Available online at http://www.journalijdr.com

IJDR

ISSN: 2230-9926

International Journal of Development Research
Vol. 08, Issue, 05, pp.20206-20209, May, 2018

ORIGINAL RESEARCH ARTICLE

OPEN ACCESS

A GEOGRAPHIC INFORMATION SYSTEM (GIS) BASED LAND SUITABILITY ANALYSIS AND CHARACTERIZATION FOR INDUSTRIAL SITING IN ABAKALIKI AREA, SOUTHEASTERN NIGERIA

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ARTICLE INFO

Article History:

Received 18th February, 2018
Received in revised form
16th March, 2018
Accepted 10th April, 2018
Published online 28th May, 2018

Key Words:

Arc-GIS, georeferencing, Geostatistical, industrial, Softwares, Suitable, thematic, mismatch

ABSTRACT

The Implication of appropriate site for industrial use is critical to environmental health. Determination of factors such as population, geospatial characterisation including climate are the baseline statistics needed to generate thematic map layers. Assessment of terrain provides information for optimum spatial utilization in line with Sustainable Development Goals (SDGs). Geostastical data acquired from investigation were imported into appropriate software's such as Rockworks 16, Microsoft excel, Global mapper and Arc-GIS. Thematic map layers of geology, lineament, soil class and depth, topographic elevation, slope, water table, hydrology, landuse, drainage and flood incursion characteristics are generated using baseline information. These thematic maps discrete pixels were objectively scaled, weighed and assigned a numerical rating according to their relative importance, delineated into different suitability class, converted to Geographic Information System (GIS) compatible format by scanning, digitization, common georeferencing, projection and conversion to common scale. They were then overlaid by interpolation using Arc-GIS Map Algebra. Final output of the thematic maps systematically demarcated into zones and encoded with values representing capability scales sliced into three suitability categories as highly suitable (S2), moderately suitable (S1) and marginally suitable (S0) which is important for planning, land-use and land management especially for industrial site criteria devoid of mismatch.

Citation: Onwe Mkpuma Rock,Nwankwo G. I.,Ema Michael Abraham and Emberga T. T., 2018. "A geographic information system (gis) based land suitability analysis and characterization for industrial siting in abakaliki area, Southeastern Nigeria", *International Journal of Development Research*, 8, (05), 20206-20209.

INTRODUCTION

Land scarcity, unchecked population rise and unemployment explosion presently ravaging the world has led to land mismatching and generated gross poor standard of living. The accompanying geoenvironmental hazards are threatening our land, causing several incidences of failure and collapse of infrastructural facilities. Cumulative geoenvironmental health issues contributing toward retardation and increases in cost of development. These geoenvironmental hazards arise due to land mismatch (inappropriate capability indexing and allotment).

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Land suitability indexing (i.e. evaluation, planning and use) is pertinent as a baseline platform for right decision making. All the processes of land suitability evaluation is an assessment of fitness tracks for sustainable development (Chen *et al*., 2010; Bhagat *et al*., 2009). Using analytical manual overlay procedure, Nwankwor *et al.,* (2004), carried out land capability index studies for residential purposes. Onunkwo *et al.,* (2011, 2012) performed a similar study using GIS approach. Civco *et al.,* (2002), compared several methods of land use selection and concluded that no single method can be used to solve the entire problems. But, presently GIS applications are gaining more grounds in land use mapping (Hopkins, 1977). It provides better economic procedure to manipulate and practically safer to achieve sustainability and optimum spatial utilization of land in line with Sustainable Development Goals

(SDGs). The process requires integration of several factorial data sets (characteristics) of the land to model its alternative uses and making choice. In identifying an area for industrial siting, a set of data such as settlement density, bedrock geology, litho-structural characteristics, depth to water table, surficial materials (soil), erosion vulnerability and flood zones as well as climatic condition, topographical nature such as slope are evaluated.

Study Area: This research was carried out in Abakaliki area Southeastern Nigeria. It covers between latitudes 0389325 - 0444717N and longitudes 0663306 - 0718503E, covering about 56.31km^2. It has a highest altitude above sea level of about 245m, figure 1. The area fall within Tropical temperate climatic zone characterized by seasonal atmospheric conditions caused by North-South fluctuation of a discontinuity zone between the dry continental (Saharan) air and the humid maritime (Atlantic) air. This culminates to two main seasons prominent in the area– rainy and dry seasons. Other minor climatic conditions in the area are the short dry season– August break and the harmattan patches of November to February. Mean annual rainfall is 2000 to 2500mm and mean monthly rainfall vary from 50 to 300mm while mean annual temperature of 31.2^{0}C ranging from 33^{0}C in dry season to 28^{0}C in wet season. The area falls within the tropical rainforest to savannah belts with lush vegetation characterized by variety of tree shrubs, grasses and abundant palms, (Onwe *et al*., 2015, 2016). Dominant vegetation are cereals (rice, maize), vegetables and fruits. The area consists predominantly of shale rock type. This weathers to lateritic clays, silts and clay soil deposits.

Industrial Siting Indicators

Weighting, Ranking Criteria and Overlay Process: Characteristic features of different land area, form the evaluation factors criteria to determine its suitability. Weight influence or importance of these factors varies for different

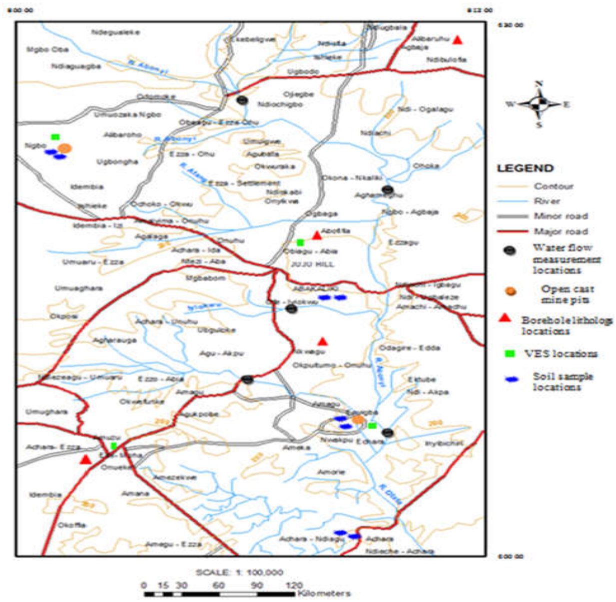

Figure 1. Map of the study area. (Source: drafted from Map published by the Office of the Surveyor General of the Federation, Abuja Nigeria 2010; Sheets 302 and 303)

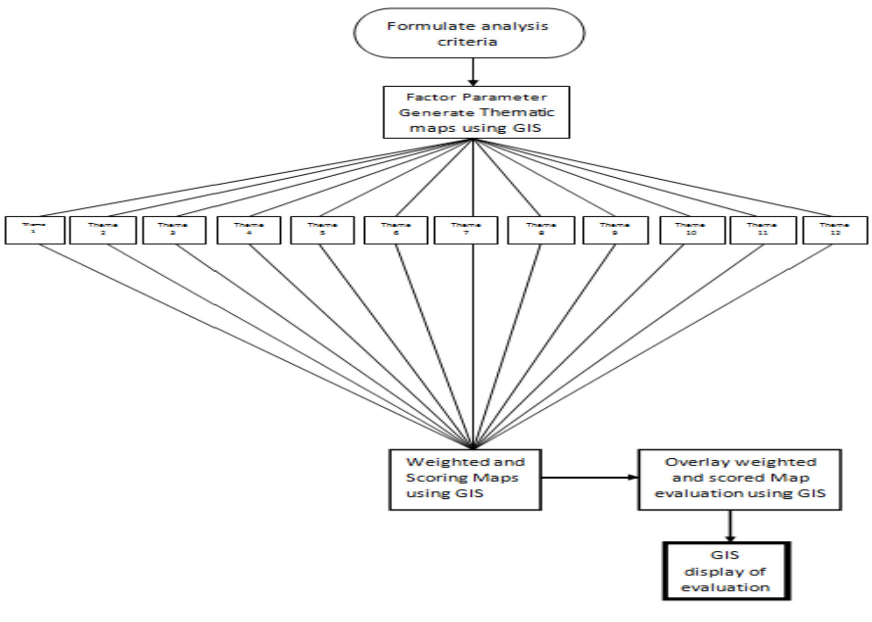

Fig. 2. Schematic Thematic maps overlay model

parcel of land for different uses. Weighting therefore, denotes the relative importance or influence of factor's attribute on land suitability for an anticipated purpose. Ranking procedure involves the choice of appropriate rating scale. Based on the capability of each factor for a land use, a suitability score was assigned using a weight or scale values. The ranking scale influence ranges from 0 – 100%. A zero renders the land valueless, unsuitable irrespective of how capable other factors may support for a particular use (Nwankwor *et al.,* 2004; Chapin 1965). The overlay process involves individual theme overlain in a GIS Arcview software model builder. The operation requires the theme must be compatible with the table of values of the weights, the maps must be of common georeferenced and scale as to establish compatibility and easy matching, (Civico, *et al.,* 2002). Figure 2, is a schematic overlay model.

Industrial siting thematic data indicators and percentage influence

Any land area development for industrial set up needs proper surficial and subsurficial investigation to ascertain its capability for the purpose (Dimitri and Krynine, 2003). Sidle (1985), Mongkolswat *et al* (1991), noted that slope of 2-6% is gentle enough and suitable for industrial development; slopes >12% can cause problems or construction difficulty and costly to develop. Slopes >35% on unconsolidated terrain is generally subject to landslide. Slope shape also influences the distribution of soil water. Concave slope concentrate groundwater and subject to cause sliding. Convex slopes distributes groundwater hence are least prone to slide. Onwe *et al* (2015, 2017b) put development areas close to water source but at a least distance of 1000m away from Flood plain. Position of groundwater table has a significant effect on the bearing capacity of soil. Shallow water table can cause severe implications to civil works foundation. The presence of water table at a depth less than the width of a foundation from the foundation bottom reduces the bearing capacity of the soil. Unconsolidated soils cannot offer strong foundational engineering base. Soil texture and drainage conditions affect land use suitability. Expansive soils are problematic. Well drained coarse soils offers lesser limitations to industrial development. Geologically, carbonates, fractured and permeable rocks form solution channels. They are susceptible to solution, facilitates fluid migration and affect environmental stability. The percentage influence values were obtained through weighted suitability cells or pixels datasets relative importance reclassification of the thematic maps to a common measurement scale overlay tool. The tool ensures thematic integration, superimposition and geospatial connectivity of discrete cells, perform the analysis on neighbourhood cell using the Majority filter tool. Similar suitability index code pixels are integrated. The output cells generated was converted to polygon where the area for each polygon was determined using the geometry calculator.

MATERIALS AND METHODS

Soil and geostatistical survey were carried out using hand Auger and simple GX-1 Drill rig. Samples were collected in a systematic georeferenced grid pattern. Soil samples were analysed for class, depth, texture (porosity) to estimate particle size distribution, Atterberg limit, compaction characteristics, shear stress and compressive strength.

Terrain geomorphometric features such as drainage network, patterns, including erosion were assessed and interpretations derived. Drainage channel geometry (depth, width and mean flow velocity) was also estimated at several locations along the water courses to enable determination of stream discharge and flood characteristics. Flood incursion threshold map was developed using the google earth. The flood incursion map was then imported into ArcGIS software for spatial analyses. Onwe *et al*., (2017) measurement method for fracture orientation, aperture, trace length and spacing were adopted and used to infer subsurface geostructural condition. Core drilling, groundwater borehole lithologs, open cast mine pits, road cuts and river channel banks study were complimented with indirect subsurface geophysical survey. Vertical Electrical Sounding (VES) and Lateral profiling using a Terrameter (SAS 1000) Schlumberger array was conducted at different locations and or trace to infer both vertical and horizontal litho boundaries. Meteorological data, (Onwe *et al*., 2016) in the surrounding stations were used for climatic interpretation. Geostructural characteristics (lineament/fault), physiography (topography, elevation and slope), groundwater depth, drainage, flood and flow system, soil (types and depths) and landuse thematic maps and other soil geotechnical characteristics were generated. These were gridded and partitioned into pixels, attributes graded and encoded numeric value and were used as the baseline information for this study. All the pixels coded thematic imported into GIS-software interface. This simulates attribute data into discrete thematic layers, yielding insight of the geospatial heterogeneity distribution. Discrete thematic maps generated including satellite Digital Elevation Model (DEM) images were cross checked, common georeferenced within same cordinates, imported into ArcGIS domain via interpolation. Simulation of these discrete thematic layers results terrain containing different local information of land system (pixels) of land suitability class. The site suitability, (S) analysis approach takes a generalized form as follows:

$$S = \sum_{j=1}^{n} cj\, xj \quad \ldots\ldots\ldots\ldots\ldots (1)$$

where xj = are the factors affecting suitability; cj = are characteristic feature attributes of each factor. Using a sufficient dataset, the cj's are objectively scaled, weighed and assigned a numerical rating according to their relative importance.

Analytic Hierarchy Process (AHP) of Shu-Li Huaiig (1990) xjs scale averaging procedures were adopted. This uses the linear combination method as its evaluation technique for the proposed suitability model. It relied directly on the numeric value similarity and multiplication properties of matrices synthesized through an overlay function in Geographical Information System to delineate an area into different suitability classes or rate suitability index of a terrain and then integrating similar portions. The overall study concept involved interpolation and integration of similar coded portions of the discrete thematic layers of geology, lineament, soil class, soil depth, topographic/ elevation, slope, water table, hydrology, physical, landuse, drainage and flood incursion maps, using ArcGIS software. All the maps were presented in UTM Projection, Zone 32, Datum WGS84. A GARMIN 78sc GPS was used to record the latitude and longitude of sampling points which were imported into the GIS platform.

Table 1. Thematic map layers dataset used to determine percentage influence

Input Theme	% Influence	Input Field	Input Label	Scale Value	Remarks
Layer 1 Slope	12	1 2 3	0-9 (G.S.) >9-19 (sloppy) >19 (steep)	2 1 0	Consideration is important for the stability of buildings & haulage. Construction cost.
Layer 2 Elevation	6	1 2 3	280 – 432 432 – 585 >585	1 2 2	Not very important but used in the derivation of DEM for slope. Consider impact to Haulage
Layer 3 Geology	12	1 2	Abakaliki shale Abakaliki pyroclasts	1 2	Geology consideration is important in structural/ foundations stability
Layer 4 Drainage	10	1 2 3	Moderate Moderate Well drained	1 1 2	Wet land can led to instability of foundations. USDA 1951
Layer 5 Water table	12	1 2 3	Very shallow Shallow Deep	0 1 2	Depth influences moisture content of overlying body. Shallow depth leads to weathering, instability
Layer 6 Flood	9	1 2	Buffered Active Non Active	0 0	Weakens buildings. Could lead to disaster & environmental pollution. Buffer ≥ 1km
Layer 7 Geostructural	11	1 2	Buffered Active Non Active	0 0	Promotes instability and failures. Buffer ≥ 1km
Layer 8 Soil depth	12	1 2 3	Deep Deep Shallow	2 2 1	Affects stability of structures and foundations
Layer 9 Soil class	10	1 2 3	Ferric Acrisols Dystric Nitosols Gleysols	2 1 0	Soil strength depends on class
Layer 10 Hydrology	6	1 2	High Low	2 1	Important source of water supply. Buffer ≤ 1km
Total	100				

The overlay process involves identifying areas (polygons) with specified similar conditions and combination, selecting model builder from the Arcview software menu. The individual theme is overlain. Each theme is matched to the table related to it at the appropriate space to make up the weighted overlay. After inserting the scale of the percentage influence and the scale values, the model operation when applied produces a land capability overlay map layers.

Industrial siting indicators thematic map layers

Following the procedure outlined in the methodology, the various thematic map layers of relief, slope, soil types and depth, geology, water table, Linearment, drainage were generated. They were then overlaid to generate industrial sitting composite map.

RESULTS AND DISCUSSION

To create the capability map, all the thematic or parameter index map layers were overlaid using the Geoprocessing Arcview GIS tool. This method overlay the resultant thematic map layers, integrating discrete but similar portions by their given weight correspondence and are overlapping, summing them together to get the index. The study area was divided into three capability classes ranging between a minimum value of 0 and a maximum value of 2. The result of the GIS Spatial analysis performed using Arcview Model Builder operation produced suitability zone map options- not suitable, low suitable and suitable as shown in figure 3. According to suitability map of the study area, the NOT suitable portions are probably due to the lower slope terrains towards the stream/river courses and flood plain that is mostly covered with loam and sandy loam which allows enhanced percolation. The north eastern area not suitable could be due to steep slope and near surface water. They were studied with a view to understand the engineering characteristics.

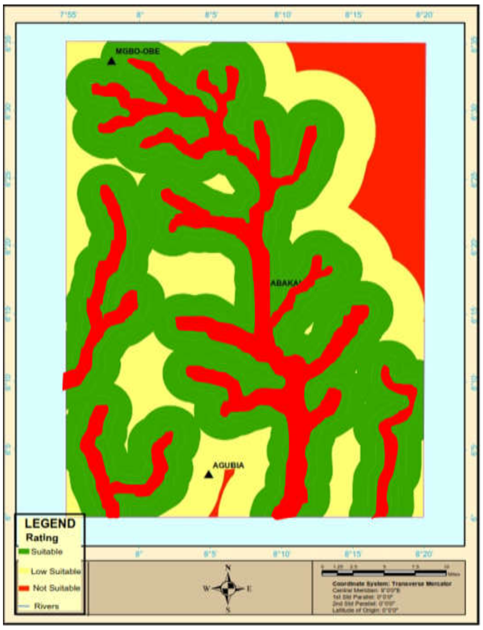

Figure 3. Composite land capability index map for industrial siting of the study area

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