Geophysical-Geotechnical Evaluation of Site Suitability Assessment of Roads in Mountainous and Rugged Terrains Using a GIS-MCE Approach: A Case Study of Simbu Province, PNG

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Abstract

The rugged topography of Papua New Guinea (PNG) makes it a challenge for the government to extend standard road infrastructure in the remote and mountainous parts of the country. Although road construction is one of the priority investments by government in recent times, public infrastructure objectives are not met due to technical and financial challenges. The performance of the road network in Simbu Province of the Highlands Region is a serious concern particularly with regard to poor connectivity, poor accessibility and constant failing of serviceable roads due to their difficult geography at the landscape level. This study seeks to develop a site suitability model for evaluating technical requirements of roads in difficult terrains and mountainous areas using GIS and multi-criteria evaluation (MCE) approach through Analytic Hierarchy Process (AHP). Towards this end, the paper classifies geophysical-geotechnical influences as principal factors determining road suitability. Comparatively important geophysical factors, including altitude, slope, river network and rainfall data, are integrated to generate alternative suitability Map 1. Geotechnical factors including lithology, soil texture and landform are integrated to generate alternative suitability Map 2. The final suitability map is produced by combining both weighted composite map layers in order to identify the most suitable site in a cost-effective, environment-friendly and well organised manner.

Keywords: *GIS, AHP, MCE, geotechnical-geophysical evaluation, road site suitability model, Simbu Province, PNG*

1. Introduction

Road network plays a very important role in a developing country like Papua New Guinea (PNG), where majority of the population reside in rural areas and the main source of their earning is based on agricultural products. Previous studies carried out by Adedeji et al. (2014) and Davis (2000) argued that efficient and effective rural transportation serves as one of the channels for the collection and exchange of goods and services, movement of people, dissemination of information and promotion of the rural economy. Road infrastructure is one of PNG government's priority investments aimed at building regional super highways to connect rural communities to the major urban centres in the country by 2050. However, due to difficult geography, it is a challenge for the authorities to deliver their infrastructure objectives as already observed by Care International in PNG (CIPNG) and Community Development Agency (CDA) in a joint baseline survey conducted in some remote districts of Simbu in 2013. Simbu province is one of the mountainous and rugged terrain regions that continue to face enormous development challenges due to poor road connectivity and difficult geography. Road infrastructure in the region has emerged as a serious concern particularly with regards to ongoing technical challenges encountered by engineers and governing authorities in delivering new projects and maintaining serviceable roads.

This paper is an attempt at developing a suitability model using GIS and MCE approach for identifying suitable sites for planning road projects in mountainous and hilly terrain areas of PNG. To cater for the needs of appropriate sites in undulating areas, site suitability analysis has become inevitable, as observed by Kumor and Ritesh (2014). It is a method of understanding existing surface and subsurface characteristics, the quality and factors of an area that will determine the alternatively suitable locations for a particular activity. It involves mapping techniques including GIS applications that help in processing the geographical database that display the features of a given site to determine whether the site is suitable for various planning objectives and alternatives. Although there is a series of techniques being applied to develop weights for the MCE approach, Eastman (1995) argues that one of the most promising techniques is that of pair-wise comparison earlier developed by Saaty (1980) in the context of a decision-making process known as the Analytic Hierarchy Process (AHP). A research carried out by Shiba (1995) had noted that using the AHP to identify the benefit structure of a road network demonstrates that AHP is a particularly useful tool for resolving political, economic and environmental conflicts. Using the MCE approach, Abdi et al. (2009) also noted that AHP process is a tool that can be used to solve any complex decision problems to provide a consistent and quantifiable solution involving multi-criteria analysis. As pointed out by Coulter et al. (2006), AHP has the potential to provide a consistent approach to the ranking of forested terrain road investments based on the multiple criteria evaluation approach.

This model will gradually become a visible planning tool to aid engineers and decision makers to incorporate technical challenges in the strategic planning process for any planned road project. Dean (1997) noted that the pursuit of finding cost effective and environmental-friendly paths for new road networks is highly desirable. Obviously, this study intends to give out geotechnical and geophysical properties of the region in a GIS environment. It is then integrated together using suitability rating and weighting with simple statistics leading up to multi-criteria decision through APH approach to generate alternatively suitable geotechnical-geophysical sites that can be finally integrated as composite suitability sites for road connectivity in mountainous and rugged terrain regions in a cost-effective, environment-friendly and well organised manner.

2. Study Area

This case study research was carried out in Simbu province, one of the mountainous and rugged terrain regions in the highlands of PNG. The physical geography of this region is almost roofed with steep mountain ranges and difficult terrains with excessive rock formation. It is the only province in the region that hosts the highest number of steep mountains and the highest mountain in PNG - the famous Mt. Wilhelm. It also hosts one of the biggest rivers (Wahgi) and a number of fast flowing rivers and streams. The province is made up of six districts, namely: Gumine, Salt Nomane Karimui, Kerowagi, Kundiawa Gembogl, Sinesine Yongomugl and Chuave. It has a very small and densely populated landmass compared to other provinces in the country. As indicated in the map in Figure1, Salt Nomane Karimui is the only district in Simbu covering more than half of the provincial landmass. The total population of Simbu Province is about 376,473 as recorded by the national census of PNG in 2011 and it covers a total landmass of about 613, 359 ha.

Almost half of the population is completely disconnected and/or faced with unbearable challenges in accessing available roads because of mountainous and difficult terrains. Also, difficult geography makes it a challenge for the governing authorities to extend road access to the dispersed population living in remote parts of the region. Plans and targets have been in place for road connectivity, but these attempts remain unsuccessful mainly because of difficult geography. As a result of poor accessibility and poor connectivity, the situation has placed substantial limitation on economic activities and the ability to access public amenities. This province continues to face enormous developmental challenges due to widespread breakdown in social and economic services.

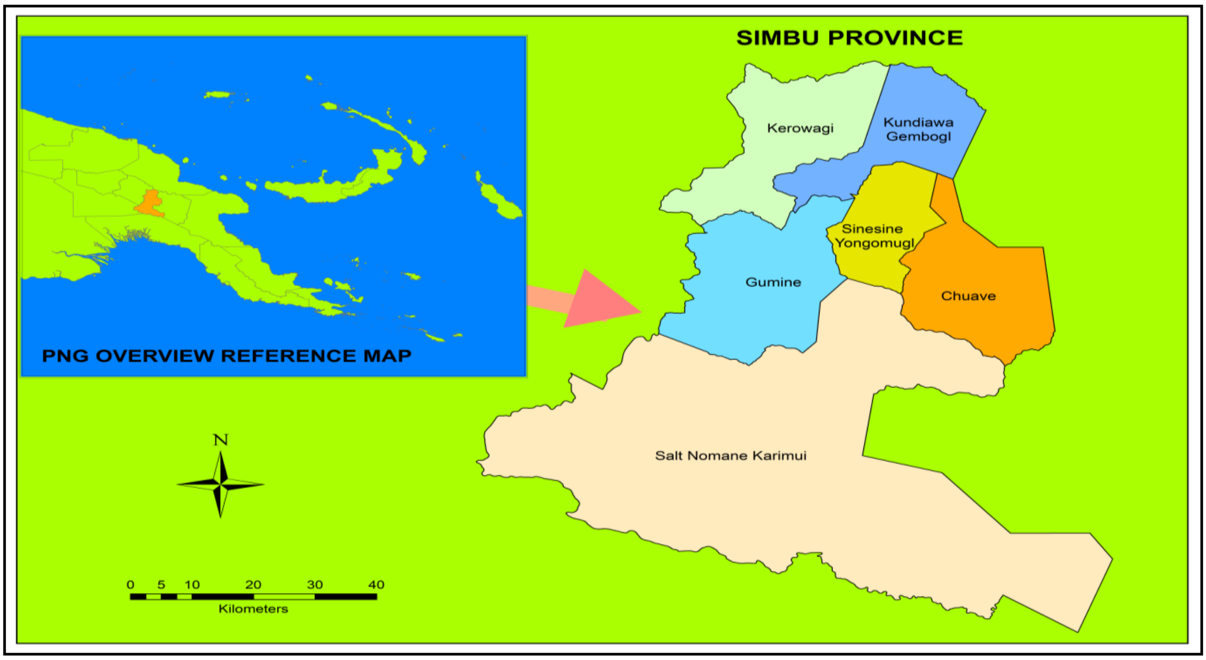


Figure 1**:** Locality Map of the Study Area

The people's traditional means of survival lies in subsistence farming where people cultivate land for food and shelter. However, due to poor road connectivity and geographically unfavourable landscape, subsistence farming does not yield substantial harvests from large scale economic crops. As a result, the potential of economic activities in this province remains relatively poor compared to those of other provinces in PNG.

3. Materials and Method

3.1 Data and Software Used

For the purpose of analysis, a range of data sources and GIS software were used. ArcGIS v10 software package was used for site suitability analysis through the MCE approach, while MapInfo Professional 11 was used for data conversion and verifications. GIS data in vector and raster formats were collected from the Department of Surveying and Land Studies at the PNG University of Technology. Data collected are PNGRIS Meta Data including lithology, soil, landform, rainfall, rivers and SRTM DEM data for PNG at 30m spatial resolution. Field GPS data were collected from field visits for data verification and transformation. Personal interviews were conducted with field experts to collect information on suitability factors and judgments on each parameter to draw up weightage. Personal observation was carried out during field visits to verify expert's opinions to assign rankings and weightings. Online literature from various publications was accessed to identify techniques applied in similar previous studies, knowledge gaps in suitability modelling and likely factors to integrate in this study.

3.2 Method

In order to generate integrated suitability sites, Geographic Information System (GIS) and a mathematical approach were applied in this study. Based on surveyed literature, interviews, personal observations and opinions from field experts, eight relatively important suitability factors were selected for this analysis. For the purpose of suitability alternatives, the factors were classified into two principal classes, i.e., geophysical and geotechnical factors. Parameters of geophysical factors are slope, drainage, rainfall and altitude while geotechnical factors are land form, lithology and soil texture.

The steps covered in completing this study (Figure 2) include: data collection, data preparation, database development, data processing, data integration, overlay, display, and reporting. ArcGIS10 software was utilised to produce lithology, soil type, rainfall, drainage density and landform maps from PNG Geodata while slope and terrain factor maps were prepared from 30m spatial resolution SRTM DEM data for PNG by using the extraction, reclassification and slope analysis tools in ArcGIS 10.

For the evaluation of suitability indicators through the MCE approach, AHP method was employed to generate relatively important weights for each specific class of factors. All thematic layers from DEM data and PNG Geodata were clipped and extracted by mask operations to generate the study area. To perform spatial analysis, all thematic layers were georeferenced and reprojected to a common standard WGS 1984 UTM rectangular coordinate system.

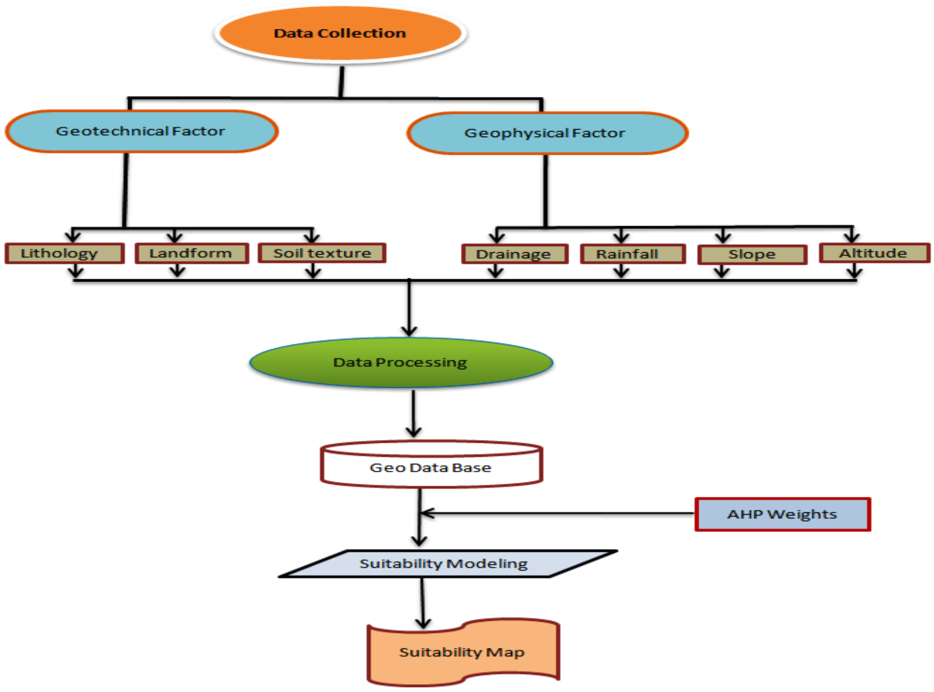


Figure 2**:** Methodology Design Layout

Drainage density was performed by utilising line density in spatial analysis tool to define a zone of density from existing river data from PNG Geodata and extracted by mask operation to generate the study area. In order for integrated overlay analysis, all vector layers that are soil texture, lithology, landform and rainfall were rasterized to produce integrated thematic maps.

3.2.1 Integration of Thematic Layers

All thematic layers of geophysical factors and geotechnical factors were integrated through weighted overlay operation in spatial analysis tool to generate respective suitability alternatives. The weights of each theme were assigned based on their suitability influence for roads. During the weighted overlay analysis, ranking was done for each individual parameter of each thematic map and the weightage was assigned according to the influence of the different parameters. The weights of different themes were given on a scale of 1 to 9 to rate relative preferences for any two elements of the hierarchy based on Saaty's Analytic Hierarchy Process (Saaty, 1980). Ranking the weights of different features of each theme was assigned on a scale of 1 to 7 according to their level of influence on the site, suitable for road construction. Higher weightage, i.e. 7 (seven) was given to higher suitability indicator and lower weightage, i.e. 1 (one) for lesser suitability indicator. By integrating multi-class thematic layers of geophysical and geotechnical factors through weighted overlay analysis, suitability sites were found and classified as highly suitable, suitable, moderately suitable, marginally less suitable and less suitable. Index overlay method was employed to generate alternative suitability maps by integrating multi-class thematic layers in ArcGIS10 through weighted overlay operations. Through this model technique, the map classes generated in each input map layers were assigned with different scores, apart from the weights of each map layer. The average score of this process was then defined by employing the formula (Borham Carter, 1994).

$$S = \Sigma \, S_{ij} W_i \, / \, \Sigma W_i \qquad \text{Equation 1}$$

Where, S is the weight score of an area object (polygon, pixel), Wi is the weight for the ith input map and Sij is the rating score of the jth class of the ith map.

3.2.2 AHP Suitability Process

The primary nature of AHP is to build a comparison matrix expressing the relative values of a set of attributes in the integrated analysis (Lukoko and Mundia, 2016). Relative importance weights (RIWs) are developed from AHP method which can be used as a decision support tool to solve complex decision problems. The AHP model developed from this study is shown in Figure 3.

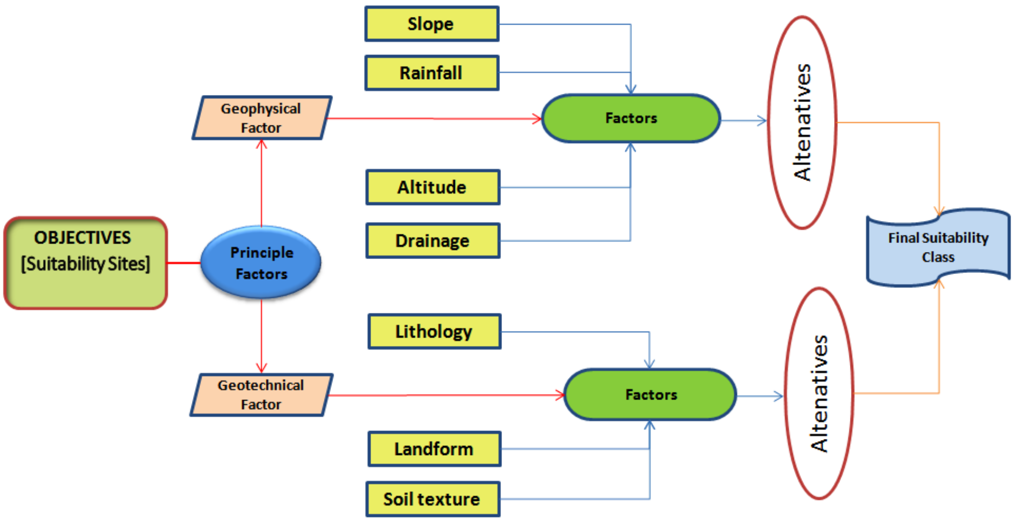


Figure 3: AHP Suitability Model

The steps developed in this study involved a multi-level hierarchical structure of objectives, integrated criteria, sub criteria, and alternatives. It includes objectives at the first, two principal factors at the second, eight subsidiary factors at the third, suitable alternatives at the fourth and last of all final suitability class. Personal observations and interviews with field expertise articulated from the opinions about the value of one single pair-wise comparison at a time were considered a helpful tool throughout the stages of assigning weightage to each parameter. As such human judgement incorporated in the analysis constitutes an important part of the study.

3.2.3 Weighted Overlay Model

Integration of more than one thematic layer in the spatial analysis through weighted overlay usually works through a series of steps to reach a final integrated result. This model study involves three stages of weighted overlay analysis as shown in Figure 4. Thematic layers of geophysical factors were integrated through weighted overlay operations to generate composite map layer of geophysical suitability sites. Thematic map layers of geotechnical factors were integrated through weighted overlay operations to produce composite map layers of geotechnical suitability sites. Integrated thematic layers of geophysical and geotechnical suitability maps were integrated again through weighted overlay analysis to generate the final composite suitability map. The combined analysis of multi-class thematic maps in ArcGIS through weighted overlay analysis demonstrates the relative importance weights of each parameter on road suitability assessment.

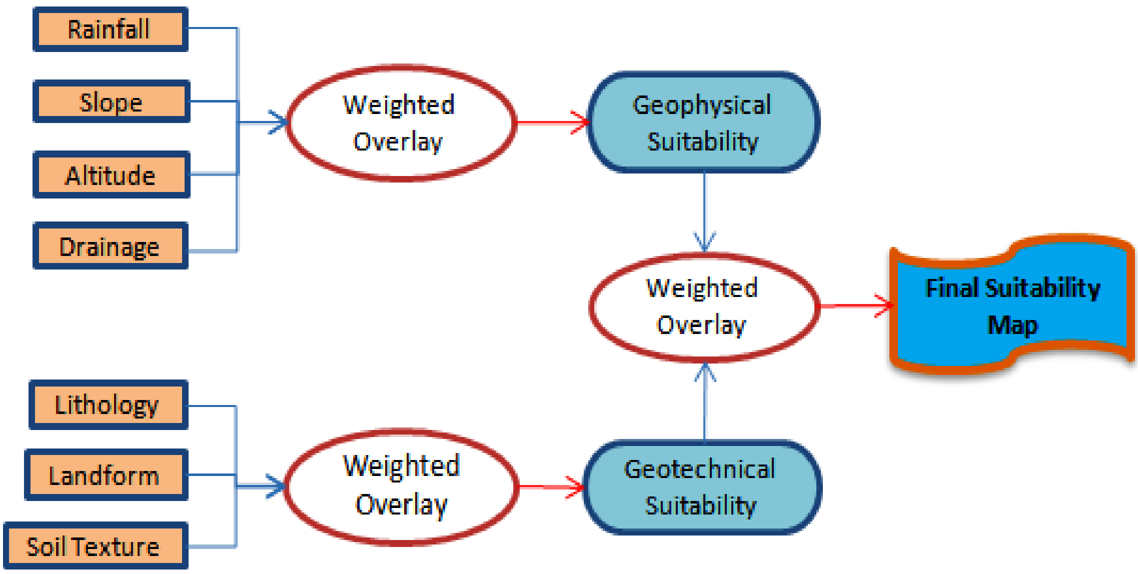


Figure 4: Suitability Model

In order to generate the final integrated composite suitability map layer in the final weighted overlay operation, a single class of evaluation method for integration was applied from suitable ranks and weightage of each parameter. Hence, the weighted index overlay method developed from this study reflects the relative importance of the parameters and the classes belonging to each parameter which in the process demonstrate the level of suitability at each stage.

4. Results and Discussion

Roads are very important projects for any country; their planning, design, construction and maintenance are among the major duties of civil engineers around the world. Subsurface (geotechnical) factors and surface (geophysical) factors are uniformly important parts of the planning process as both have caused so much technical challenges in road projects. The maps of geophysical factors and geotechnical factors are shown from Figure 5 to Figure10. The description of each thematic feature and its weightage are presented in Tables 1 to 11.

Lithology, amongst other geological factors on the alignment and stability of roads, is a very important factor considered in the planning and designing processes of any road construction. Knowledge of geological properties of a region helps in locating feasible sites for any construction activities as the bearing capacity of the subsurface strata is considered to be an important parameter. Rocks are the most common material that is used in the construction of foundation. Hence, local geology of an area is important when planning a major construction .The full knowledge of geology increases the strength, stability, and durability of civil engineering projects. The lithology map of our study area is shown in Figure 5 and its description is provided in Table 1. The formations of rocks in most parts of the study area are sedimentary and igneous rock types. Igneous rock types are formed from volcanic lava and magma. These rocks are primary rocks formed on earth’s crust and they are hard, stable, durable, and capable of bearing more loads so they are often used in the foundation of roads including limestone that is primarily considered suitable. However, intensity of suitability level in these rock types differs and special considerations are drawn on its specific split up and their properties. Sedimentary rocks are the secondary rocks formed by accumulation, compaction, and consolidation of sediments produced from the decay and weathering of pre-existing rocks. These sedimentary layers of rocks are used for the construction of roads and are considered alternatively suitable while few areas have indicated the presence of metamorphic types of rock formation.

Table 1: Lithology characteristics of the study area

SI.No	Lithology	Ranks
1	Acid to intermediate igneous	7
2	Mixed sedimentary and limestone	6
3	Mixed or undifferentiated metamorphic	5
4	Basic to intermediate volcanic	2
5	Basic igneous	1
6	Limestone	7
7	Pleistocene sediments	5
8	Pyroclastics	4
9	Mixed or undifferentiated volcanic	2
10	Mixed or undifferentiated sedimentary	1
11	Fine grained sedimentary	6
12	Mixed sedimentary and volcanic	4
13	Alluvial deposits	3
14	Mixed or undifferentiated igneous	2

Table 2: Characteristics of Soil Factor in the Study Area

SI.No	Soil Type	Description	Rank
1	Cryofolists	Freely drained, little decomposed and mostly shallow organic soils found in cold climates	2
2	Cryorthents	Undifferentiated mostly shallow soils found in cold climates on moderate to steep slopes	1
3	Dystropepts	Moderately weathered soils with altered B horizons and low (<50%) subsoils bases at duration values	4
4	Humitropepts	Moderately weathered soils having high org carbon contents (>12 kg/m2) and low subsoil BS values	5
5	Hydrandepts	Well drained moderately weathered ash soils having irreversibly dehydrating clays and dark topsoils	7
6	Rendolls	Shallow, dark, weakly acid to neutral soils formed on calcareous parent materials	6
7	Tropofluvents	Mainly well drained undifferentiated soils with high (>0.2%) or fluctuating org C to> 125 cm	3
8	Tropoquepts	Poorly to very poorly drained, slightly to moderately weathered soils with altered B horizons	4

Understanding soil types provides useful information for project planners and designers to develop acceptable engineering designs to meet site-specific requirements. Soil types fundamentally provide a broad idea on the basic soil properties of a location and as such broad inferences could be drawn on its suitability for its construction. Perhaps, mountain forests and hilly or steep terrain soil types occur in forests and hilly terrain areas and when understanding that type of soil nature certainly helps designers to be acquainted with soil depth to foothold and efforts required for making a good foundation during construction. Obviously soil depth in mountainous and steep hills are very shallow, it requires special types of treatment while making the foundation. There are eight types of soil available in the study area as shown in Figure 6 with their discretion in Table 2. Most of the physical problems are related to unfavourable soil and site conditions. Hence, site specific soil property and information at a regional level like this are vitally important for planers and decision makers to incorporate in their initial planning stages to take special consideration in sensitive areas.

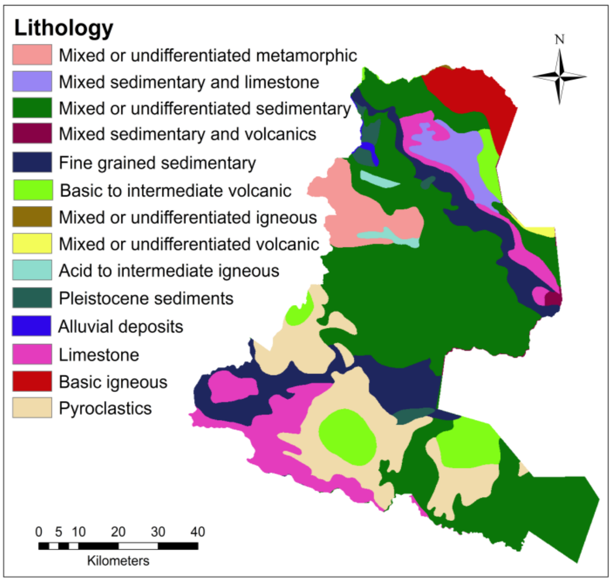


Figure 5 : Lithology Map

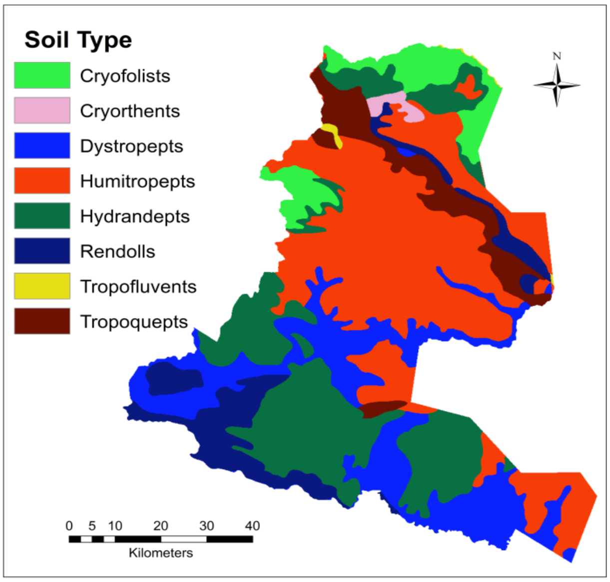


Figure 6: Soil Texture Map

Landforms are vitally important to designers and planners because they often place substantial limitations on the location, intensity, and character of any physical infrastructure development. Perhaps, landforms have a big influence on road investment decisions because some geographical locations are difficult or expensive to build on due to steep slopes, the presence of water or extensive rock formations. In other locations, it is dangerous to build because of natural hazards such as flooding, landslides and erosion. Landform map of the study area is shown in Figure 7 and its description is provided in Table 3.

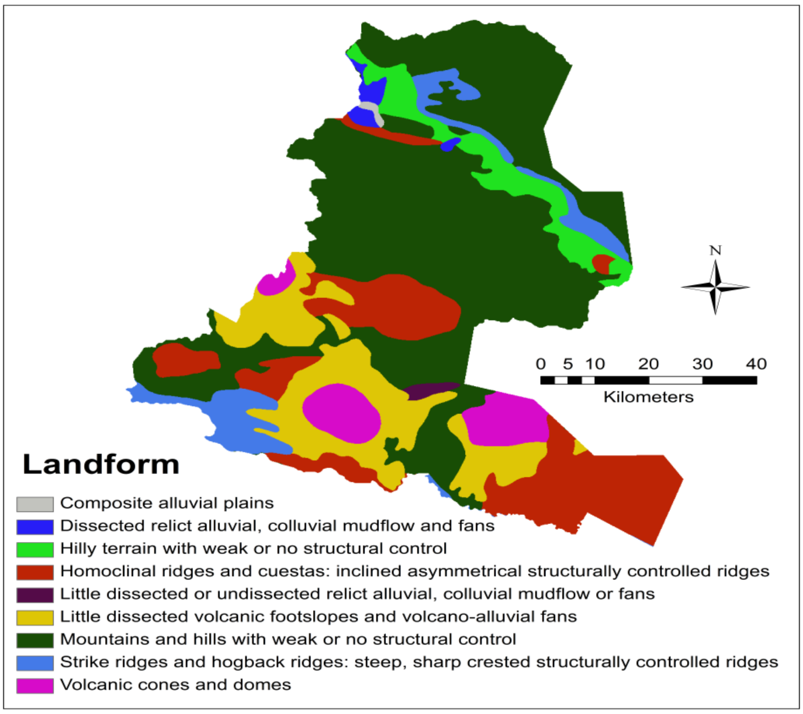


Figure 7: Landform Map

Obviously most of parts of the region are challenging and difficult for road infrastructure development as they are filled with mountains and hills with weak or no structural control and furthermore they are covered with steep and sharp strike ridges and hogback ridges. Only southern parts of the region are likely suitable for infrastructural development as they are predominantly dominated by various volcanic land formations.

Table 3: Landform description of study area

SI.No	Landform	Ranks
1	Composite alluvial plains	6
2	Dissected relict alluvial, colluvial mudflow and fans	4
3	Hilly terrain with weak or no structural control	2
4	Homoclinal ridges and cuestas: inclined asymmetrical structurally controlled ridges	7
5	Little dissected or undissected relict alluvial, colluvial mudflow or fans	1
6	Little dissected volcanic foot slopes and volcano-alluvial fans	5
7	Mountains and hills with weak or no structural control	1
8	Strike ridges and hogback ridges: steep, sharp crested structurally controlled ridges	2
9	Volcanic cones and domes	3

Slope is an important criterion for hilly terrain for finding suitable sites for construction. As the slope steepness increases, possibility of slope failure also increases. Hence, steep slopes are disadvantageous for construction purposes because the slope increases the construction cost. Road alignment positions itself on a suitable geographical surface, and it is considered most stable as these sites are well-suited to low-cost methods of slope protection and stabilisation work and subsequently less likely to cause environmental mischief. Figure 9 indicates the slope map measured from <5 degrees to > 30 degrees with its description in Table 4. Slope angle <5 degree has no limitation on the geometry of the road system as it is considered highly suitable. However, certain areas may only be expensive due to drainage problems. Slope angle 5 -10 degrees is suitable for road but must run parallel or diagonally to contours as routing is virtually dictated by terrain. Slope angle 10 – 20 degrees requires special care in this terrain for any road design as it poses greater economic and ecological costs and technical problems are more often likely. Slope angle 20 – 30 degrees creates extreme ecological and technical problems at this terrain and is expensive to build roads. Cut and fill on the uphill and downhill are often expensive. Slope angle >30 degrees at this terrain is too steep and technically not fitting for road construction as it may be extremely damaging to the terrain. Therefore, for special reasons, it must be planned with extreme care.

Table 4: Slope angle of the study area

SI.No	Slope Angle	Description	Rank
1	< 5	Gentle	**7**
2	5 - 10	Moderately sloping	**6**
3	10 - 20	High Moderate steep/Hillside	**4**
4	20 – 30	Steep hillside	**3**
5	>30	Very steep	**1**

Table 5: Altitude description of the study area

SI.No	Altitude	Description	Rank
1	< 600m	Gentle/V-shape Valleys	**2**
2	600 - 1200	Low Moderate Terrain	**6**
3	1200 - 1800	Moderate Terrain	**7**
4	1800 - 2400	High Moderate Terrain	**5**
5	2400 - 2800	Steep Terrain	**3**
	>2800	Very steep and rocky peaks	**1**

Altitude is one of the important factors to be considered in road projects as it creates several geotechnical challenges and ecological problems. The map of altitude is shown in Figure 8 with its description in Table 5. It is measured in meters from <600 to > 2800. Terrain height at <600m is gentle and fitting for construction at some point but lower altitude is obviously difficult for construction in mountainous and difficult terrain as most part of it is covered by fast flowing river banks with extensive rock formations and steep clips. It also features V-shaped valleys that often have rivers and streams at the base which poses flooding and landslide problems. Terrain height from low moderate to high moderate (600m - 2400m) is most fitting for construction as it may possibly allow low-cost method of routing on the terrain and is less likely to cause environmental mischief. Terrain heights from 2400m - 2800m are expensive and technically challenging for road construction. Terrain height > 2800m is considered not fitting for road construction as it covers sharp rocky mountain tops and steep hilly edges and sloppy ridges. It covers excessive rock formation which is technically impracticable for any construction activities.

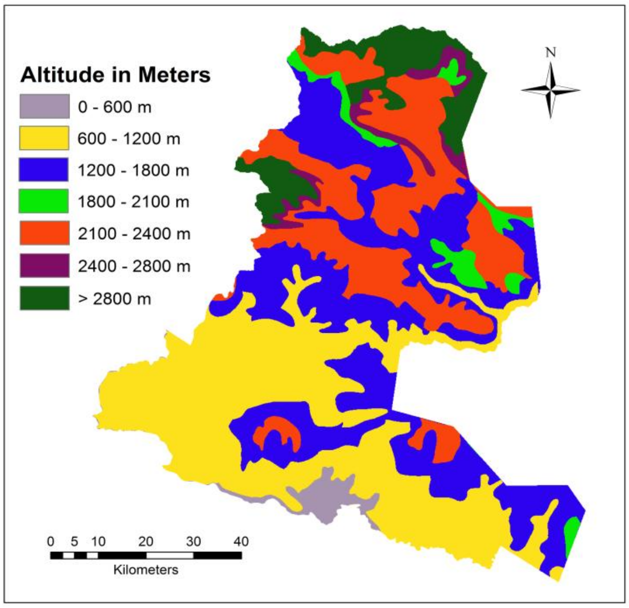


Figure 8: Altitude Map

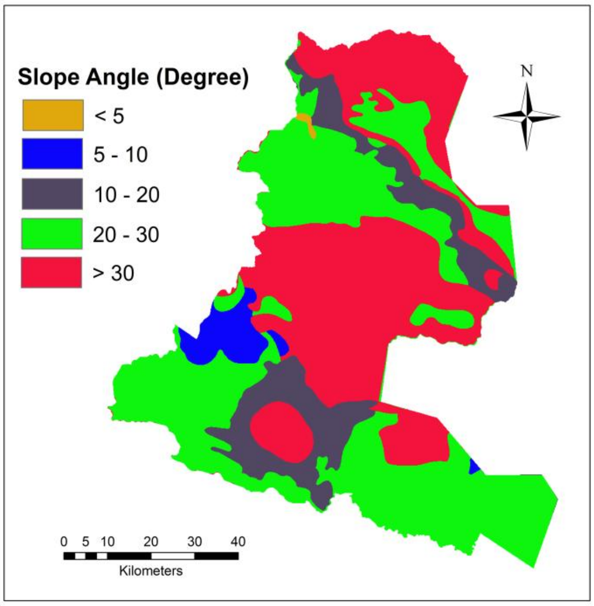


Figure 9: Slope Map

Weather pattern within the study area is most influential towards road stability. Among others, rainfall is most important to know as it influences surface and underground stability and integrity of road pavement and stability of adjacent terrain. Roads in mountainous and rugged terrains necessitate study of weather patterns so as to plan weather resistant roads. Roads in mountainous and difficult terrains are sensitive to surface runoffs that erode road surfaces quickly thereby disrupting road stability and conditions and also cause excessive flooding risk and frequent landslide problems. The annual rainfall map is shown in Figure 10 and descriptions are provided in Table 6 respectively. Annual rainfall is measured in millimetre and ranges from lowest 1,500mm to highest 7,000 millimetres. It is generally accepted that low rainfalls at any topographical surface are highly suitable for any construction and high rainfall regions are unsafe as they pose so much environmental, economical and technical problems during and after construction. Whilst annual rainfalls ranging from 1,500mm to 300mm are suitable for construction activities, 3,000mm to 7,000mm and more are problematic and need to be handled with extra care in the planning process.

Table 6: Annual rainfall distribution of the study area

SI.No	**Rainfall**	**Description**	**Rank**
1	1500 – 2500mm	Low	**6**
2	2500 – 3000mm	Moderate	**5**
3	3000 - 4000	High	**4**
4	4000 - 7000	Very high	**3**

Table 7: Drainage density description of the study area

SI.No	Drainage Density	Description	Ranks
1	0 -0.3	Very Low presence	3
2	0.3 -0.7	Low presence	7
3	0.7 - 1	Moderate	6
4	1 – 1.3	High Water availability	4
5	1.3 - 3	Very High presence	2

River-drainage system causes serious problems at the landscape level as it affects the integrity of the road pavement and stability of the hilly terrain. A high density of streams or ditches tends to indicate a high water table and potential risk to surface water. Low density of streams indicates a free draining subsoil and or/bedrock. Hence, the presence of streams greatly influences the stability by toe erosion or by saturating the slope material or both. Road in mountainous regions are naturally sensitive to serious landslide, flooding and catastrophic erosion due to excessive stream flows. It is also expensive due to site drainage problems and perhaps increased routine maintenance costs, periodic closures and reconstruction of failed sections. Drainage density map is shown in Figure 11 and a description of its influence is presented in Table 7. It is measured in square kilometre (sq. km.) ranging from lowest 0 -0.3 sq. km to highest 1.3 – 3 sq. km. It should be noted that low density and high density are obviously found in mountainous and rugged terrain regions and are not fitting for construction purposes as articulated by field experts. It is predominantly found at the peaks of mountain ranges, rocky hills, base of V-shape valleys and steep clips along the river banks and streams line at the lower altitudes. Road planning in the region of low water presence from 0.3 sq. km to high water availability presence of 1.3 sq. km is practically fitting for construction as the alternative options.

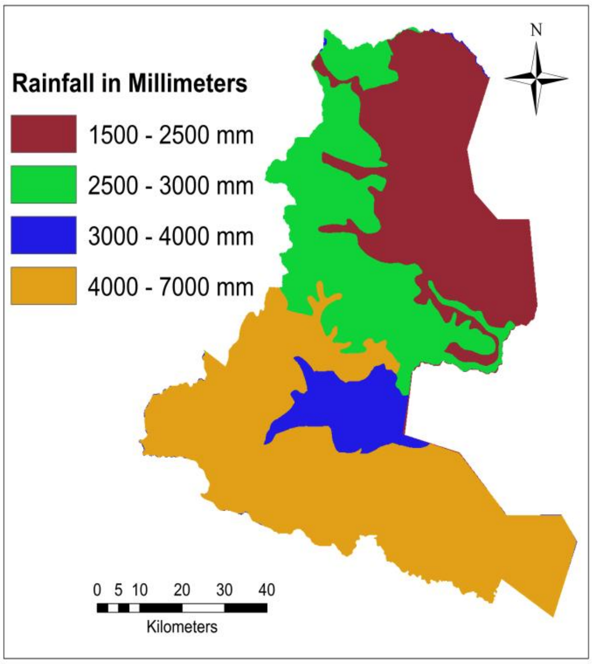


Figure 10: Rainfall Distribution Map

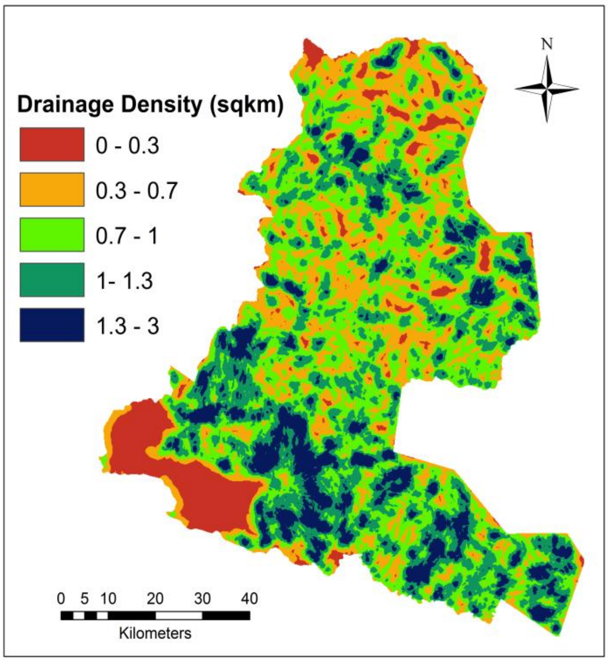


Figure11: Drainage Density Map

4.1 Weightage on Suitability Assessment

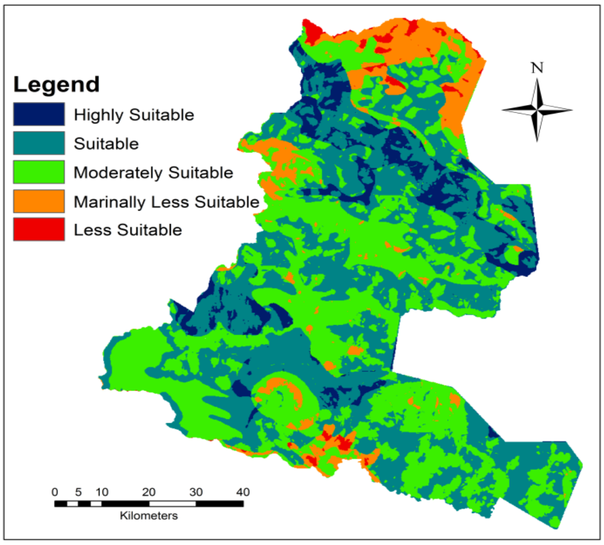
Suitable weightings and rankings of the thematic layers and their individual features were based on the intensity of influence on the surface and sub-surface of terrain suitable for road construction in the mountainous and rugged terrain region. In the construction of pair-wise matrices and determination of relative importance of weightages (RIWs), expert opinions were integrated as exceptionally important judgement. The assignment of scale of 1 to 9 is based on Saaty's Analytic Hierarchy Process (Rao Mukund et. al., 1991) as it is widely accepted method for scaling the weights of parameters by constructing a pair-wise comparison matrix of parameters where entries indicate the strength with which one element dominates over another vis-à-vis the relative criterion. The detailed assigned weightages of two principal factors are shown in Table 8.

Table 8: Weightage of the Suitability Factors

Principal Factors	Suitability Indicator	Weightage (%)
Geotechnical	Lithology	38
	Soil Texture	29
	Landform	33
Geophysical	Slope	29
	Rainfall	18
	Altitude	32
	Drainage Density	21

4.2 Integrated Suitability Alternatives

Geophysical suitability alternatives, geotechnical suitability alternatives and final integrated suitability results are shown in various maps from Figure 12 to 14. Table 9 provides a summary of alternatives and final composite suitability results. Geophysical suitability results in Figure 12 show highly suitable class in dark blue colour, suitable class in light blue colour, moderately suitable class in light green colour, marginally less suitable class in yellow colour and less suitable class in red colour. Suitable and moderately suitable cover large areas, but roughly about the same area 2,590.244 sq. km. and 2,521.45 sq. km. respectively while suitable covers 420.61 sq. km. and are found in the northern region towards the central region and few pots in the southern region. Marginally less suitable covers 512.125 sq. km. and less suitable covers 76.345 sq. km. which are obviously dominating the peripheries of the northern region, few areas within the southern region and few spots scattered across the study area.



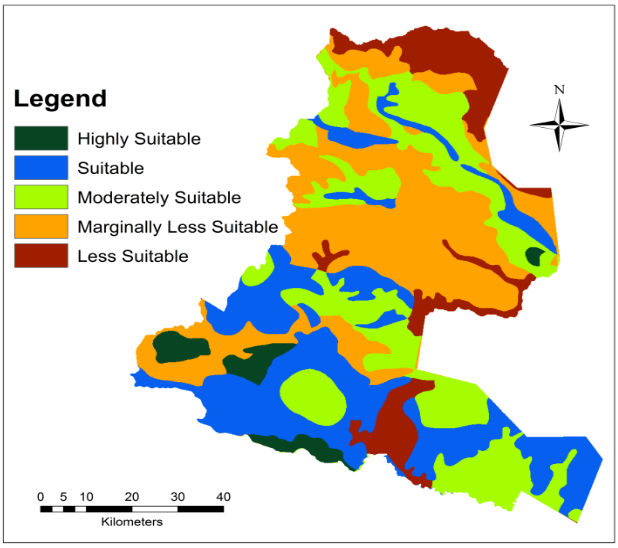


Figure 12: Geophysical Suitability Map

Figure 13: Geotechnical Suitability Map

Geotechnical suitability map in Figure 13 indicates highly suitable class in dark green colour, suitable class in blue colour, moderately suitable class in light green colour, marginally less suitable class in orange colour and less suitable class in dark red colour. A highly suitable site covers few areas of southern region and a spot in eastern end with 235.487 sq. km. Suitable and moderately suitable sites cover almost about the same area 1,622.452 sq. km. and 1,654.192 sq. km. respectively in most parts of southern to central region and few areas in the northern region. Marginally less suitable sites cover a large area up to 1,937.45 sq. km. spreading over central towards northern region and small parts of south-west fringes while less suitable covers part of northern periphery, small areas in southern region and few areas in central towards eastern fringes covering up to 683.547 sq. km.

The final integrated suitability map is shown in Figure 14. It is the composite overlay product of the geophysical suitability thematic layer and geotechnical suitability thematic layer. Final integrated composite map shows highly suitable sites in dark green colour and covers 87.706 sq. km. Suitable sites are shown in green colour and cover 1884.398 sq. km. Moderately suitable sites are in light green colour and cover 432.926 sq. km.; marginally less suitable sites are in yellow colour and cover 1387.579 sq. km. and less suitable sites in orange colour and cover 327.668 sq. km. Highly suitable site appears only in few parts of southern region while suitable and moderately suitable sites cover almost the entire southern region towards central and northern regions with strikes cross the northern region. Moderately less suitable site covers the central region, few areas across the northern region and few spots in the southern region while less suitable site covers northern peripheries and small areas in the southern region.

Table 9: Integrated suitability alternatives

Weighted Overlay Suitability Level			
Suitability Alternatives	**Class**	**Area (sq. km.)**	**% Cover**
Geophysical Suitability Map	Highly Suitable	420.61	6.87
	Suitable	2590.244	42.32
	Moderately Suitable	2521.45	41.2
	Marginally Less Suitable	512.125	8.37

	Less Suitable	76.345	1.25
Geotechnical Suitability Map	Highly Suitable	235.487	3.84
	Suitable	1622.452	26.45
	Moderately Suitable	1654.192	26.97
	Marginally Less Suitable	1937.45	31.59
	Less Suitable	683.547	11.15
Final Suitability Map	Highly Suitable	87.706	1.43
	Suitable	1884.398	30.8
	Moderately Suitable	2432.926	39.75
	Marginally Less Suitable	1387.579	22.67
	Less Suitable	327.668	5.35

The results of two alternative suitability sites and final integrated composite map indicate that the northern part of the study region is unsuitable for construction and similarly central region and few areas in southern region that are relatively difficult for roads. Thus road designs require special care in these regions. It imposes greater limitations on the geometry of road system and routing is obviously dictated by terrain. All types of road can possibility be constructed but at greater economic and ecological costs than is experienced for road in geographically suitable areas. Suitable to moderately suitable sites are the only alternative options for roads while suitable sites cover only few areas in the southern region. Any road can be constructed in this region but it will frequently cause embankment problems as routing is obviously dictated by terrain.

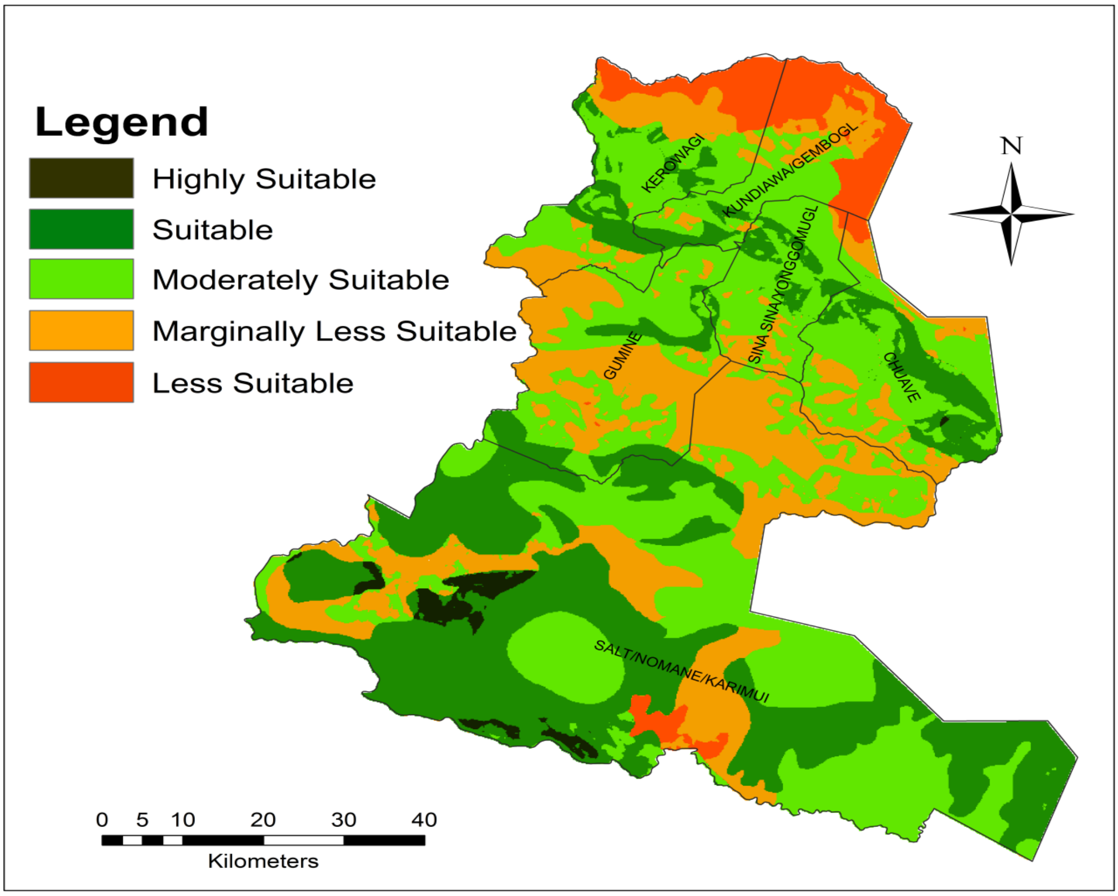


Figure 14: Final Suitability Map

5. Conclusion

The PNG government has invested a lot of funds on road infrastructure in the country, but their objectives are not met and/or delivered up to their expectation mainly due to technical challenges. To accommodate the needs of appropriate locations in undulating areas, site suitability analysis has become inevitable. Site suitability is the method of understanding existing surface and subsurface qualities and factors that will determine the location of a particular activity, such as road construction.

This paper has presented a quantitative approach for selecting suitable sites for roads in rugged terrains and mountainous regions using GIS and MCE through the AHP process. Use of AHP in MCE approach permits the derivation of relative weights of each parameter for integrated analysis. However, GIS and MCE techniques developed in this paper is appropriate for initial planning stages. The paper provides the public and government agencies with a clear understanding of the road construction activities and budgeting requirements for the study area, over the time period of planning process. Hence, the results derived from this suitability model depend upon data accuracy. For that reason site specific technical and environmental factors can be incorporated into the model for more comprehensive results to incorporate construction costs and site specific route evaluation and selection.

This suitability model involves detailed investigations of surface and subsurface of an area including mapping techniques utilizing GIS tools that help in processing geographical database and display the areas of the site that are suitable for various planning objectives and alternatives. Perhaps site suitability modelling integrating subsurface geotechnical and surface geophysical factors provides the best alternatives for planners and decision makers to adopt a cost-effective and environment-friendly planning approach for roads in mountainous and difficult terrain regions of PNG and similar locations around the world.

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