce a suitable airport site. In the context of Semothraki Island in Greece, which is the study area of this research work, policy makers can rely on this approach for decision making regarding the best site selection and development of a new airport. In order to help decision making when it comes to expanding an existing airport so as to maximize its economic benefits and minimize the potential negative impacts this expansion work will have on the immediate environment and other infrastructure, it is necessary to take into account multitude of criteria that are relevant to the project at hand (Ron Vreeker, 2002). Three different methods namely Regime Analysis, the Saaty Method and Flag Model were combined in this research work for the case study of Maastricht area in the southern part of the Netherlands. Multi-criteria spatial analysis is a powerful method in the siting and development of airports' hub systems in air transportation for a given region (Maria Rosaria Guarini, 2018). In their work, they argued that this is necessary because air transport traffic has seen continuous growth both by the number of passengers that uses air transport and the volume of cargo that are transported in commercial and cargo aircrafts. In their work, they stated that global air traffic doubles every 15 years and European as well as Italian air traffics have witnessed a 4.5% and 4.9% continuous growth respectively since November 2015. In their opinion, Geographic Information System (GIS) approach can be used to develop multi-level air transportation hub systems that will rank each airport based on their number of flight operations as well as passengers and cargo throughput which in turn will help decision makers in choosing appropriate site in locating new airport to enhance efficiency of air transportation and maximize the economic benefits of the project. Demand due to expansion in passenger's traffic can put a lot of pressure on infrastructure that supports air travels such as airside runway. In her work (Milan, 2015), applied multi criteria decision making methods in ranking different runways for three candidate airports in London, United Kingdom. Multi criteria decision making assessment combined with analytic hierarchy process (AHP) was used to evaluate if more airports are required in the city of Cape Town in South Africa (Davina Zietsman, 2014). The authors identified five clusters of criteria in their method which included socio-economic development, spatial and urban planning, transportation improvement, environmental preservation, and financial viability. They explained that not all of these criteria were applicable for use as including all will result in double counting, redundancy and unnecessary large structure. In addition, some criteria do not have attributes and others were of insignificance importance to the project at hand. Their method which incorporates local experts' judgment concluded that more sites for locating new airports to serve the city of Cape Town are currently not required since the passenger capacity in the city is below the threshold of 27 million passengers per year that requires multi airports' city.

Geographic Information Science (GIScience) approach has not only seen applications in selecting a site for airport's construction, expansion of existing airport's runway, or choosing of regional airport hub for passenger's traffic but also in other field such as selecting where to construct an energy farm for power generation and other social-economic needs or for environmental protection. In choosing a site for wind farm location in Nigeria (Mayaki E. A, 2018), identified four criteria namely proximity to power demand, distance from airport, average wind speed, and interference with existing shipping route. In scoring weights to the criteria and ranking them according to their relative scale of importance, analytic hierarchy process (AHP) was combined with Fuzzy TOPSIS to make a selection of the suitable sites for the project. Another study to site a wind farm in Nigeria was carried out by (Ayodele T.R, 2018). They identified different criteria which were grouped under environmental, economic, and social factors. Type 2 Fuzzy analytic process was the method that was implemented in their study. In the siting of wind turbine farm in the New York State of the United State of America (Rob van Haaren, 2011), implemented a three stage ranking of multi-criteria methodology and narrow it down to the most relevant criteria based on land use and geological constraints. The result of their study was then compared to the existing wind turbine farms. This method can be relied upon in choosing the most suitable sites for constructing a wind turbine farm in a large geographical area especially now that climate change is threatening the sustainability of the world source of energy.

Other areas that have seen the application of Geographic Information Science (GIScience) methods in choosing a site apart from airports and energy farm is in landfill for the appropriate management of solid wastes. Spatial multi-criteria decision technique was proposed by (Hala. A. Effat, 2012), in locating potential landfill sites for adequate management of solid waste disposal in the Sinai Peninsula of Egypt. The authors grouped all the criteria under three theme namely environmental, economic, and social themes. From the three different themes, suitability index maps were produced for each city in the investigated region. This method presents several options to stakeholders for good decision making in developing efficient waste management system especially where there is inadequate funding and limited resources. A study to choose appropriate landfill sites location for waste management in Kano, Nigeria was carried out by (Abubakar Aminu Usman, 2015). They identified eleven criteria which were further classified into two group namely the constraint criteria and the factor criteria. Boolean logic, Fuzzy technique and analytic hierarchy process (AHP) were used to assign weights to the different criteria. The overlay maps from the two classified criteria produced a final suitability map for locating landfill sites. Other works by (Khoshand, 2018; Hakan Ersoy, 2009; Tercan, 2020; Johannes Langemeyer, 2016) additionally displayed the use of spatial multi criteria analysis in selecting landfill sites for adequate waste management in Iran, Turkey, and Germany respectively. They argued that landfill is in the very fabrics of urban development as well as in cities' growth and hence cannot be overlooked. Improper location of landfill site for waste management can release air pollutants to the environment which may be detrimental to public health and equally limit the expansion and growth of the urban area. Therefore, spatial multi criteria method can be applied in choosing suitable locations for solid waste management but there was no consensus among the different authors on what criteria should be included or left out when deciding on where to locate a landfill site.

The problem of choosing a site to locate multi-renewable energy source simultaneously can be solved by applying the methods of Geographic Information Science (GIScience). Renewable energy source such as solar, wind, biomass and geothermal are gaining attention around the world and as such, evaluation of potential sites for locating these sources of energy is of great importance (Saman Nadizadeh Shorabeh, 2021). In the context of Eastern Iran where this research was carried out, analytical network process (ANP) was combined with Fuzzy logic to obtain scoring weights in ranking the different criteria that were taken into account in choosing sites for these projects. The Weighted Linear Combination (WLC) method produced suitability maps that identifies the most optimal locations for siting renewable energy farms in the study region.

The versatility of Geographic Information Science (GIScience) has made it possible for its methods to be applied in solving varieties of problems facing humanity on earth. One of the interesting aspects of this is in using GIScience methods to solve the problem of air pollution. Incidentally, spatial multi criteria method has been shown as a viable tool capable of solving the problem of air pollution as a result of traffic congestion and parking difficulties in the city of Shanghai in China (Li .W, 2017). Combination of analytic hierarchy process (AHP), GIS and big data accessed from mobile phones helped in determining optimal locations for future electric car (EVCARD) stations based on certain criteria such as potential users, potential travel demand, potential travel purposes, and distance from existing electric car (EVCARD) stations. In their work, subsequent locations for efficient use of electric car (EVCARD) sharing can be determined by the use of spatial multi criteria method which removes arbitrary and random siting of EVCARD stations.

Multiple studies on the use of Geographic Information Science (GIScience) methods in combination with multi-criteria techniques, analytic hierarchy process (AHP), Fuzzy techniques, analytical network process (ANP), TOPSIS, and Boolean logic in the selection of sites for different projects at various locations have yielded an insightful approach and shown that GIScience is technically sound and a powerful scientific approach that is devoid of human influence for solving a complex problem and in siting a project at a given location. Furthermore, it proved to be a useful tool in reducing environmental and social impacts as various criteria are critically examined and weighted before embarking on any potential project. This provides a more comprehensive alternative to the empirical methods at the planning level with many advantages for gigantic infrastructure like the airport that requires a lot of capital, land area, and human resources to set up. Even though there were numerous studies carried out to locate similar projects in the same region from the literature review, there had not been any consensus regarding the criteria to be included or removed from the same project. Neither was there any set of number of criteria considered adequate for siting a particular project from the plethora of available criteria. Furthermore, the literature review showed that various studies have been conducted in Nigeria based on spatial multi-criteria analysis and Geographic Information Science in siting of wind farm (Mayaki E. A, 2018; Ayodele T.R, 2018), landfill for solid waste disposal (Abubakar Aminu Usman, 2015), and the expansion of airport’s runway (UCHE Eugene Onyebuchi, 2011). However, no study has been conducted in using GIScience to locate suitable sites for airports with air traffic control tower in Nigeria. This study is set out to cover this research gap by using spatial multi-criteria analysis to locate suitable sites for airports that will have air traffic control tower within its premises in Nigeria. The method proposed in this study will identify multiple criteria based on experts’ opinion and analytic hierarchy process (AHP) will be used to rank the criteria. The weighted linear combination of these criteria will produce a suitability map for airports with air traffic control tower sites. Since airports with air traffic control tower provide air guidance and control to aircraft flying within an airspace, this method will help to evenly distribute and segregate airports with air traffic control tower in the study area in order to improve safety of civil aviation and increase accessibility of airports by air travelers and also help to ensure proper allocation and management of budgets by policy makers in funding the project.

3. METHODOLOGY

The methodology used in this research work include spatial multi-criteria analysis and analytical hierarchy process (AHP) which incorporates experts' opinion. This involves mapping the study area, collecting and processing data, choosing and addressing the influence of different criterion using experts' opinion, assigning weights to different criterion using the analytic hierarchy process (AHP) to produce a suitability map in a weighted overlay and evaluating the result using layers of existing airports of the study area. The flow chart of the whole process is shown in Figure 2. The objective of spatial multi-criteria analysis and analytic hierarchy process (AHP) is to assist in spatial decision making when dealing with spatially referenced data from the range of competing factors or criteria by ranking these criteria relative to their scale of preference to one another (Jacek, 2007; Saaty, 1990).

The data that was used for this study was obtained from Open Street Map (OSM, 2021). The Digital Elevation Model (DEM) of the study area was downloaded from USGS Earth Explorer Shuttle Radar Topography Mission with 30 meters spatial resolution (USGS, 2021). The slope of the study area was derived from the downloaded DEM using spatial analysis tool of ESRI ArcGIS software (ESRI, 2020). The map layer of the study area was obtained from ESRI Living Atlas (ESRI, 2020)

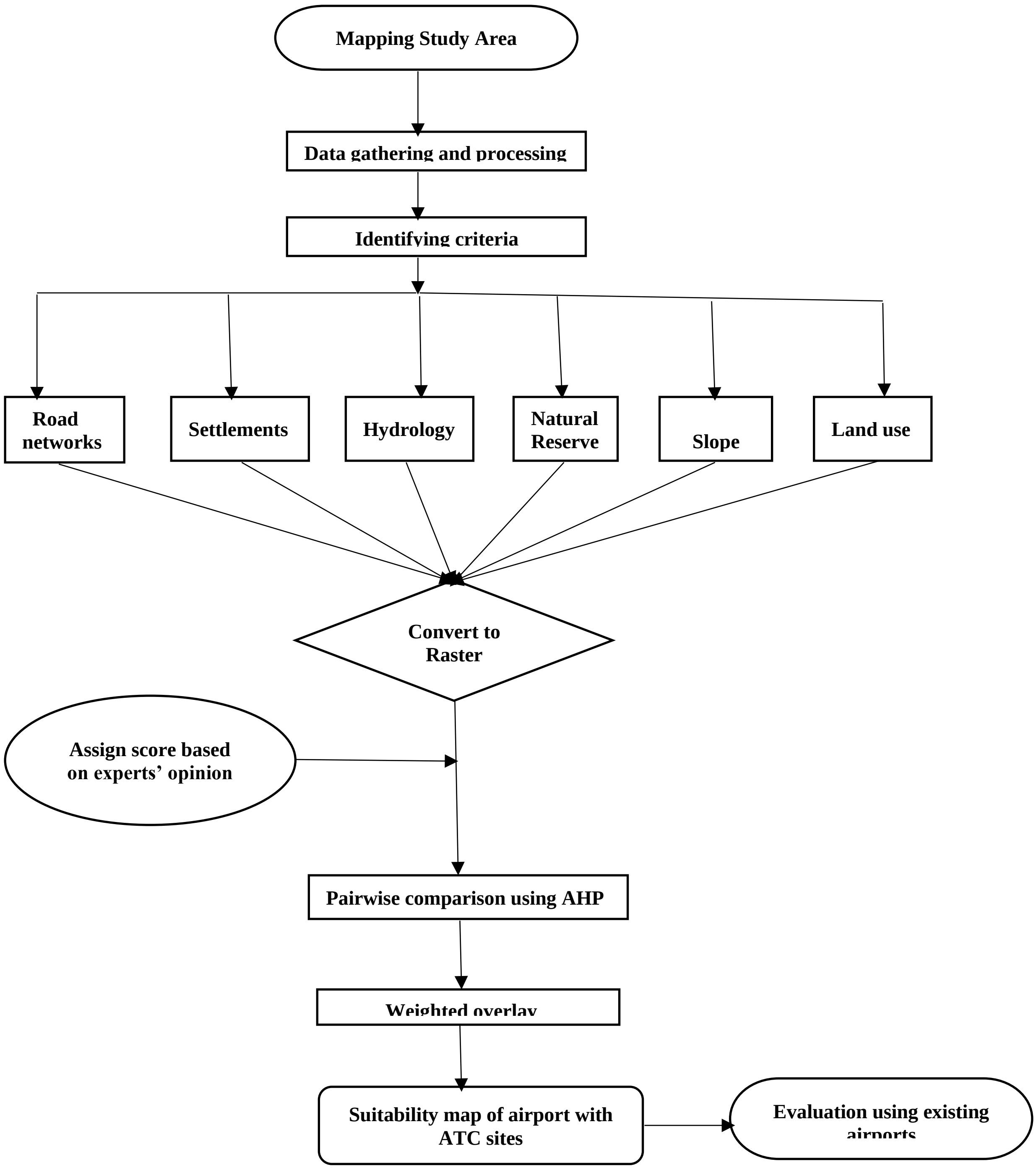

Figure 2. Flowchart of the methodology

3.1 Justification for Criteria Choice

The overall raw data was cleaned and processed by removing repeated values and missing values using ESRI ArcGIS 10.7 software (ESRI, 2020). Some of the criteria that were used in this project include road networks, settlements (cities or large urban centers), hydrology (water bodies), natural reserve (national parks), slope (from digital elevation model) and land use (Hokey Min, 1997). Scoring method was used to assign weights to each of these criteria by local experts based on Saaty scale of relative importance table (Saaty, 1990). The influences of these criteria were addressed such that new airport location should be easily accessible. As such, airports should be sited nearer to road networks (Maria Nadia Postorino, 2012). Secondly, siting of an airport to a nearby city or large urban center is not of strong importance considering the fact that noise pollution and air pollution may be a deterrent factor. However, airport location should not be sited very far away from the city or urban centers because this might discourage travelers from accessing and using it due to the added extra cost of transportation (Merkisz-Guranowska, 2016). Additionally, hydrology or water body is not of strong importance when considering location to site new airports. Even though rivers or canal channels can provide cheap and easy access to the airport, the socio-economic cost of siting an airport near water bodies may outweigh its benefit. Another reason is that there may not be enough room or buffer zone for aborted take-off or emergency landing when airport is sited very close to water bodies. This may compromise the safety of the aircraft during an aborted take-off or emergency landing. In addition, water bodies have the potential to attract wildlife such as birds which could lead to bird strike or runway encroachment (Brian J. Fox, 2013) thereby affecting the safety of aircrafts negatively. Similarly, new airport should not be located near natural reserve or national park. This is because aircraft noise can cause panic among wildlife which may lead them to kill their young ones or even attempt to attack humans. Another reason is that bird strike is a hazard to aircraft jet engines which has resulted to a lot of aviation accidents. Hence, it is recommended to site new airports as far away from natural reserve or national park as possible (ICAO, 2016). Furthermore, slope of the new airport site should be as flat as possible to create a good flight path and avoid obstruction during take-off or landing. Therefore, new airports should not be located where there is steep slope, rough terrain or mountainous ridges which could pose a risk to the safety of an aircraft due to microburst or clear air turbulence which are common in these areas (ICAO, 2016). Finally, airport sites should be located to serve the purpose of land use in its environment. The siting of an airport in a given environment should be such that it will not have a negative impact to the modification of the natural environment. The different forms of surrounding land use should not have negative impact to the airport in that location as well (ICAO, 2016). The argument behind each criterion is shown in Table 1. ArcGIS 10.7 (ESRI, 2020) analytical tool was used to convert the layers of the selected criterion into raster cells and later re-classified after assigning weights to each criterion to produce a sub-model of each criterion. The weighted raster cell sub-models were combined together using the overlay function in ArcGIS toolbox to produce an overall suitability map. The result is a suitability map with a relative score of 1 to 8 (ESRI, 2021). The areas with a relative score of 8 in the map imply high suitability while the areas with a relative score of 1 indicate low suitability.

Criteria	Argument/Justification	References
Distance to road networks	Airports that are sited near to road networks increase their accessibility and usability.	Maria Nadia Postorino et al, 2012 (cross ref)
Distance to settlements (cities, urban centers)	Locating airport nearby residential areas is not a strong important factor due to noise pollution. However, airport should not be too far away from human settlements because of extra transportation cost.	Merkisz-Guranowska A. et al, 2016
Distance to hydrology (water bodies)	Airport siting near water bodies could be advantageous or disadvantageous because it could provide cheap and easy access but could attract wildlife or have limited space for maneuverability.	Brian J. Fox et al, 2013
Distance to natural reserve (national parks)	Airport should be located so that the habitat of wildlife will not be disrupted and also to eliminate the dangers of bird strike.	ICAO Annex 14, 2016 (cross ref.)
Slope	Airports should be located such that there is no danger of obstruction to flight path during take-off or landing.	ICAO Annex 14, 2016 (cross ref.)
Land use	Airport should be located in an environment that is compatible to its land use and purpose.	ICAO Annex 14, 2016 (cross ref.)

Table 1. Summary of argument or justification behind choosing each criterion

3.2 Data Sources and Preprocessing

The input data used for this study were collected from different sources with different spatial resolution or scale. A lot of pre-processing went into preparing the data layers using ArcGIS 10.7 software for the final analysis of the map. Table 2 gives a summary of data sources, their format and description.

Data layers	Resolution or scale	Description	Sources
Study Area	1:2,500,000	Shapefile of national boundary of Nigeria	(ESRI, 2020)
Road networks	Shapefile	Polylines data of road networks	(OSM, 2021)
Settlement	Shapefile	Points dataset with cities and urban centers	(OSM, 2021)
Hydrology	Shapefile	Polygon data with large water bodies and lines of rivers/streams	(OSM, 2021)
Natural Reserve	Shapefile	Points dataset of wildlife park	(OSM, 2021)
Slope	30m x 30m	Raster dataset derived from DEM	(USGS, 2021)
Land use	Shapefile	Polygon of land use	(OSM, 2021)

Table 2. Summary of data sources.

4. RESULTS

4.1 Analytic Hierarchy Process (AHP) and Pairwise Comparison Matrix

Factors that influenced choice of criteria include local features of study area, local experts' opinion, literature review from previous studies, availability of data of study area, applicable rules and regulations from authorities like International Civil Aviation Organization (ICAO), Nigeria Civil Aviation Authority (NCAA), and Federal Airports Authority of Nigeria (FAAN). Assigning weights to each criterion was primarily done by local experts who are associated, experienced and well versed with the foregoing factors. Weights were assigned after evaluating the relative importance of each criteria on a scale of preference to one another by using the Saaty scale of relative importance (Table 3). Analytic Hierarchy Process (AHP) that was developed by (Saaty, 1990) was used to improve assigning of weight to each criterion in order to make the process as objective as possible. The process involves determining the relative importance of different criteria by using decision matrix to assign scale to each criterion. The relative level of importance was determined based on how important distance is to airport in relation to other different criteria such as road network, settlement, hydrology, and natural reserve while criterion such as slope was considered based on how flat is the land surface, and land use was considered based on mapped out plan for that area. The Saaty scale of relative importance (Table 3) shows that the value of 1 is of equal importance, the value of 9 is of extremely importance, the values of 2, 4, 6, and 8 are of intermediate importance while 1/3, 1/5, 1/7, and 1/9 are values for inverse comparison. The input matrix in Table 4 is normalized to get the pairwise comparison matrix which produced the weighted criteria as shown in Table 5. The summary in Table 6 is the weighted sum of the weighted criteria which was used to generate the ratio of weights in Table 7 in order to calculate the consistency index. Consistency ratio was calculated from the ratio of consistency index and random consistency index. The Random Consistency Index (R.I) as shown in Table 8 are constant values as given by (Saaty, 1990). The Consistency Ratio (CR) of all the input matrices was further evaluated which was found to be below the threshold level of 0.1. Therefore, the result can be accepted, and the criteria weights can be used for the weighted overlay model.

Intensity of Relative Importance	Definition	Explanation
1	Equal Importance	Two criteria contribute equally to the objective
3	Moderate Importance	Experience and judgment slightly favor one criterion over another
5	Strong Importance	Experience and judgment strongly favor one criterion over another
7	Very Strong Importance	A criterion is strongly favored, and its dominance is demonstrated in practice
9	Extreme Importance	The evidence favoring one criterion over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate Values	When a compromise is needed
1/3, 1/5, 1/7, 1/9	Values for Inverse Comparison	Transpose of criterion

Table 3. Scale of Relative Importance (Saaty, 1990)

	Distance to road network	Distance to settlement	Distance to hydrology	Distance to natural reserve	Slope	Land use
Distance to road network	1	5	7	9	2	2
Distance to settlement	1/5 (0.20)	1	7	9	3	3
Distance to hydrology	1/7 (0.14)	1/7 (0.14)	1	2	2	2
Distance to Natural reserve	1/9 (0.11)	1/9 (0.11)	½ (0.50)	1	2	2
Slope	½ (0.50)	1/3 (0.33)	½ (0.50)	½ (0.50)	1	5
Land use	½ (0.50)	1/3 (0.33)	½ (0.50)	½ (0.50)	1/5 (0.2)	1
Total	2.45	6.92	16.50	22.0	10.20	15.0

Table 4. Input Matrix

	Distance to road network	Distance to settlement	Distance to hydrology	Distance to natural reserve	Slope	Land use	Weighted Criteria
Distance to road network	0.41	0.72	0.42	0.41	0.20	0.13	0.38
Distance to settlement	0.08	0.14	0.42	0.41	0.29	0.20	0.26
Distance to hydrology	0.06	0.02	0.06	0.09	0.20	0.13	0.09
Distance to Natural reserve	0.05	0.02	0.03	0.05	0.20	0.13	0.08
Slope	0.20	0.05	0.03	0.02	0.10	0.33	0.12
Land use	0.20	0.05	0.03	0.02	0.02	0.07	0.07

Table 5. Normalized Pairwise Comparison Matrix

	Distance to road network	Distance to settlement	Distance to hydrology	Distance to natural reserve	Slope	Land use	Weighted Sum
Distance to road network	0.41	0.72	0.42	0.41	0.20	0.13	2.29
Distance to settlement	0.08	0.14	0.42	0.41	0.29	0.20	1.54
Distance to hydrology	0.06	0.02	0.06	0.09	0.20	0.13	0.56
Distance to natural reserve	0.05	0.02	0.03	0.05	0.20	0.13	0.48
Slope	0.20	0.05	0.03	0.02	0.10	0.33	0.73
Land use	0.20	0.05	0.03	0.02	0.02	0.07	0.39

Table 6. Weighted Sum of Normalized Pairwise Comparison Matrix

	Weighted Sum	Weighted Criteria	Weighted Ratio (λ)
Distance to road network	2.29	0.38	6.03
Distance to settlement	1.54	0.26	5.92
Distance to hydrology	0.56	0.09	6.22
Distance to natural reserve	0.48	0.08	6.0
Slope	0.73	0.12	6.08
Land use	0.39	0.07	5.57
Mean of Ratio (λ_{max})			5.97

Table 7. Ratio of Weights (Weighted Sum/Weighted Criteria)

Consistency Index (C.I) = $\frac{\lambda_{max} - n}{n-1}$ ……………………………………….. (1)

Where n is the number of criteria

C.I = $\frac{5.97-6}{6-1}$

C.I = -0.006

n	1	2	3	4	5	6	7	8	9	10
R.I	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Table 8. Random Consistency Index (R.I) [Constant values given by Thomas L. Saaty]

Consistency Ratio (C.R) = $\frac{Consistency\ Index\ (C.I)}{Random\ Consistency\ Index\ (R.I)}$ …………….. (2)

C.R = $\frac{0.006}{1.25}$

C.R = -0.0048

If the Consistency Ratio is less than 0.1, then the level of consistency is acceptable (Saaty, 1990) for the set of judgments by the index for the corresponding random matrix. Therefore, the criteria weights are reliable and can be used to calculate the weighted overlay model.

Criteria	**Weight**	**Influence (%)**	**Suitability Scale**	**Rank**
Distance to road network	0.38	38	0 to 0.5 (km)	9
			0.5 to 1.0	8
			1.0 to 1.5	7
			1.5 to 2.0	6
			2.0 to 2.5	5
			2.5 to 3.0	4
			3.0 to 3.5	3
			3.5 to 4.0	2
			4.0 to 4.5	1
Distance to settlement	0.26	26	0 to 0.5 (km)	1
			0.5 to 1.0	2
			1.0 to 1.5	4
			1.5 to 2.0	6
			2.0 to 2.5	8
			2.5 to 3.0	9
			3.0 to 3.5	7
			3.5 to 4.0	5
			4.0 to 4.5	3

Distance to hydrology	0.09	9	0 to 0.5 (km)	1
			0.5 to 1.0	2
			1.0 to 1.5	4
			1.5 to 2.0	6
			2.0 to 2.5	8
			2.5 to 3.0	9
			3.0 to 3.5	7
			3.5 to 4.0	5
			4.0 to 4.5	3
Distance to natural reserve	0.08	8	0 to 0.5 (km)	1
			0.5 to 1.0	2
			1.0 to 1.5	3
			1.5 to 2.0	4
			2.0 to 2.5	5
			2.5 to 3.0	6
			3.0 to 3.5	7
			3.5 to 4.0	8
			4.0 to 4.5	9
Slope	0.12	12	0 to 0.5 (%)	9
			0.5 to 2.0	8
			2.0 to 5.0	7
			5.0 to 10	6
			10 to 15	5
			15 to 20	4
			20 to 30	3
			30 to 45	2
			> 45	1

Land use	0.07	7	Shrub land	9
			Barren land	8
			Forest	7
			Business area	6
			Administrative	5
			Industrial area	4
			School zone	3
			Crop land	2
			Swampy area	1

Table 9. Reclassifying Criteria to a Common Numeric Scale

All the criteria were further reclassified into a common numeric scale (Table 9) before performing the weighted overlay analysis. This is to give them equal importance in determining the most suitable locations (Malczewski, 1999). A suitability scale of 1 to 9 units were predefined and used to rank the level of suitability of each criterion. 9 was ranked as most preferred while 1 was ranked as least preferred. The output of the reclassifications are the corresponding raster cells (sub-model suitability map) from figure 3 to figure 8 below with a suitability score of 1 to 8.

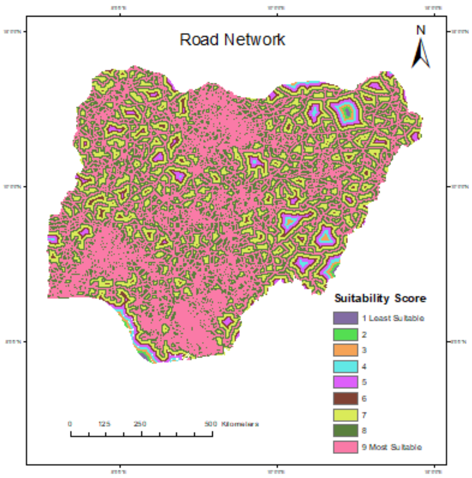

Figure 3. Road Network sub-model suitability map

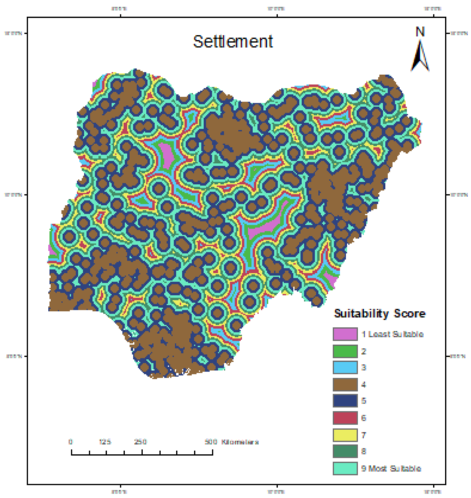

Figure 4. Settlement sub-model suitability map

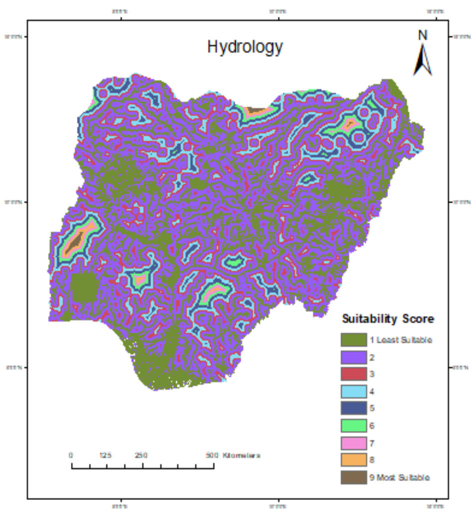

Figure 5. Hydrology sub-model suitability map

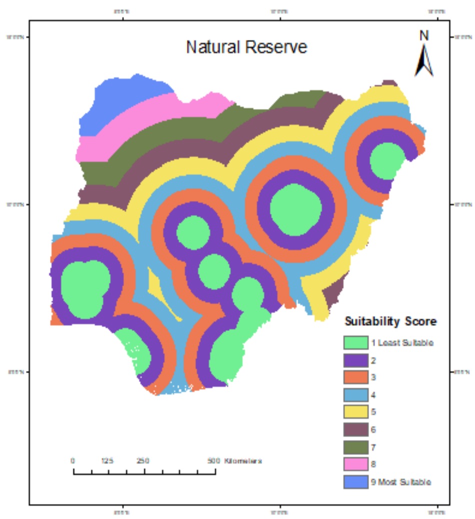

Figure 6. Natural Reserve sub-model suitability map

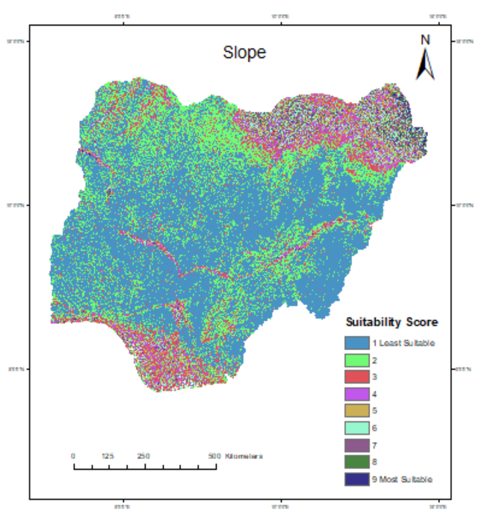

Figure 7. Slope sub-model suitability map

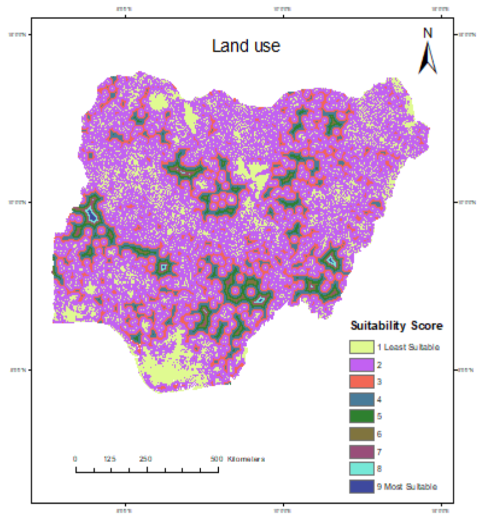

Figure 8. Land use sub-model suitability map

The overall suitability map is produced by combining all the criteria in a weighted linear combination (WLC). Each criterion is assigned a percentage influence. The standardized suitability score of each criterion is then multiplied by its percentage influence, and the results are added together to create a suitability index (S.I) which produced the suitability map (Figure 9).

$$S.I = \sum wisi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where S.I = Suitability Index

wi = Relative importance of criterion *i*

si = Standardized relative score of criterion *i*

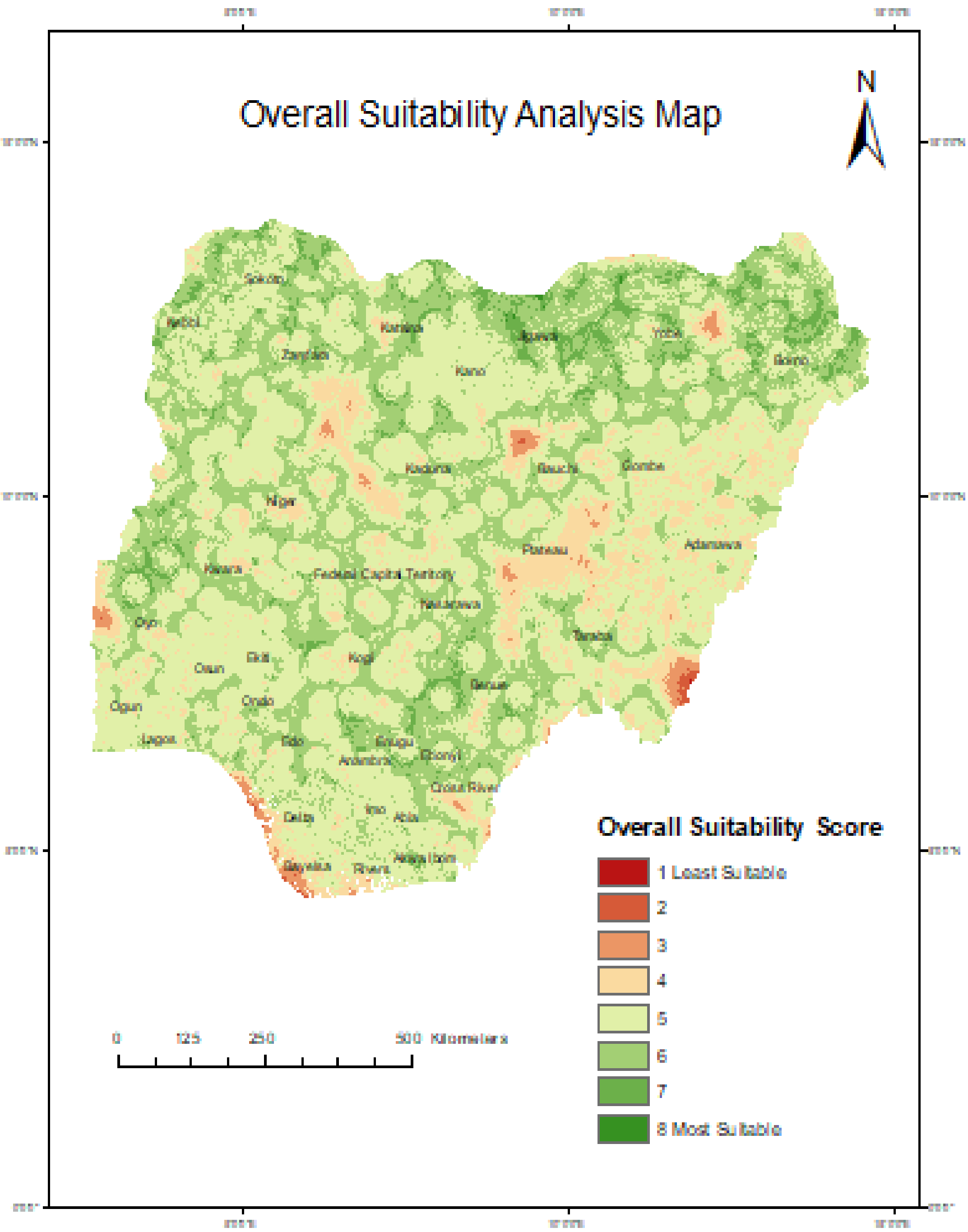

Figure 9. Suitability Map for Airport with Air Traffic Control Tower

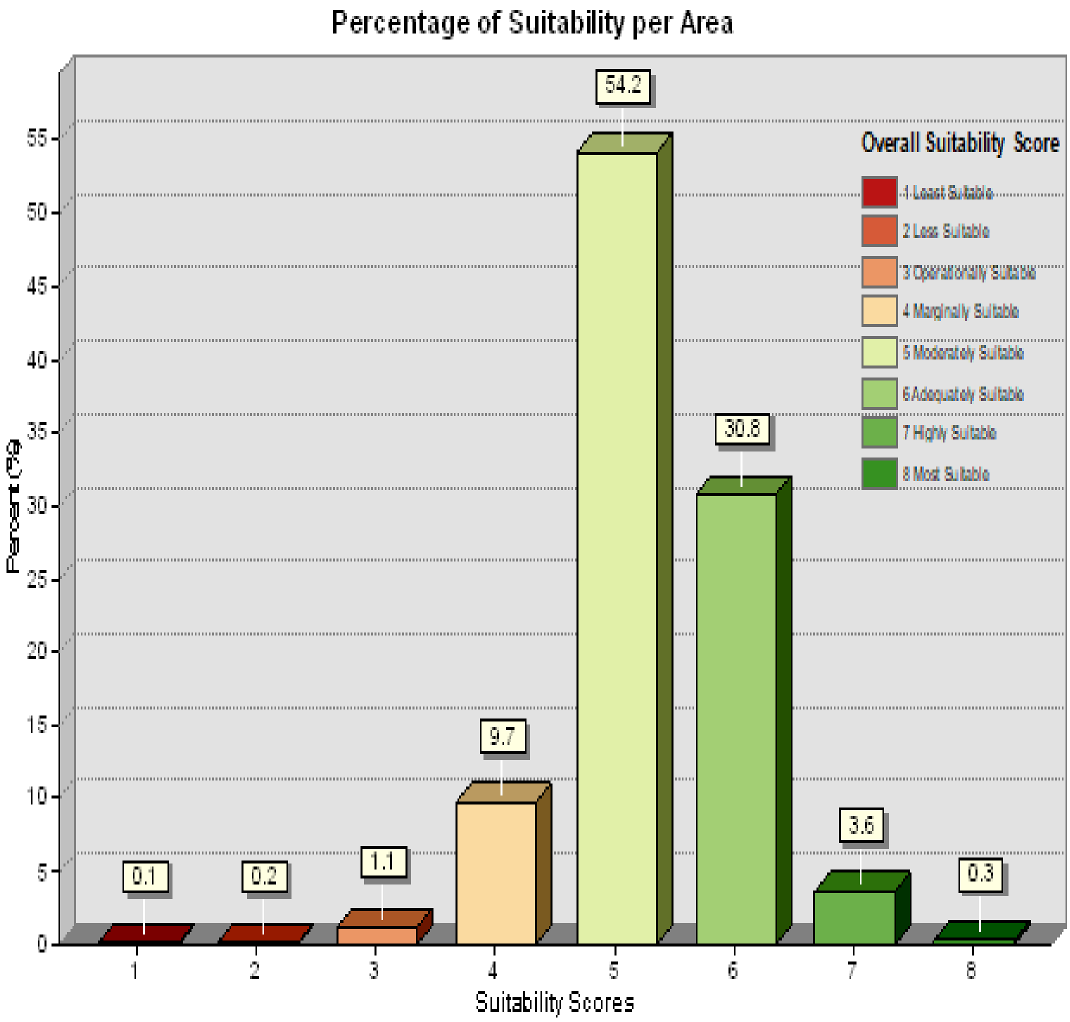

Figure 10. Percentage of Suitability for Airport with Air Traffic Control Tower per area

The result of the analysis of locations most suitable for airports with air traffic control tower sites is presented here. Six criteria which include road network, settlements (cities or large urban centres), hydrology (water bodies), natural reserve (national parks), slope, and land use were chosen in order to produce a suitability map (Fig. 9) for airport with air traffic control tower sites. These criteria were combined in a weighted overlay using the analytic hierarchy process (AHP) to assign weight to each criterion based on experts' opinion. The model that was produced showed a suitability map with a score of 8 to 1. From the suitability map, the score of 8 shows regions or locations that are most suitable for airport with air traffic control tower sites while the score of 1 shows regions or locations that are least suitable for siting an airport with air traffic control tower. The evaluation scale of 8 to 1 was used because this gave the best outcome in

ArcGIS software and this also means that locations with a suitability score of 8 is as twice more preferable than locations with a suitability score of 4 (ESRI, 2021).

The road network sub-model suitability map (Fig. 3) shows that major part of south-west, south-east and north-central are most suitable for airport with air traffic control tower sites. This could be attributed to the good road networks in these regions which makes accessing airports an easy and convenient task.

The settlement sub-model suitability map (Fig. 4) which include cities and large urban centres indicates that western part, south-eastern and a large portion of the central area of Nigeria are most suitable for airports with air traffic control tower sites. This surprisingly left out big cities like Lagos, Abuja, Kano, Port-Harcourt, Calabar and Enugu from locations most suitable for airports with air traffic control tower. Explanation of this surprise result could be traced to the fact that airports with air traffic control tower should be located adequately away from the cities or areas with large population settlement to minimise the negative effect of aircraft noise and air pollution (Merkisz-Guranowska, 2016; Ricky N. Lawton, 2016).

The hydrology sub-model suitability map (Fig. 5) illustrates that most of the country are moderately suitable for locating an airport with air traffic control tower. Some big cities such as Port-Harcourt and Calabar are however constrained by proximity to water bodies which restrict large portions of these cities to lower suitability for locating an airport with air traffic control tower.

The natural reserve or national park sub-model suitability map (Fig. 6) reveals that area that are most suitable for locating an airport with air traffic control tower are in the north-western part of the country to the north down to the middle belt and south-south. Big cities and large urban centres such as Sokoto, Kano, Kebbi, Dutse, Lokoja, Yola, Onitsha, Port-Harcourt, and Calabar are located in these regions.

The slope sub-model suitability map (Fig. 7) discloses that a large portion of Nigeria is suitable for airport with air traffic control tower. The areas that are excluded from high suitability are mostly the eastern, middle belt and western parts of Nigeria. This is as a result of steep slope and abundance of hills and mountains in these locations which could post a risk to flight path during take-off and landing of aircrafts (ICAO, 2016).

The land use sub-model suitability map (Fig. 8) shows that more than 80% of the country is moderately to highly suitable for airport with air traffic control tower sites.

This can be attributed to the fact that most of the land use types in Nigeria are still under-developed and large portions of land are usually left fallow as forest or used for agricultural activities (Aisha Olushola Arowolo, 2018). Therefore, there is abundance of land available for major projects like constructing an airport with air traffic control tower.

The overall suitability map (Fig. 9) which was obtained by combining all the six sub-models together shows that a large portion of the land area of Nigeria is moderately to highly suitable to locate airports with air traffic control tower. Three regions that indicate high scores in the suitability map are the west, the north-west and north-north part of the country. Regions in the south-east, middle belt and some portion of south-south indicate a moderate score in the suitability map. Lagos, the economic hub of Nigeria which is located in the south-west region of the country also scored very high in the suitability map.

Furthermore, the percentage of suitability per area (Fig. 10) indicates that about 30.8% of Nigerian land area with a suitability score of 6 can be classified as adequately suitable for airports with air traffic control tower. About 54.2% land surface area of Nigeria with a suitability score of 5 can be classified as moderately suitable for airports with air traffic control tower, and about 9.7% land surface area of Nigeria with a suitability score of 4 can be classified as marginally suitable for airports with air traffic control tower. Furthermore, 3.6% with a suitability score of 7 and 0.3% with a suitability score of 8 of Nigerian land surface areas can be classified respectively as highly suitable and most suitable for airports with air traffic control tower.

Some of the factors that made these regions suitable for locating airports with air traffic control tower can be attributed to proximity to good road networks and settlements which include cities and large urban centres. The slope of these regions is another contributing factor because some of these suitable areas have flat slope which is good for siting airports with air traffic control tower and would minimize the risk of obstruction along the flight path during take-off and landing of aircrafts, hence safety of air travel will not be compromised. The flatness of the slope will also provide good buffer zones and area for aborted take-off or emergency landing which is a critical factor to air safety. Land use type of Nigeria is another contributing factor because vast areas of land are left fallow or are used for agricultural purposes. Therefore, enormous portions of land are available for gigantic project like airports with air traffic control tower.

4.2 Using Existing Airports to Analyze and Validate Suitability Map

Layer of existing airports with air traffic control towers in Nigeria from Open Street Map (OSM, 2021), was used to analyse and validate the suitability map. The resultant map (Fig. 11) which was generated after spatial overlay of existing airports with air traffic control tower on the suitability map shows that 5 airports (10.4%) with a suitability score of 7 fall under the areas that are classified as highly suitable for airports with air traffic control tower. 12 airports (25%) with a suitability score of 6 fall under areas that are classified as being adequately suitable for airports with air traffic control towers while 28 airports (58.3%) with a suitability score of 5 fall under the areas that are classified as moderately suitable for airports with air traffic control tower. However, 3 airports (6.3%) with a suitability score of 2 fall under areas that are classified as being less suitable for airports with air traffic control tower. One of the airports that falls under the area that is classified as being less suitable for airports with air traffic control tower is located in Jos plateau of the north-east region of the country and the other two airports are located in the Niger Delta area of the south-south region of the country.

From the suitability map, it can be seen that spatial distribution of existing airports with air traffic control tower in the study area avoided regions or areas with a suitability score of 1 that are classified as least or not suitable for airports with air traffic control tower especially in the eastern region, north-eastern region and some pockets within the study area. This further validates the accuracy and performance of the model. Therefore, the model is robust and can be used by policy makers in decision making and proper allocation of resources for planning and developmental purposes.

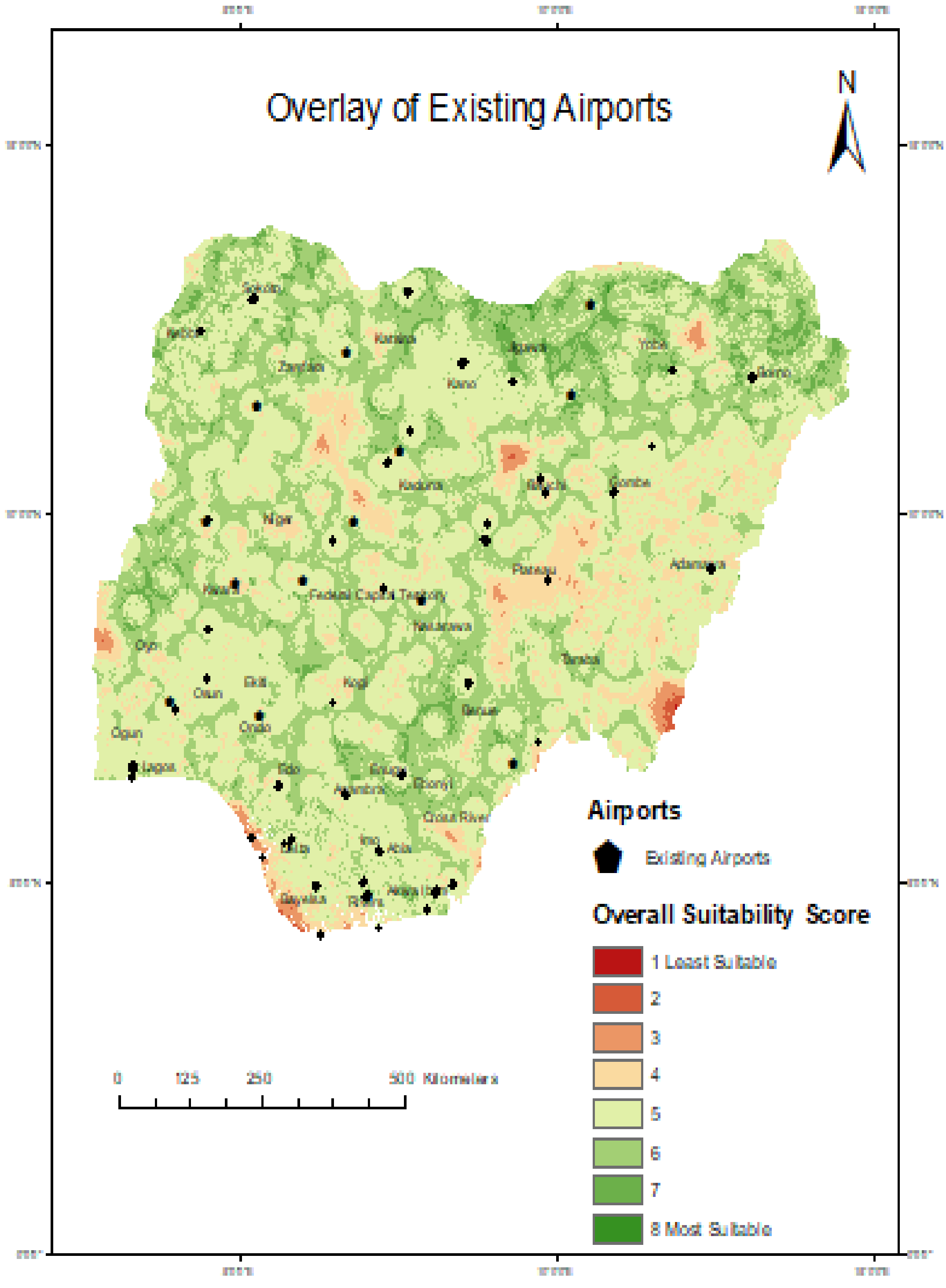

Figure 11. Existing Airports over Suitability Map

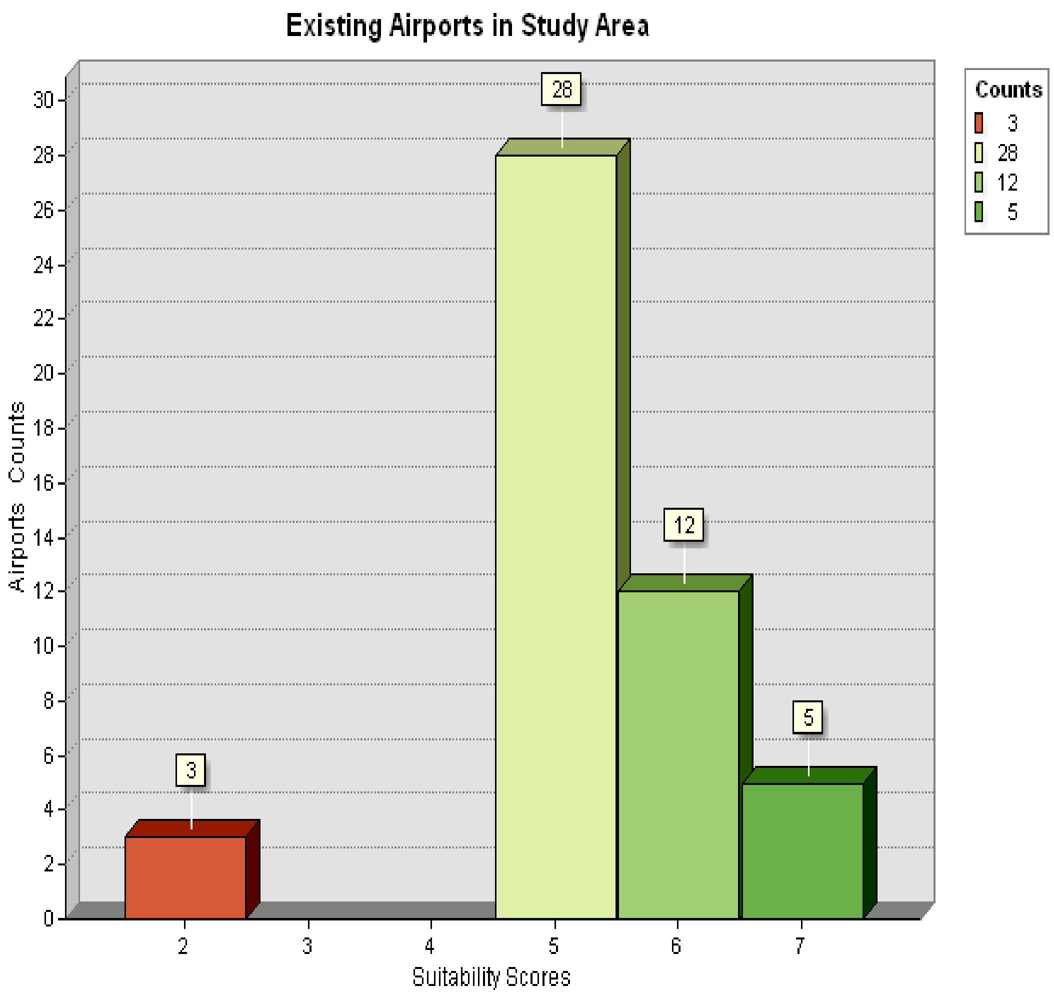

Figure 12. Existing Airports Counts in Study Area

Suitability Class	Suitability Score	Airport Counts	Percentage
Less suitable	2	3	6.3
Moderately suitable	5	28	58.3
Adequately suitable	6	12	25
Highly suitable	7	5	10.4

Table 10. Existing Airports in Study Area

5. DISCUSSION

The spatial multi-criteria analysis result of this study reveals locations with different classes of suitability for siting an airport with air traffic control tower in Nigeria. The analytic hierarchy process (AHP) which incorporates experts' opinion was used to combine six criteria in a weighted overlay to produce a suitability map with a suitability score of 1 for least suitable locations and 8 for most suitable locations. The six criteria that were used for this analysis include distance to road networks, distance to settlement (cities and large urban centers), distance to hydrology (water bodies), distance to natural reserve (national parks), slope, and land use. Some of these criteria were identified in the literature review (Cláudio Jorge Pinto Alves, 2020; Davina Zietsman, 2014; Maria Nadia Postorino, 2012; UCHE Eugene Onyebuchi, 2011; Athanasios, 2003). The process of assigning weight to each criterion was based on local experts' opinion and by the use of analytic hierarchy process (AHP). The study discovered that distance to road network (38%), distance to settlement (26%) and slope (12%) played a major role in the suitability score of each locations and hence determine where airports with air traffic control tower can be located in the study area. The results of this analysis revealed eight levels of suitability with their corresponding scores which include 8 for most suitable, 7 for highly suitable, 6 for adequately suitable, 5 for moderately suitable, 4 for marginally suitable, 3 for operationally suitable, 2 for less suitable and 1 for least or not suitable (Fig. 10). A comparison between the resulting suitability map and existing airport layer of the study area was made. The overlay map (Fig. 11) including graph and table of the overlay map (Fig. 12; Table 10), reveals that 5 airports or 10.4% of the existing airports with air traffic control tower fall under the area classified as highly suitable. 12 airports or 25% of the existing airports with air traffic control tower fall under the area classified as adequately suitable. 28 airports or 58.3% of the existing airports with air traffic control tower fall under the area classified as moderately suitable while 3 airports or 6.3% of the existing airports with air traffic control tower fall under the area classified as less suitable. The location of just 10.4% of existing airports under highly suitable area explains the lack of adequate controlled air traffic services which can be linked to air traffic accidents and incidents (Onyinye Ogonna Onwughalu, 2021; Daramola, 2014). Further analysis reveals that areas classified as least or not suitable for airports with air traffic control tower are devoid of any existing airport in the overlapping map. These areas that are devoid of any existing airports are located in the east, north-east, south-south, west and north-central regions of the country (Fig. 11). The reasons for this result can be attributed to steepness of their slopes, presence of mountains and hills, poor road networks, availability of swamps or creeks, and low population density which will make siting an airport with air traffic control tower in these areas unattractive. In contrast, Lagos area which is also located in the southern region of the country with swamps and creeks indicated a high suitability score and thus is classified as highly suitable for airport with air traffic control tower. This can be attributed to good road networks, flatness of slope and high population density of Lagos area. The comparative analysis of the existing airports with the suitability map which revealed that 28 (Fig. 12; Table 10) of the existing airports with air traffic control tower (58.3%) fall under the areas classified as moderately suitable demonstrates that most critical factors identified in this study may not have been put into consideration when making decisions to site these airports with air traffic control tower. This shows that using scientific approach such as Geographic Information Science (GIScience) in decision making is more advantageous over traditional or empirical approach which might be susceptible to human influence and judgment (Jacek, 2007). Furthermore, using GIScience in situation like this will not only help in proper allocation of federal budgets and distribution of resources to area where they are mostly needed, but it will also help to segregate infrastructures such as airports with air traffic control tower for adequate airspace coverage and minimize the risk of air traffic mishap in the country.

5.1 Limitations

In order to optimize this study and use it as a benchmark for decision making, some limitations need to be taken into consideration. Geographic data is constantly changing due to man-made activities or natural phenomenon and may not be available at some point in time when a new study of this nature may be carried out (Maras, 2000). As such, new studies and new data acquisition need to be carried out each time in order to agree with the reality on ground and be compatible with the model. Secondly, the quality of data is a function of its source. As such, results of the analysis will be influenced by the quality and source of the data. Even though data for this research work was primarily gotten from Open Street Map (OSM, 2021) which is a credible source, it would have been more interesting if data was readily available from local source to make it more involving. But this was not possible at the moment. It will be a good idea if policy makers can invest in collecting, storage and provision of quality geographic data at the local level for future projects of this nature. Other limitations was in the low number of local experts who took part in this study as discovered and cited in other studies of this nature (dos Anjos Luís, 2021). Getting local experts' opinion proved to be a herculean task as some of the experts were hesitant with their opinions and others were simply unavailable. However, the study was able to be carried out with few experts who are professionals in the aviation industry, experienced Civil Engineer/Surveyor and an Architect. More local experts' participation would have increased the knowledge-base of this study and added more flavor to it. Another limitation of this study was the inability to conduct ground truth in order to compare this result with the reality on the ground due to limited resources in terms of time and finance. However, the existing airport layer of the study area which was gotten from Open Street Map (OSM, 2021) was used to validate this study which is quite consistent with the model. Additional limitation is non-implementation of sensitivity analysis which would have helped to determine the relationship between changing different weights of each criterion and how this changes impact the overall results (Chen, 2010). However, local experts whose opinions were incorporated in this study are professionals in their fields and are knowledgeable about the analytic hierarchy process (AHP).

5.2 Future Work

For further studies, this research work can be improved by incorporating cost and economic analysis of constructing an airport with air traffic control tower to provide an estimate of erecting such project for budgeting and decision making. In doing so, a more detailed spatial multi-criteria analysis can be carried out at the level of local government area instead of at the national level. It is also worthwhile to increase the criteria and include meteorological elements such as the wind direction and/or wind speed to see how this will affect the result as well as the orientation of the runway, taxiway, apron, and terminal building. Another possible areas of research is to find out the long term effects of air pollution and noise pollution of airports to the immediate environment and how to make the airports more sustainable and environmental friendly or simply green airports with air traffic control tower. For more work in the future, other spatial dimensions can be included in the criteria in order to find out hot spots of aviation accidents in the study area so as to improve emergency response and management.

6. CONCLUSION

To find suitable locations for airports with air traffic control tower, several criteria were considered using analytic hierarchy process (AHP) in combination with local experts' opinion. These criteria include distance to road networks, distance to settlements (cities or large urban centers), distance to hydrology (water bodies), distance to natural reserve (national parks), slope, and land use of the study area. Of all these criteria, distance to road networks (38%), distance to settlement (26%), and slope (12%) contributed the most in deciding where airports with air traffic control tower can be located. The result of the overall suitability map shows that 0.3% of the study area is classified as most suitable, 54.2% is classified as moderately suitable, and 0.1% is classified as least suitable for airports with air traffic control tower. Further analysis reveals that 10.4% of the existing airports with air traffic control tower are located in areas classified as highly suitable, 58.3% of the existing airports with air traffic control towers are located in areas classified as moderately suitable, and 6.3% of the existing airports with air traffic control tower are located in areas classified as less suitable. This indicates that more efforts need to be put in place in order to build new airports' infrastructures in locations classified as most suitable for airports with air traffic control tower. This will ensure that these infrastructures are yielding their full potentials. Furthermore, there are no set number of criteria to be included in site selection of airports with air traffic control tower. It all depends on local features of the study area.

One of the ideas of using the approach of Geographic Information Science (GIScience) in solving airports location based problem as found in this study is to minimize the risks associated with human influence due to personal interest and other attendants' affiliations. This will also help in decision making and proper federal budget allocations by providing areas or regions that are lacking infrastructures such as the airports with air traffic control tower. In addition, this approach will ensure proper coverage of the nation's airspace by airports with air traffic control tower which will in return boost the nation's air traffic safety net, provide easy accessibility to passengers utilizing air as a means of transportation, and generate more revenue for the nation. Furthermore, infrastructures such as the airports with air traffic control tower drive regional development by attracting good road networks, water supply and power generation, provide employments to local communities, and attract other businesses as well as foreign investment. As a result, this will improve the standard of living and overall well-being of the local community as well as the nation at large. So, Geographic Information Science can aid policy makers and other stakeholders by determining where and how to invest in a gigantic project like the airports with air traffic control tower to support the nation's infrastructure, provide adequate coverage and management of the nation's airspace, minimize the risk of air traffic accidents, and attract foreign investment in the country. The spatial multi criteria analysis approach in this study is simple and flexible. It allows for future studies to be carried out by the addition or removal of more criteria and by changing the ranking of each criteria. It can be carried out by non-experts in solving location based problems while minimizing the effects of human influence in critical decision making such as the one identified in this study.

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