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Application of GIS Sieve Mapping and Overlay Techniques for Building Site Suitability Analysis in Part of FUT, Gidan Kwano, Minna, Nigeria

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Abstract

Objective: To produce a visual representation of the suitable areas for siting buildings; this is with a view to reduce the cost of construction usually associated with environmental factors using spatial analyst tool of ArcGIS 10.1 to overlay map layers of constraint and criterial. **Methods/Statistical Analysis:** This study adopts a Geographical Information System (GIS) sieve mapping approach to select suitable locations for siting proposed blocks of flats for university staff school in allocated part of undeveloped area of Federal University of Technology, Gidan-Kwano campus, Minna. The constraints considered include areas not inside or close to stream and swamp while the criteria are the slope not above 25%, sites area above 2000 Sqm areas within 400 m to electricity power line and areas 100 m away from the main road. 3D coordinates (xyz) data were obtained from ground survey using the Hi-Target V30 GNSS receiver to create the topographic map of the site. **Findings:** The result revealed that only four (4) sites are suitable for siting building covering an area of 2.98Ha (1.65%) out of the total area of 55.30Ha. It was found from the suitability map that the southern part of the research area is most suitable for siting building. **Applications/Improvements:** This type of analysis should be done before any structure is sited to avoid assumptions about the suitability of sites. There is the need for further study on the impact of geotechnical factors in the suitability analysis.

Keywords: GIS, Map Overlay, MCE, Sieve Mapping, Site Analysis, Suitability

1. Introduction

Site suitability analysis involves the determination of the fitness of a given expanse of land for a defined use[1]. Site suitability assessment is the fitness of certain kinds of land use in terms of socio-economic and natural features[2] which requires a scientific approach to prevents wrong decision making, enhances development control and investment for sustainable land use[3].

The Gidan Kwano Campus of the Federal University of Technology Minna is undergoing physical infrastructure development with buildings being constructed without analysing the suitability of the project site for siting building using Geographic Information System or any known geotechnical procedure etc. except for Gidan Kwanu Dam under construction within the University campus where geotechnical survey was done. The buildings are sited based on land allocation in the master plan which is done using quantitative criteria/standards such as proximity to road, infrastructures etc. Also, the school has no valid soil map covering the entire campus although soil test is conducted before constructing the building. Recently, studies have been conducted within the campus of FUT Minna. For instance, in[4] has conducted a study to analyse the soil texture in Minna and environs. The study found that the soil texture varies in the upper horizons to deeper horizons from sandy loamy to sandy clay. Similarly, in[5] investigate sites suitability for solid waste disposal on the campus using surveying and geomatics techniques. Meanwhile, in[6] developed Topographical Information System (TIS) as a critique to sustainable development and decision making

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in the University. As of today, no suitability analysis is done to select suitable site using criteria before siting buildings within the University campus. Most times, time and money is wasted in either cutting or filling some part of the building sites to get the required level which could be minimized if GIS base site selection suitability analysis is carried out before buildings are sited.

Site selection is the choice of a site which is characterized by unique preferences by individuals, societies or organizations with respect to a relative given criteria or requirements. The requirements are numerous and varies among individuals and societies depending on their financial capability and preference; this is due to the fact that some people may prefer a site within a close proximity to stream, swampy area, flood plain etc. (depending on the intended purpose), while some prefer a flat land to save cost associated with high gradient. In[7] stated that workers safety during construction is widely accepted, but the selection of safe sites for a building is generally not considered which largely depends on compilation, analysing, and refining information of an area where buildings are likely to be located. Site selection where many criteria or constraints exist is a difficult task to perform without the use of Geographical Information System (GIS) which has the capacity to combine many criteria or constraints to produce suitable site for locating blocks of flats for University staff school.

Basically, the principle of GIS suitability analysis is such that each aspect of the landscape has key features which are to some extent either suitable or unsuitable for the planned activities[8]. The outputs are often depicted on a map highlighting areas based on high to low suitability or suitable to not suitable classifications. GIS based suitability analysis is determined by viewing different aspects of the landscape, such as steepness of slope, flooding potential (closeness to streams), marshy areas etc., and combining them in the system to produce a single map. The ability of GIS to integrate varieties of information has made it a helpful tool for suitability analysis[9]. There are several GIS based approaches for site suitability selections and analysis, such as: Analytic Hierarchy Approach (AHP), Multi-criteria Evaluation Analysis (MCEA) and sieve/ overlay mapping (using criteria and constrain) among others. The adopted method is a function of the types of constraints or criteria. The MCE produces a suitability index based on a Weighted Linear Combination (WLC)[10], while the sieve mapping method implicitly weights all of the constraints equally and produces Boolean outputs through overlay operations.

GIS overlay analysis combines several spatial features to generate new spatial information by evaluating criterion map layers which is combined to determine the composite output map[11]. GIS overlay is performed using arithmetic Boolean and relational operations in both vector and raster domains executed using any GIS system with overlay capabilities. The most commonly used approach for site suitability mapping is the classical overlay technique[12]. It achieves this by utilizing weighted overlay technique to resolve problems like site suitability and selection analysis[13]. This is achieved by defining and breaking down the problem into sub model used as input layers. In[14] used this weight overlay method in analysis for site selection of water reservoirs, in Batu Pahat, Malaysia. Also, in[9] used weighted overlay tool together with the Multi-Criteria Decision Analysis (MCDA) to provide suitable map for setting up seismic stations in HarratAl-Madinah volcanic field, Saudi Arabia. The focus in this paper is to select suitable site for locating blocks of buildings (flats) for University Staff School in part of Federal University of Technology, Minna (Gidan Kwano Campus) using GIS sieve mapping/ overlay techniques which will help in minimizing cost of building projects associated with unsuitable sites.

2. Methodologies

This study is located at the main campus of the Federal University of Technology Minna, Niger State. The University was established on 1st February, 1983 at Bosso Campus, Minna and later moved to its main campus at Gidan Kwano Village along Minna-Bida Road, occupying an area of 10,650 hectares (Ha.) of land to cater for its perceived continuous expansion[15]. Minna the capital of Niger State in North Central Nigeria has an estimated population of 500,000 and a land mass of 6,784 square kilometers. It lies within latitude 9° 25’ 00” and 9° 40’ 00” North of the equator and longitude 6° 24’ 20” and 6° 36’ 40” East of the Meridian. Minna has a mean annual precipitation of 1300 mm with annual temperature of between 22°C to 40°C[10]. The dominant soil type is Sandy Loamy (SL) from 0-146 cm[16].

The data for this study was acquired using ground survey techniques (Figure 1). This data includes the perimeter coordinate used to define the extent of the area, spot height of point for production of Digital Elevation Model (DEM) and detail survey to determine the positions of features within the study area. The data was acquired using V30 Hi-Target GNSS receiver (Base and Rover) through field observations in the Real Time Kinematic (RTK) mode. The control point's coordinates (Northing, Easting and Height) were obtained from the department of Surveying and Geoinformatics, FUT Minna which has been transformed to UTM Zone 32N coordinate system with Minna Datum as the reference for datum.

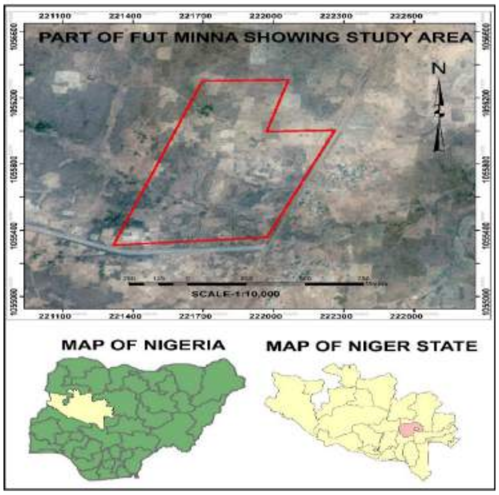

Figure 1. Part of FUT Minna showing study area in Red in relation to Map of Niger State showing Minna and map of Nigeria showing Niger State.

After office and field reconnaissance was done, *in situ* check was carried out to check the integrity of the survey control points that were used as reference points. The exercise also served as instrument check to verify if the Differential GPS (DGPS) receiver is in good working condition. The base was setup and initialize on GPS 01 and observation done with the rover receiver on GPS 08 and GPS 09 on RTK mode. The data was downloaded and the difference between observed and reference coordinates computed. The results were found to be within allowable misclosure for a third order survey (Table 1.) which indicates that both the control points and the instrument are in good condition.

Table 1. Situ check

Control GPS08	Eastings (m)	Northings(m)	Heights(m)
GIVEN	220152.791	1055170.929	232.359
OBSERVED	220152.550	1055170.640	232.350
Misclosure	0.241	0.289	0.009

A total of six perimeter points was coordinated covering an area of 55, 2985 Square meters (Sq. m) i.e., 55.30 Hectares (Ha). The choice of this coverage was informed by the extent of land allocated by the Physical Planning Department for the proposed building of University staff school. The spot heights were determined alongside detailing using Hi-Target V30 DGPS in RTK mode. Since there is no current large scale topographic map covering the study area presently, a total of 1,227 spot heights sampled points were randomly picked at about 10 to 30-meter interval depending on the nature of the terrain. Other details observed during the spot heighting are streams and marshy areas. The acquired data from the field was downloaded from the DGPS receiver and used to map layers. The created layers are perimeter survey, stream and marshy areas. The DEM was generated from the spot height while the slope map was derived from the DEM. These operations were done using ArcGIS 10.1 software. Buffer operations were also performed to generate areas that are 100 meter (m) away from the main road and areas within 400 m from electricity power line.

The criteria used for the site selection is slope less than 25% to avoid high steep terrain, areas 100 m away from the main road to minimize noise from vehicle and to preventing some children from straying into the road, and area within the distance of 400 m from electricity power line for easy access to the source of electricity. The constraints for suitable site are; areas should not be inside stream and marshy areas to avoid flooding and high cost of construction associated with marshy areas. Also, the size of the land should be above 2000 Square meters (Sqm) so that there will be enough space for building etc. The constrain layers were merged with perimeter layer to enable reclassification of the layers in other to generate Boolean images which will serve as input data to generate factor maps (Figures 2(b), (c) and (d)). The factor maps depict the suitability of a given feature classified as not suitable areas or the most suitable areas using a range of classes. The factors considered in this study are slope, streams, and swampy areas. The map is re-classified into classes ranging from not suitable (0) to suitable building sites (1) using ArcGIS reclassify under Spatial Analyst Tool. Marshy area, swamp and slop above 25% were reclassified as 0 (not suitable) as shown in Figure 2(b), (c) and (d).

The Factor maps of swampy and marshy areas as well as the generated criteria maps of area within 400 m of electricity power line and 100 m away from the main road were converted to raster layer; this was necessary since the slope map is in raster form to allow overlay operation. The overlay operation was done using Raster Calculator tool in Spatial Analyst Tool of ArcGIS by multiplying the factor (criteria) maps to generate suitability maps through the intersection (logical AND) conditions. The suitability map was converted from raster to polygon. The area >=2000Sqm i.e., 0.2 Ha were selected.

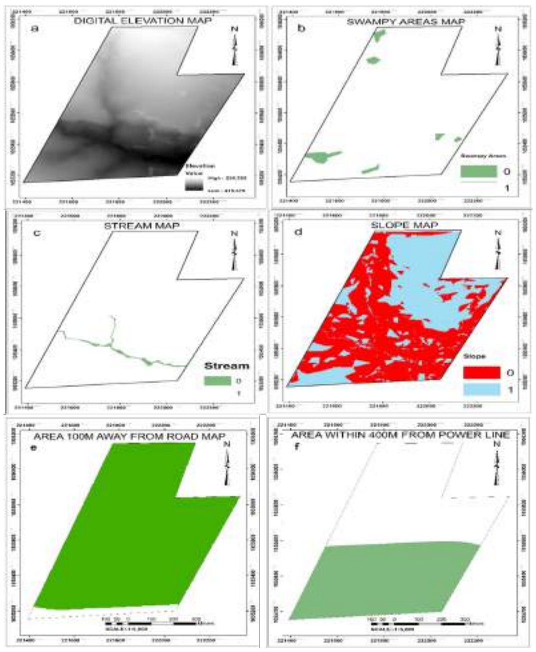

Figure 2. (a) Digital elevation model. (b) Swampy areas in green. (c) Stream green. (d) The slope maps of the study area. (e) Area 100 m away from the main road in green. (f) Area within 400 m from the power line in green.

3. Experimental Result

Figure 2(a) is the Digital Elevation Model (DEM) used to produce the slope criteria of less than 25% (Figure 2(d)). The highest and lowest elevations are 236.24 and 215.48 meters respectively above reference datum (Minna). Figure 2(b) and 2(c) are the maps of swampy area and river in green respectively (which are the constraints used for evaluating the suitable site). The criteria used for Multi-Criteria Evaluation (MCE) using sieve/overlay evaluation are shown in Figures 2(d), 2(e) and 2(f). Figure 2(d) is the slope map, green are the areas with slope of less than 25% while the red areas have slope greater than 25%. Figure 2(e) is the 100 meter buffer from the main roan, while Figure 2(f) is the area within 400 metre from power line. The areas with values 1 area suitable for siting structures while areas with 0 values are constraints (Figures 2 (b), (c), (d)). Figure 3 is the post map showing the density of points used to generate the DEM. Figure 4(a) is the map of the suitable site for buildings generated from overlay of Figures 2 (b), (c) and (d). while Figure 4(b) shows the suitable sites having areas above 0.2 Ha.

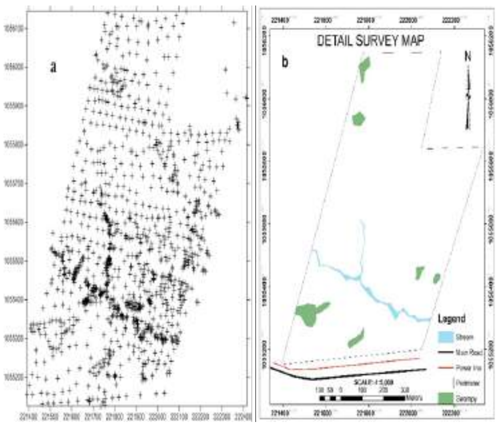

Figure 3. (a) Post map showing density of spot heights observed. (b) Detail survey showing the location of details in the study area.

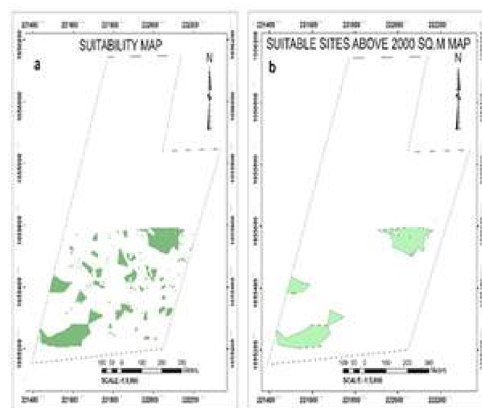

Figure 4. (a) Suitability sites for siting buildings. (b) Suitable sites above 2000 Sq.m.

Table 1 is the control in-situ and instrument check results showing the difference in values between the given coordinates and the observed coordinates, while Table 2 shows the sizes and numbers of plots suitable for siting buildings.

Table 2. Sizes and numbers of suitable site

Total Area	Area of Suitable Sites		Area of Suitable Sites >0.2.		No of Suitable Sites	
Ha.	Ha.	%	Ha.	%	Total	>0.2Ha.
55.30	4.59	8.30	2.98	1.65	171	3

3.1 Discussion

This study was conducted to produce map showing suitable areas for siting buildings using GIS base Sieve mapping techniques. From Figure 2, the DEM shows that the entire area is relatively flat having height range of 20.85 m. The northern part of the study area has higher elevations (236.329 m) and relatively flatter than the southern part which has lower elevation (215.476 m) and steeper as seen from the DEM (Figure 2(a)) and the slope map (Figure 2(d)). The marshy areas are found more on the southern part of the study area which could be as a result of the stream located at the southern part as shown in Figure 2(c). It can also be observed from the slope map that the north-eastern part of the map and some south western part of the study area are relatively flat with slope of >=25%.

From Figure 4(a), there are suitable areas for siting building only in southern part of the map; this is because the main road and the electricity power line are located in the southern part of the map (Figure 3(b)) which was used as some of the criteria. The northern part of the map doesn't have any suitable site because it is not within the 400 m proximity to the power line criteria (Figure 2(f)) although it is within the boundary of 100 m away from main road. Also, the location of suitable sites above 2000 Sqm. (0.2 Ha.) are all located in the southern part of the study area due to the criteria used in the selection of the suitable sites. There are total of 171 sites suitable for siting buildings out of which only three (3) are above 2000 Sqm (Table 2).

Figures 4(a) and 4(b) show the spatial distribution of total number of suitable site and areas above 2000 Sq.m. respectively.

It can be observed from Table 2 that out of 55.30 Ha of land, 4.59 Ha (8.30%) is suitable for siting structures based on the multi-criteria and constraints used in evaluating the suitability. This shows that more than 90% of the study area is not suitable for siting structure. This type of result can only be archived using GIS and this type of analysis is very important before siting building because it produce the data needed to save cost during building construction. Table 2 also revealed that only 2.98 Ha. (1.60%) of the total land is suitable for siting building according to the size of land above 2000 Sq.m. This shows that the larger portion of land didn't meet the requirement as such not suitable for siting buildings according to the given criteria and constraints. This was also verified by ground truth using hand-held GPS to verify if the result obtained from the analysis is agreement with the reality on ground.

4. Conclusion

Building site suitability analysis based on the sieve mapping/ overlay techniques using Multi-Criteria Evaluation has been discussed in this paper. Suitable site selection for locating structures is imperative especially for a university community where a lot of building construction activities is taking place. The result revealed that more than 90% of the land is not suitable for siting buildings. GIS has proven to be one of the best tools for decision making in general planning of land and site selection for optimum used. The suitability of land for sitting building depend on many factors; the purpose, financial capacity of the owner, personal preference etc. GIS base site suitability analysis could be carried out before the acquisition of land to meet the requirement of the prospective land buyer. It can aid elected officials and land managers in making crucial decisions and establish policies regarding the use of particular areas of land[14]. Some of the thematic layers which would have made this analysis more interesting are the soil profile and geological maps of the university campus. This information is currently not readily available. Also, the coverage of this study has been constrained by the size of the land (55.30Ha.) allocated for the staff school project which is relatively small compared to the size of entire university (10,650Ha). Therefore, this study being the first effort in the study area is considered a preliminary investigation with a view to looking into the impact of the geotechnical factors in our future study.

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