Applied GIS

a free, international, refereed e-journal
(ISSN: 1832-5505)

URL:
http://www.appliedgis.net

MANAGING EDITOR:
Ray Wyatt – ray.wyatt@unimelb.edu.au

Volume 10, Number 3
July, 2014

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All papers published during 2014 are part of *Volume* 10.
Each paper constitutes one *Number.*

Hence this paper should be cited as:

Kursah, M.B. (2014) – Geo-environmental assessment to identify a least-cost road in Ghana, *Applied GIS*, 10(3), 1-22

Geo-environmental assessment to identify a least-cost road in Ghana

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Abstract - Unlike many studies which simply generate least-cost paths, this paper develops a geospatial methodology for amalgamating many geo-environmental factors in order to determine the costs of construction for pre-defined or existing roads. The geo-environmental factors used were elevation, presence of watercourses, soil characteristics and land cover type. They were reclassified to cost values/attribute weights based upon their impact on road construction, and they were then combined, using the *weighted overlay* tool in *ArcMap,* to generate a thematic cost layer. The total construction cost for each road was then extracted from this layer using the *Extract by Mask* tool. Although the cheapest road was longer, it less costly by 3.2%, mainly because of its higher elevation, avoidance of major valleys, suitable soils and less problematic land cover, all of which reduced the need for cut-and-fill and culverts. It is suggested, therefore, that government agencies adopt this powerful technique for reliable and well integrated road planning and assessment. Nevertheless, the method could be improved by including additional factors such as proneness to floods and access to people and socio-economic activities.

Keywords - costs layer, geo-environmental factors, least-cost path, thematic costs layer, weighted overlay

1. Introduction

Ghana is located on West Africa's Gulf of Guinea and has ten administrative regions, with the Northern region being the third poorest (Ghana Statistical Service, 2005). Road transport carries 94% of national freight and 97% of national passenger traffic, and the Northern region is typical in this respect (Republic of Ghana, 2002).

The study area contains the four administrative districts of Yendi, Saboba, Chereponi and Gushiegu, in the north-eastern corridor of Northern region of Ghana (Figure 1a) and it is strategic both for the Northern region and for Ghana as a whole due to its potential as a food crops-producing area. But transport infrastructure in the area is in poor condition, consisting mainly of paved roads with potholes, and this seriously impedes mobility within the districts themselves and surrounding areas (Ghana Statistical Service, 2005).

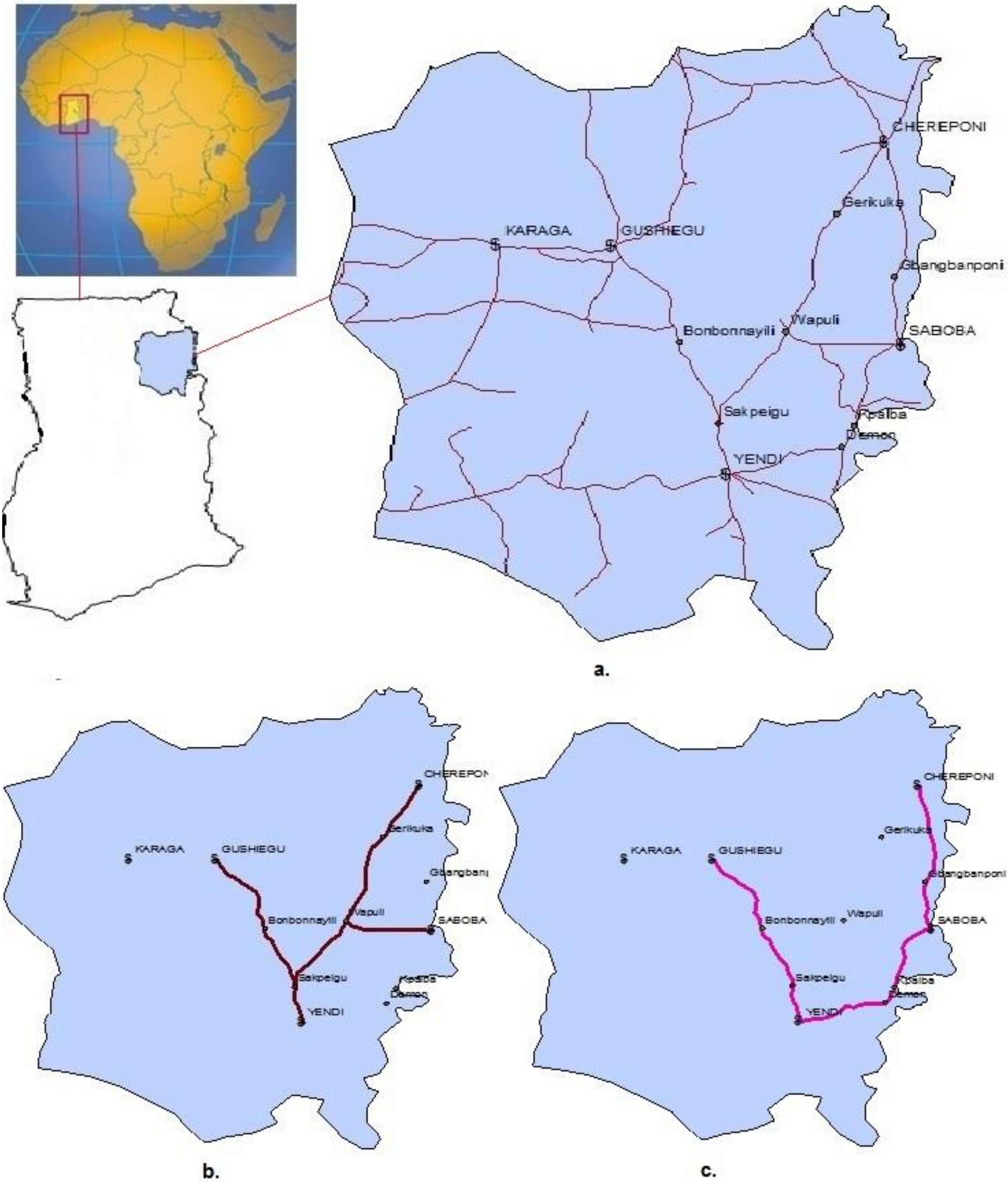

Figure 1 - Maps of existing roads (a.); the proposed Wapuli road (b.) and the proposed Kpalba road (c.)

Consequently, recent national development plans such as National Development Policy Framework have focused on investment to improve roads in these districts. One of such focus includes the upgrading of roads to link Yendi to the three district capitals of Saboba, Chereponi and Gushiegu. However, the choice of which road to do this has not been an easy decision to make (Kursah, 2013; 2010).

One of the proposed options is the *Wapuli road* (Figure 1b) and its total length is 170km. The second option is the *Kpalba road* (Figure 1c) and its total length is 169km. Debate about these two alternatives over the last two decades has been based on:

1) cost of construction,
2) flood risk, and
3) access to people and socio-economic activities.

The flood risk issue has been researched into by Kursah (2013), but this paper will focus on the first issue – determining the road with the least-cost of construction. Which of the proposed options is less expensive to construct?

Providing an answer to this question will help policy makers to take a firm decision on which of the roads to upgrade. We will use GIS to incorporate the geo-environmental factors of soil types, land cover and drainage among others. Incorporating geo-environmental factors into GIS for road planning has been done elsewhere, and it has been found to be more accurate and more useful to planners than the manual method is (Saha et al, 2005).

Nevertheless, although several studies have used GIS to model and identify least-cost paths/roads (for example Ismail Jusoff, 2009, Saha et al, 2005; Collischonn & Pilar, 2000), little has been done in terms of determining the least-cost alternative amongst pre-defined or existing roads. This demands a different approach; and so this study will add a new perspective.

Its specific objectives are to;

1) generate a thematic cost layer for the study area,.
2) identify which of the proposed roads has the least construction cost, and.
3) make recommendations based on the findings.

Because monetary costs of road construction are extremely difficult to acquire in the study area we here use cost values derived from weights assigned to the respective geo-environmental factors that influence the cost of road construction.

The next sections review the related literature and briefly describe the characteristics of the study area. This is followed by the methodology and the results of the study. After that, a SWOT analysis of the proposed roads is provided. Finally, the study ends with a discussion and recommendation to stakeholders in the districts and suggestions for further research.

2. Literature review

A thematic cost layer is:

> *a raster map where value at each pixel (cell) gives the estimated relative cost of passing through the pixel,* (Saha et al, 2005).

That is, in GIS the cost of passage through a surface is expressed a grid where the values associated with the cells are used as weights to determine least-cost paths. These weights represent the resistance, friction or difficulty in crossing the cell, and may be expressed in terms of cost, distance, time or risk (Collischonn and Pilar, 2000). Put differently, constructional works on road upgrading are hindered by costly geo-environmental factors (Ismail and Jusoff, 2009) and GIS has been used to outwit such costly geo-environmental hindrance in route/road planning (Saha et al, 2005).

In a study to identify the least-cost for a pipeline, Feldman (1995) used the *spatial analyst* tool in *ArcMap* in order to identify the least-cost route from a thematic cost layer derived from terrain, geology and land use in the Caspian sea region. The least-cost route was 21%

longer (51km) than the straight-line route (42km) between the source and the destination points, but adopting it led to a reduction in the construction cost of 14%. The least-cost route realised savings by avoiding higher-cost industrial and urban cells on the straight-line route.

With the *weighted overlay* tool, Saha et al (2005) generated a thematic cost layer, in a landslide-prone area of the Himalayas, to determine the least-cost road between two points. Geo-environmental factors used included landslide occurrence, cost of land acquisition, and requirements for bridge blasting, excavation and cut-and-fill works. With GIS, these factors were assigned cost values which were then multiplied by weights that ranged from 0 to 9, with zero signifying the least-impact and 9 signifying the highest impact upon road-construction costs. The actual weights were:

- existing landslide (9)
- landslide hazard (8)
- drainage (7)
- land cover/ land use (6)
- lithology (4) and
- barren areas (3).

Barren areas were given the lowest weight both because such areas are under government control and have no compensation cost and because no environmental problems like tree cutting exist in these areas. The ratings for drainage were based upon the width of the watercourse; with the widest ones assigned the highest cost because of the need to build longer bridges. Their conclusion was that in manual road planning, the alternative best road may be unknowingly overlooked whereas the use of GIS considers all possible geo-environmental factors with certainty.

Kursah (2013) also used the *weighted overlay* tool in *ArcMap*, to amalgamate elevation and soil factors to generate what the author referred to as a *composite flood risk layer.* It depicted the suitability of each cell to retain flood waters and the author was able to use it to measure the length of the roads falling within flood risk areas.

After identifying the four geo-environmental factors of elevation, slope, lake barriers and distance to existing roads, Ismail and Jusoff (2009) showed used GIS to identify suitable areas for road development. To derive a cost layer they assigned 80% as the *percentage of influence* (factor weight) to slope, 20% to distance from existing road and 0% to lake barriers, as the latter were seen as absolute barriers. Then, using the *raster calculator* tool in *ArcMap*, the individual cost layers were combined to generate a thematic cost layer.

Other studies have identified that in road planning, topography is often a vital constraint and least-cost path analysis frequently considers steep slope areas as absolute barriers to road passage (Jaga et al, 1993). However, steeper slopes are not absolute barriers; they simply add cost to road upgrading. Nevertheless, there are many illustrations of where a winding, long but less steep path is preferred over one that is shorter and steeper (Collischonn & Pilar, 2000).

In conclusion, most GIS studies of least-cost roads focused on yet-to-be defined paths. However, this study adopts a different approach. It uses GIS to identify which one of the two existing roads has a lesser cost of construction, thus, making this study quite novel.

3. The Study Area

The study area consists of four administrative districts - Yendi, Saboba, Chereponi and Gushiegu, all named after their respective administrative capitals. The road network sought is one that will link these district capitals. The proposed road to link Gushiegu and Karaga is undisputed because only one feasible option exists and so the Gushiegu-Karaga road is not considered in this study. Figure 2 shows the location of settlements in the study area.

Figure 2: Map of the study area showing the location of settlements

Topographically, the study area has fairly gentle slopes and undulating lowlands with a few rock outcrops underlain by Voltain rocks. Elevation ranges between 50m and 300m at valley bottoms and plateau surfaces respectively. The eastern border, along River Oti, has the lowest heights. Relatively higher elevations are along small ridges, from Yendi through to Gushiegu (Kursah, 2013). Three perennial rivers, the Oti, the Daka and the Nasia, are found in the area. Vegetation in the area is grassland interspersed with guinea savannah woodland.

The four districts have a total of 349,781 people with an average density of 28 persons per square kilometre (Ghana Statistical Service, 2005). Roads linking the district capitals are either trunk or paved, and many of the former are unmotorable in all sections due to potholes and flooding during rainy seasons (Kursah, 2013, 2010, 2009). The government intends to upgrade these to a tarred status, as shown in Figure 3. T he power line from Yendi to Saboba and its planned extension to Chereponi is along the Kpalba road.

To sum up, the relatively varied features of the districts justify the use of GIS to incorporate various geo-environmental factors for determining road- construction costs.

a. Section of existing road showing potholes   b. Intended road after upgrading

Figure 3 - Sample of existing roads (a) and the intended road after construction (b). “b” is a section of the 3-kilometre road constructed near the Saboba township

3. Methodology

3.1. Factors used in the thematic cost layer

As shown in the literature reviewed, road-construction costs are impacted by factors that include, but are not limited to, elevation, land cover/land use, watercourses, soil types, geology, landslides and slope. Based on peculiar local geography of our study area and consultative discussions with the planning, civil engineering and other relevant authorities in the districts, five relevant factors were identified:

1) elevation,
2) intervening watercourses,
3) soil,
4) land cover, and
5) forest reserves.

Other factors such as slope and landslide susceptibility, though possibly relevant in another geographic area, are either insignificant (slope) or non-existing (landslide) in our area. The s*lope* tool in *ArcMap* shows an average slope of around four degrees. Also, as these roads already exist, the slopes may have already been levelled-out, even if it they existed in the first place. It is also worth noting that there are no “constraint” factors in this analysis like there are in most suitability studies. This is because the road pathways already exist or are known.

3.2. Datasets and sources

Based on the geo-environmental factors identified above, the following datasets were acquired:

1) a digital elevation layer (90m resolution) from the CGIAR Consortium for Spatial Information (CGIAR-CSI), and
2) vector layers showing watercourses, land cover/land use, soils, forest reserves, road networks, district boundaries and settlements; all from Centre for Remote Sensing and Geographic Information Services (CERSGIS).

The DEM from CGIAR-CSI was used because it is unclassified and shows more details than other data sets. Nevertheless, using a DEM that is already classified means some heights may be masked out and grouped into a larger class. For example, 45m and 50m may have been classified into one class.

Fieldwork was undertaken in the area to identify control points such as major road junctions and river confluences. The location of these features was taken with *Garmin Oregon 450* GPS. Such control points were used to check positional accuracy of the layers, especially, because they were from different sources. The datasets were also checked for accuracy with similar data from other sources.

3.3. Choice of method

Various analytical procedures collectively referred to as multi-criteria evaluation (MCE) or multi-criteria decision making (MCDM) methods have been integrated with GIS to strengthen its decision-support capabilities (Jiang and Eastman, 2000; Malczewski, 1999). GIS-based MCE or MCDM is a procedure that combines and transforms input spatial data into an output resultant decision (Attuah & Fisher, 2010).

In *ArcMap* two commonly used MCE or MCDM approaches are the *Boolean operation* (usually used with the support of a *raster calculator*) and *weighted overlay* or *weighted linear combination* (WLC), (Riad et al, 2011, Jiang and Eastman, 2000). The appropriateness of the methods depends on the type of problem being addressed, the user's skills, GIS software and resource availability. These approaches are explained below.

3.3.1. The Boolean operation and the raster calculator

The *Boolean operation* is probably the simplest and best-known type of GIS model for suitability analysis (Riad et al, 2011; Eastman, 2001). All criteria are assessed using thresholds of suitability in order to produce Boolean maps, which are then combined by logical operators such as intersection ("AND") and union ("OR") (Jiang & Eastman, 2000). The query data is then entered into the r*aster calculator* (in *Spatial Analyst*) according to the existing thematic layers (Riad et al, 2011). Only one or zero values are assigned to each unit area, specifying whether it is suitable or unsuitable, respectively.

The advantage of this method is that it is easy to understand and intuitively appealing to decision makers (O'Sullivan and Unwin, 2003) and it is less time consuming (Riad et al, 2011). However, the *Boolean operation* has limitations in its usage. For instance, Boolean intersection results in a very hard "AND" – an area will be excluded from the result if any single decisive factor fails to meet its threshold. On the other hand, the union "OR" operator implements a very liberal mode of combination, as an area will be selected so long as a single decisive factor meets its threshold (Jiang & Eastman, 2000). Hence there is no distinction between those areas that *fully* met the criteria and those that are at the edges.

Moreover, the approach is inappropriate for standardising suitability layers (Pereira & Duckstein, 1993) and for comparing the criteria if they have the same weight or level of importance (Carvalho et al, 2007). But since the road pathways in this study already exist, only levels of suitability are required - not the "AND" and "OR" operations in the Boolean method. The approach also lacks the continuity of suitability of cells, and so if the analysis needs levels of suitability, as in the case of this study, the Boolean operation is inappropriate (Riad et al, 2011).

3.3.2. The weighted overlay model

Information usually exists in different raster layers with diverse value scales; for example dollars, metres and degrees, and it is not proper to add a raster of land cost (dollars) to a raster of slope (in degrees) and obtain a meaningful result (ESRI, 2002; Eastman, 2001). Also, the factors in the analysis may not be equally important (Carvalho et al, 2007). It may be that the cost of land is more important in choosing a least-cost road than the slope or vice versa. This is where the Boolean approach is handicapped.

The weighted overlay model resolves such problems. This method has been referred with different names such as the *weighted overlay suitability model* (Riad et al, 2011) and the *weighted linear combination* (WLC) (Jiang & Eastman's, 2000; Eastman, 2001). The *weighted overlay* in *ArcMap* is an overlay analysis tool included in the *Spatial Analyst* extension. Commonly, it is used to solve multi criteria problems such as suitability modelling. It is a technique for applying a common measurement scale of values to varied and dissimilar inputs to produce an integrated result. This approach multiplies each standardised factor layer (each cell within each layer) by its factor weight and then sums the results (Eastman, 2001).

There is also the *Order Weighted Average* (OWA) method, which can be considered as an extension and a generalisation of the conventional, combination procedures in *weighted overlay* or *weighted linear combination* (Attuah & Fisher, 2010) and *weighted overlay* is used in this study because it is simple and straightforward (ESRI, 2002). Also, it allows a low score on one factor to be compensated for by a high score on another – a feature called trade-off or substitutability (Jiang & Eastman, 2000).

In order to add weights in the model one must represent the relative importance of each variable as well as the relative importance of the classes of each variable according to the given objective (Carvalho et al, 2007). If the analysis needs more flexibility or a continuous measure of suitability, in which every cell has a suitability value, as is the case of this study, then *weighted overlay* is appropriate (Riad et al, 2011; Carvalho et al, 2007). Models based on *weighted overlay* allow more flexible and continuous map combinations compared to operations based on Boolean logic (Carvalho et al, 2007). Riad et al (2011) sum up this view succinctly:

> *Comparing weighted models with Boolean models, it is identified that weighted models have more flexibility and ability for priority indication on spatial units of factor maps (p.64)… If the analysis needs more flexibility, a suitability map by the overlay weighted model is recommended where every location cell has a suitability value* (page 65)

Nevertheless, this approach is not without a shortcoming. In *weighted overlay* the weights are considered constant for each variable and/or class over the entire study area, which is not the case for most real world phenomena (Carvalho et al, 2007).

On the basis of the above discussion, the *weighted overlay* model was used in this study. It was implemented in *ModelBuilder* – a model showing all the tools and datasets used at each stage of the analysis, as shown in Figure 5) below. Using *ModelBuilder* is worthwhile because it allows one to make adjustments or changes in parameters and then re-run (Dawod et al, 2011) the entire model in a single window without the need to run each individual module again (Eastman, 2001). This makes it much easier to identify errors in the process. It also makes it possible to transfer models between researchers for future use in similar researches – either in the same region or in another geographic area.

3.4. Analysis

The cost of road construction was considered as the sum of terrain cost and land purchase cost (Saha et al, 2005). Terrain cost depends on elevation, presence of watercourses and the type of soils (Figure 4). Land purchase cost represents the amount that would be paid as compensation for each individual property or additional cost to mitigate land cover variables such as cutting of trees within or near road pathways.

Since these roads already exist and are owned by the state, there is no compensation cost and so this was not factored into the analysis. However, trees found very close to the roads may need to be cut down because the roots could sprout-out and cause defects on road surfaces, and the number of trees that need to be removed could affect the cost of road building in the area. This was why land cover and forest datasets were factored into the analysis (Figure 4).

Cost values were assigned based on their suitability and they served as inputs in *ArcMap*, with the goal being to produce a thematic cost layer in which each cell would have a cost value showing how much it will cost to construct a road over that particular cell.

During the consultation with the authorities in the districts, it was found that the intended road upgrade will be 15m wide, since the plan was to construct a single carriageway. So to achieve this, the soil, land cover, watercourse and forest layers were converted to raster format using the *feature to raster conversion* tool with a cell size of 15 metres.

The 90m elevation layer was already in raster format, so the cell size was reduced to 15m using the *resampling* tool. This means that a single cell is enough for the width of the road. Choosing a cell size equal to the width of the road makes the extraction of cost values much easier.

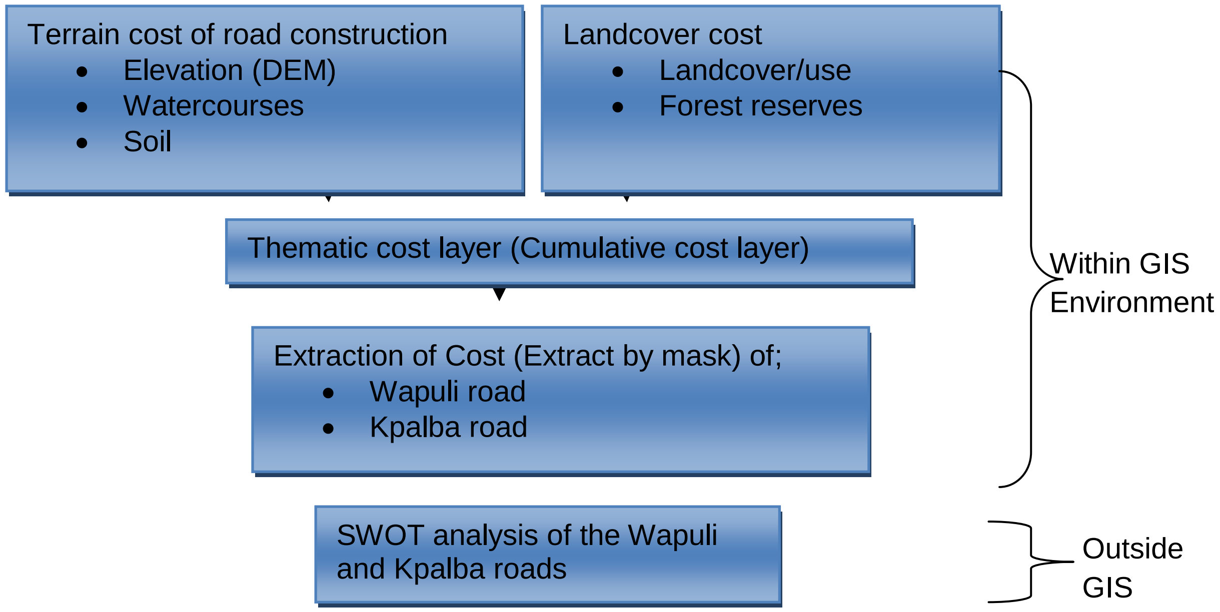

Figure 4 - The procedure

The steps to perform *weighted overlay* were;

1) define the problem,
2) identify input data (significant layers),
3) reclassify or transform the input data,
4) identify weights or percentage of influence for input layers,
5) combine the layers (in this case to a thematic cost layer), and
6) analyse and communicate the results.

The first two steps have been done in Section 1 and 4.1 above. The next sections deal with the last four steps.

3.5. Converting individual layers to cost values

The *reclassification* function helps change cell values to alternative values in raster datasets. This then allows comparisons based upon the suitability of attributes of each dataset for road construction. The first step in this process is to assign cost values (attribute weights) for each factor to be used, and reclassify all layers to cost values based on suitability of the attributes for road construction. After that, the individual suitability layers are weighted using the *weighted overlay* tool to generate thematic cost layer.

3.5.1. Assigning cost values

To give a broader approach to the weighting system; two groups, made up of five persons each, were sampled from the study area to assign cost values (attribute weights) on a scale of 1–10; with 1 representing areas that are most suitable for road construction and 10 representing areas less suitable. This was similar to the approach used by Saha et al (2005).

To minimise variability in the weighting system based on educational backgrounds, the study sampled both technocrats (civil engineers and planners) and non-technocrats (farmers and persons with social science backgrounds) and the average weights assigned by the combined groups were used.

Members of the two groups were sampled using purposive sampling – meaning only persons who had some expertise or knowledge and who had lived in the districts for at least five years were targeted. For the first group, referred as Group I, experts in road construction, civil engineering and planning were targeted. One expert in the civil engineering/planning unit of each of the four District Assemblies (local government authorities) was sampled. The fifth person was a road contractor who has worked in the study area, and thus possessed vast knowledge of the constructional dynamics in the area.

The second group, referred as Group II, comprised one farmer (some with social science backgrounds) from each district. The farmers were chosen because of their in-depth knowledge about soil types and characteristics in the area, having worked on the soils for several years. They had in-depth knowledge of soil workability and floodability. The fifth person in this group was an agriculturist with an in-depth knowledge of soil workability and terrain in the area.

The author also assigned cost values based on the literature reviewed (for example Saha et al, 2005; Riad et al, 2011) and based on both formal and informal interviews conducted on the subject matter.

Each group member was contacted personally and informed about the purpose of the research. In all, eleven persons were contacted, but one declined to take part due to a busy schedule. Each member was asked to provide reasons for cost values they assigned. They were also asked to assign a *percentage of influence* for each factor, or what is referred as *factor weight* by Jiang and Eastman (2000) - the relative importance of the factors (1-100).

Each person assigned cost values or attribute weights to the respective factors and the outcome was interesting. Varying educational and occupational backgrounds did not significantly influence the weights assigned by the groups. In the few occasions where the assigned weights differed slightly, the average value (rounded up to the nearest integer) of the two groups and the researcher's weights, was used in the model. Only the average cost values (attribute weights) from the respondents (rounded up to the nearest integer) were indicated for the respective factors.

Rounding up the cost values to the nearest integer generated simplicity and easy computations. The two groups and the researcher are henceforth referred as the "respondents", and the basis for assigning the respective cost values and percentage of influence for each factor is explained below.

3.5.1.1. Watercourses

The watercourses were divided into two types -major and minor rivers, depending on the size of the valleys and the level of water they contain. Due to their larger coverage area, implying the need for comparatively larger culverts, embankments and bridges; a 360 metres buffer on each side was created along the major rivers. This720m (360m + 360m) buffer was identified, during field work and interviews, as the area within which major constructional work such as embankments, culverts and bridges would be most necessary to avoid flood waters from the rivers and so the cost of building a road becomes much higher. Hence the respondents (the two groups and the researcher) assigned the highest cost value of 10 to this zone.

For the minor rivers, a lesser buffer of 225m was created on both sides. Due to lesser coverage, flooding capability and lesser need for culverts and bridges, these minor rivers were assigned a cost value of 5. Even though three respondents assigned a cost value of six, the average cost value from all respondents was 5 (rounded to the nearest integer).

Note that the cells outside the buffer area of the rivers were considered by the *weighted overlay* tool as *NoData*, and this is problematic – *NoData* on any input layer equals *NoData* in the final output. To avoid this problem, these cells were reclassified and assigned a value of zero (0). Since the cost values from the individual layers of the corresponding cells will be summed up before multiplying with respect to the percentage of influence (factor weight), a value of zero will not change or affect the total cost values in the final output. The *NoData* does not mean lack of data in this respect.

Also, the five factors further need percentage of influence (factor weight) that is, relative importance of each of the five factors in determining total cost values. In low lying topography such as in study area, watercourses and their floodability play an vital role in the total cost of road construction, as explained above. Accordingly, a factor weight of 20% was assigned to watercourses.

3.5.1.2. Elevation

Respondents assigned the highest cost value of 10 to areas with heights less than 100m due to their susceptibility to flood waters. Heights around 100m and below have been found to be the worst areas inundated by flood water in the study area (Kursah, 2013). By contrast, a value of one was assigned to areas with the highest heights (> 260m<300m) – the highest heights are less than 300m, so they will not impede road development. Other heights were assigned cost values as follows:

- 101-120m (9),
- 121-140m (8),
- 141-160m (7),
- 161-180m (6),
- 181-200m (5),
- 201-220m (4),
- 221-240m (3),
- 241-260m (2).

This depicts an inverse relation between cost value and height.

With lower heights and flood potential in the area, the cost of road construction will require more cut-and-fill, embankments, culverts and even bridges, and so elevation is equally as important as watercourses. Moreover, it has been found that elevation and soil type are the two most important factors influencing floodability in the study area (Kursah, 2013). Accordingly, it was assigned a percentage of influence of 20%.

3.5.1.3. Soils

Different soils influence cost of road construction due to their varying forms of compaction, water retention, resistance to erosion and workability. T he classification of soils by the IUSS Working Group (2007) of the Food and Agricultural Organisation (FAO) shows that six classes of soils are found in the study area. These are plinthosol, leptosol, lixisol, acrisol, planosol and fluvisol.

The characteristics of these soil classes are shown in Table 1 and respondents' own knowledge of the area formed the basis for assigning cost values to them. Fluvisol was assigned the highest cost value (10) since it is alluvial in nature and develops under river plains and marshes, thereby making it unsuitable for road construction. Compared with other soil types, fluvisols will require more cut-and-fills and culverts.

Factor	Attributes	Characteristics (based on IUSS Working Group, 2007)	Cost value*
Soil	Plinthosol	Wet soils with an irreversibly hardening mixture of iron, clay and quartz in the subsoil. The hardened plinthite has value as subgrade material for roads construction.	1
	Leptosol	Shallow soil over hard rock or highly calcareous material, extremely gravely and/or stony. Unattractive soils for agriculture. This soil class is also a suitable material for road construction but with lesser quality compared with plinthosols.	2
	Lixisol	With subsurface accumulation of low activity clays and high base saturation. They develop under intensive tropical weathering conditions.	4
	Acrisol	Clay-rich and toxic amounts of aluminium. Extensive leaching, low plant nutrients, excess aluminium, and high susceptibility to erosion.	6
	Planosol	Coarse texture, periodic water stagnation and slowly permeable subsoil. Seasonal waterlogged, form in clayey colluvial deposits with oxygen deficiency in wet seasons. It is not a good material for road construction.	8
	Fluvisol	Genetically young soil in alluvial deposits, river plains, valleys and tidal marshes and associated with periodic flooding. It also has low pH-values, toxic aluminium levels and high concentrations of salts. It is extremely poor material for road construction.	10

** Cost values are rounded up to the nearest integer*

Table 1 - The cost values assigned to the different soils

Plinthosol was assigned the least cost value of one due to, among other things, its characteristics of been a good subgrade material for road construction (IUSS Working Group, 2007). Moreover, it has been found that areas with fluvisols and plinthosols are the most suitable, and the most unsuitable soils to retain flood water in the study area, respectively (Kursah, 2013).

With respect to other factors, soil was considered to have the same percentage of influence as elevation and watercourses. This is because elevation and the presence of water bodies influence the type of soil found in an area. For example, fluvisol soils are found in areas with lower elevations and near water bodies. Hence an equal *percentage of influence* of 20% was assigned to it.

3.5.1.4. Land cover

The attributes of land cover which affect cost of road construction are settlements, farmlands and vegetation. Settlements affect the cost of road building through compensations whenever there is a need for demolition of houses and structures. The highest cost value of 10 was assigned to cells containing settlements. None of the settlements fall within the road pathways, because there is a law in Ghana banning any house or structure very close to roads. Since the roads exist, there will be no compensation cost for farmlands; hence it was not used in this analysis.

However, the presence of trees along road pathway will affect cost of road construction. The higher the number of trees, the higher the additional cost to cut these trees and destroy their roots (all things being equal). Therefore, the relatively thicker riverine savannah vegetation, with the most number of trees, was assigned the next highest cost value of 9, while unclassified/bushfire vegetation, with the least number of trees per acre, was assigned the least cost value (1), since there are fewer trees to cut or dig-out. The cost values for the intermediate vegetative attributes are shown in Table 2.

Compared to watercourse, soil and elevation; land cover is less important in determining cost of road construction since digging out roots of trees is not as costly as constructing culverts. Therefore, *a percentage of influence of* 15% was assigned to it.

Factor	Vegetative Attributes	Cost value
Landcover/ use	Unclassified/bushfire	1
	Grassland with/without scattered tree/shrub	2
	Grass/herb with/without scattered trees (0-5 trees/ha)	3
	Widely open cultivated savannah woodland (6-10 trees/ha)	4
	Open cultivated savannah woodland (11-20 trees/ha)	5
	Closed cultivated savannah woodland (>20 trees/ha)	6
	Open savannah woodland (<25 trees/ha)	7
	Closed savannah woodland (>25 trees/ha)	8
	Riverine savannah vegetation	9
	Settlement	10

Table 2 - The cost values assigned to land covers/ land uses

3.5.1.5. Forest reserves

Since the first objective of this study is to produce a thematic cost layer for the entire area, forest reserves or groves were considered as a factor , and the cells containing the seven dotted forest reserves were assigned the highest cost value of 10. This ensures that the districts will maintain these forest reserves or groves. Also, it is common for such forested areas to serve as places of social activities, such as shrines, for residents.

For the percentage of influence (factor weight), cells containing these forest reserves were assigned a lesser value of 5%; because none of them falls within the pathway of the roads. As explained above, the cells which fall outside the forested areas are considered by the *weighted overlay* tool as *NoData*, and this will be problematic because *NoData* on any input layer equals *NoData* in the final output. To avoid this problem, a value of zero was assigned to these cells (the non-forested cells). Zero was assigned because it will not change or affect the total cost value of cells in the final output. Therefore, the percentage of influence (5%) applies to only cells containing forest reserves.

The soil, elevation, land cover, watercourses and forest layers were reclassified to individual cost value, or suitability layers, based on the cost values or attribute weights assigned above, and the individual outputs are shown in the flow diagram of Figure 6 below. The next section describes how the individual suitability layers were combined to generate a thematic cost layer.

3.5.2. Combining individual suitability layers to form a thematic cost layer

The *weighted overlay* tool in *ArcMap* was used. Each standardised suitability factor was multiplied by its corresponding percentage of influence (factor weight), and then combined to generate a thematic cost layer showing cost values of road construction over each cell. This was done in the *ModelBuilder*, as shown in Figure 5 below.

The individual suitability layers, or cost value layers, were used as input rasters in the *weighted overlay* tool with watercourses, elevation and soil having the same percentage of influence or factor weight (20% each), land cover (15%) and forest reserves had 5% (Table 3) as discussed above. The *weighted overlay* tool then calculated the total cost value for each cell, as shown in Figure 7 below. The values represent the total cost that would be incurred when building a road through each cell.

Factors	**Percentage of influence/relative importance of the factors (%)**
Watercourse	20
Elevation	20
Soil	20
Landcover	15
Forest reserve	5
Total	**100**

Table 3 - Percentage of influence/ factor weight of the factors

Note that a field validation process was undertaken in sampled areas, especially within areas of very high and very low cost values, in order to check the accuracy of the final result.

3.6. Extracting cost values for the roads

With the thematic cost layer as an input raster and the Wapuli road option converted to raster as the *input feature mask*, the *extract by mask* tool was used to extract cells and their corresponding cost values which Wapuli road passes through. To obtain the total cost value for Wapuli road, its cell count was multiplied by the cost value for its unique set of cells, as shown in Table 4 below. The same was done for the Kpalba road alternative, with Kpalba Road being used as the *input feature mask* of course.

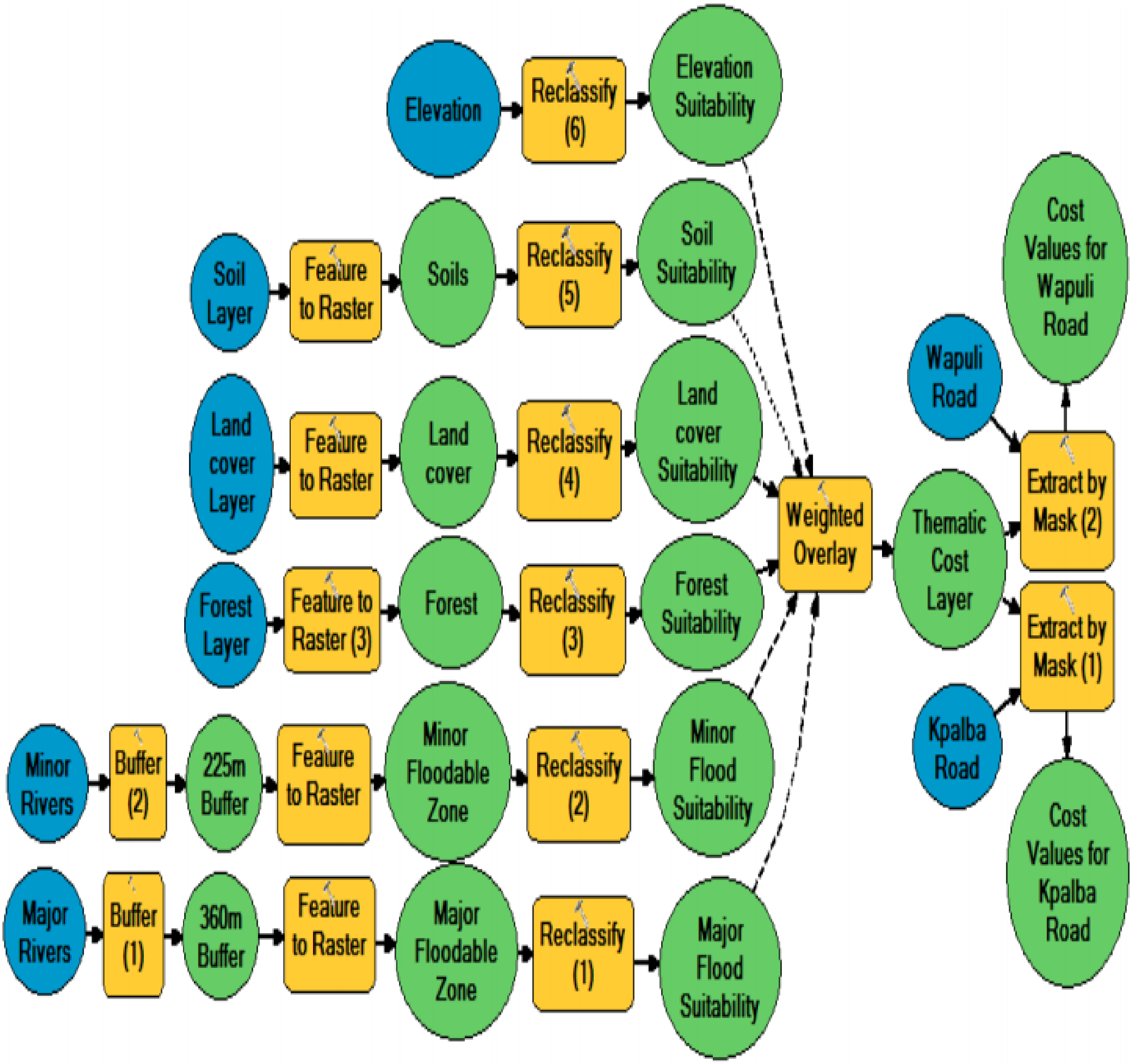

Figure 5 - *ModelBuilder* showing the layers and tools used to generate the cost of road construction. Watercourse is separated into *major* and *minor* rivers, but in total there are five factors because both *major* and *minor* rivers is one factor (watercourse).

4. Results

Figure 6 shows the analysis. Due to limited space, only a small part of the roads at Wapuli junction and at the Kpalba township is shown in the *extract by mask* stage.

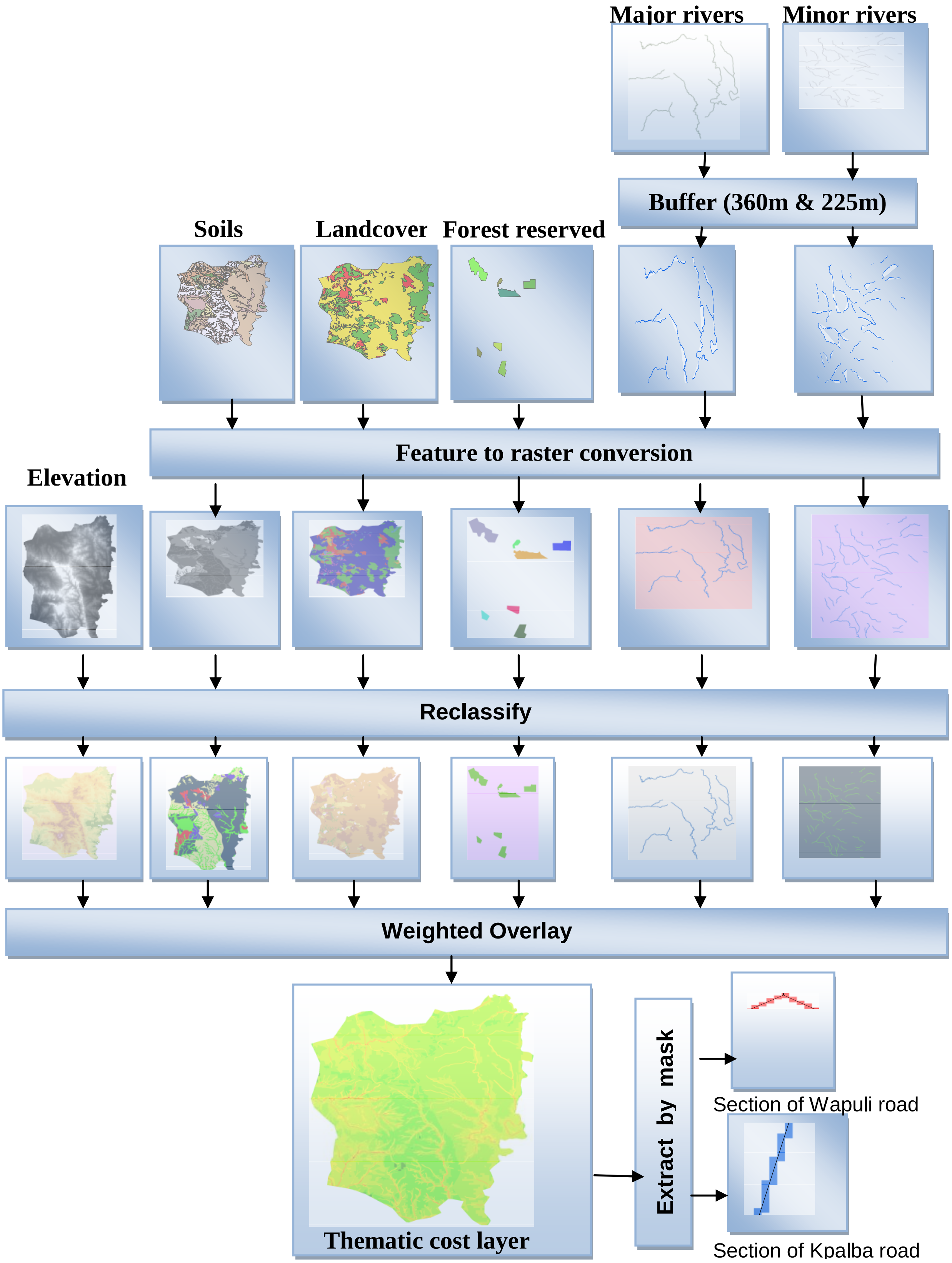

Figure 6 - A flow diagram showing the GIS tools that were used.

4.1 The thematic cost layer

Figure 7 shows the thematic cost layer. The greenish colour cells around Yendi through to Gushiegu are the areas with the least cost values, and so they are most suitable for road construction. These areas have relatively suitable soils (plinthosol and leptosol), relatively higher heights and they avoid major river basins. It has been identified that plinthosols and leptosols are good subgrade material for road construction (IUSS Working Group, 2007).

By contrst, the yellowish-reddish colour cells show costly areas. These are, firstly, the eastern border from Kpalba, through Saboba to Gbangbanponi, and along the River Oti tributary which crosses the two roads near Kpalba and Wapuli. The second area is the western border south of Karaga. The third one is the north-western part, north of Karaga.

These three areas have lower elevation, unsuitable soils (fluvisol and planosol) for road construction and they function as major drainage basins in the area. Fluvisols and planosols have been identified to be poor for road construction as these soils are associated with marshy and floodable areas (IUSS Working Group, 2007).

It can be seen that the Wapuli road avoids areas with higher cost values and runs through relatively suitable areas, with the exception of areas around river channels. For this road, the highest cost values are found on Wapuli-Saboba road, especially around Wapuli bridge.

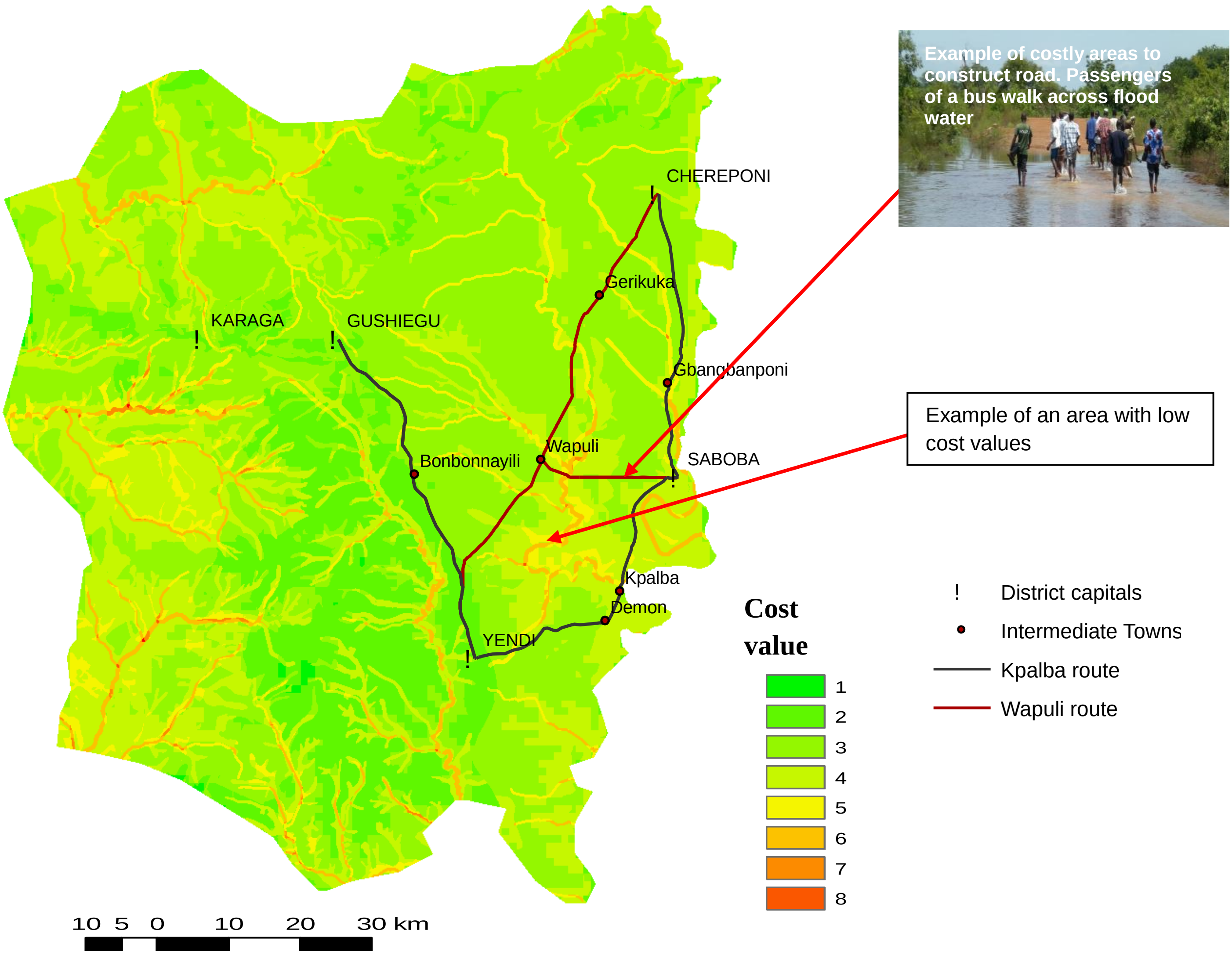

Figure 7: The thematic cost layer showing the road-construction cost in each cell

4.1 The cost of constructing the roads

The cost values for each road were extracted from the thematic cost layer shown in Figure 7 using the *extract by mask* tool in *ArcMap*. Total cost values of cells crossed by the roads ranges from 2 to 6. This is due to the trade-off between factors – that is, low score on one factor is compensated for by a high score on another – a prominent feature of weighted overlay models.

The cost of constructing any of the two roads is the sum of the number of cells each road passes through, multiplied by the respective cost value of the cells, as shown in Table 4. For example, if the road crosses a total of 10 cells with each cell having a cost value of 2, then the total cost of that particular road is 10 x 2 = 20. That is, the first row in Table 4 was calculated as follow;

Wapuli road Cost value (ab) = Unite cell value (a) × Number of cells (b)
That is, ab = a×b
Row one in Table 4 shows that a = 2, and b = 2418, so the cost value (ab) for the first row for Wapuli road is ab = 2 × 2418 = 4836

Kpalba road Cost value (ac) = Unite cell value (a) × Number of cells (c)
That is, ac = a×c
Row one in Table 4 shows that a = 2, and c = 2275, so the cost value (ac) for the first row for Kpalba road is ac = 2 × 2275 ac = 4550

It is worth emphasising that the *cost* referred to in this study, is not equivalent of any particular currency, but rather that influence the cost of road construction in the study area.

Table 4 shows that the majority of cells (9154) within the pathway of Wapuli road have a cost value of 3, while the cells with a cost value of 4 number only 1438. The total cost value of Wapuli road is 40292.

By contrast, Kpalba road passes through comparatively higher cost cells from Kpalba through Saboba to Gbangbanponi (along the Oti River valley). Although the majority of its cells (6685) also have a cost value of 3, this road also has fairly higher number of cells (3977) with a cost value of 4, and so it has a relatively higher total cost of 42942.

Thus, with a cost value of 40292 compared to 42942 for it counterpart, Wapuli road is less costly to construct. The percentage difference is 3.2%.

Unit cell value (a)	**Wapuli road**		**Kpalba road**	
	Number of cells (b)	Cost value (a×b)	Number of cells (c)	Cost value (a×c)
2	2418	4836	2275	4550
3	9154	27462	6685	20055
4	1438	5752	3977	15908
5	368	1840	393	1965
6	67	402	79	464
Total	**13445**	**40292**	**13409**	**42942**

Table 4 - The cost of construction of the Wapuli and Kpalba roads

4.2 SWOT Analysis

SWOT represents Strengths, Weaknesses, Opportunities and Threats and Table 5 lists these for the Wapuli and Kpalba roads. This will make it easy to compare the roads and so assist the decision-making process.

SWOT	the Wapuli road	the Kpalba road
Strengths	1. The road already exists. 2. It is less costly to construct.	1. The road already exists. 2. It is shorter -169km. 3. The power line from Yendi to Saboba and the planned extension to Chereponi is along this road and so movement of electric equipment and maintenance works may be easier
Weaknesses	1. It is longer -170km 2. It is not likely to facilitate trade with neighbouring settlements in Togo, since it is farther from the Ghana-Togo border. 3. It does not encourage interaction between any of the other district capitals (Kursah, 2010).	1. It is more costly to construct. 2. Chereponi will be further away from Yendi, by 10 kilometres, compared to using Wapuli road.
Opportunities	1. Wapuli will become an important node in the area, as traders from Chereponi and Saboba will have to go to Yendi through the town (Wapuli). 2. The shorter distance between Chereponi and Yendi means that traders from Chereponi will travel 96km to Yendi unlike 106km if they have to use Kpalba road.	1. Could be beneficial as government tries to revitalise the defunct state farm in Chagbani 2. Can facilitate trade links with neighbouring settlements in Togo, as it runs along the Ghana-Togo border for most part of its length. 3. It will possibly encourage trade between Saboba and Chereponi because traders from Chereponi will have to pass through Saboba before getting to Yendi.
Threats	1. Susceptible to flooding in and around Wapuli bridge (Kursah, 2013) 2. Could lead to the creation of monocentric city in the study area with Yendi serving as the centre (Kursah, 2010). It does not encourage direct linkages between any of the other district capitals.	1. Susceptible to flooding as it runs along the Oti River valley (Kursah, 2013), especially around Kpalba and Gbangbanponi.

Table 5 - SWOT analysis of the Wapuli and Kpalba roads

5. Discussion

Though shorter than its counterpart, the passage of the Kpalba road is plagued by relatively unfavourable geo-environmental factors, such as lower heights and the presence of the fluvisol and planosol soil types which make it costly to construct. It will require more cut-and-fills, embankments, culverts and even bridges compared to the Wapuli road which avoids many of these features.

This supports the conclusion that in road planning a winding, long but less steep path, is preferred to one that is shorter and steeper (Collischonn & Pilar, 2000) or one that has unfavourable geo-environmental factors such as terrain, geology and inappropriate land uses (Feldman, 1995).

The passage of the Wapuli road through relatively favourable geo-environmental factors may be due to its being a relatively newer road than its counterpart (Kursah, 2010). Authorities may have taken a clue from the "older" Kpalba road and its associated problems such as flood waters from the Oti River during raining seasons.

The SWOT analysis indicates that; comparatively, traders from Chereponi will have direct links to two markets with the Kpalba road - Saboba and Yendi. The relatively longer distance from Chereponi to Saboba through Wapuli, may be a discouraging factor for traders if the Wapuli road is chosen. Also, with the Kpalba road rather than its counterpart, Chereponi and Saboba may gain more in terms of easy and direct movements. However, it has been found that the Kpalba road is highly vulnerable to flood waters due to its passage along the Oti River valley, lower heights and fluvisol and planosol soils (Kursah, 2013). Therefore, the Kpalba road will be a high-risk option.

Whether to make the choice in favour of the Wapuli road or the Kpalba road should be based upon what the districts want to achieve. If the districts are solely concerned about lower cost, then the Wapuli road is the appropriate option. However, the study area is not an isotropic plain but one which has already been modified, by farming, settlements among other things. Hence planning roads in such area requires the consideration of multiple factors, and not just the cost of construction. Other factors such as flood risks and access to people and socio-economic activities -farming, market, fishing and tourism centres, should be considered before any of the options is chosen for upgrading.

The Kpalba road could still be a viable option should these other factors, mentioned above, favour it. If the districts want to upgrade the Kpalba road instead, then the districts must be ready for additional 3.2% cost due to relatively unfavourable geo-environmental factors along it. It may also be that the districts will prefer to spend more to upgrade the Kpalba road rather than the relatively cheaper option of the Wapuli road – provided that the former's benefits will be proportionately greater; either now or in the future. Also, the difference in the cost of construction between the two roads is just 3.2%, and that does not seem to be an overwhelming factor to seal the "deal" in favour of the cheaper, Wapuli road.

One shortcoming of this study is the use of an elevation layer with a 90m resolution. This means that minor rock outcrops or hilly points, which could have been higher and assigned a lower cost value, may still be masked out and grouped below its real heights. Thus, little rock outcrops could still fall within higher-cost values than they would have if, for example, 15m elevation data had been used. A 15m or even 30m resolution would have been better, but availability and cost made it inaccessible. It is recommended, therefore, that future studies should make use of a lower resolution DEM.

Observations in the districts revealed that debates over the cost of constructing roads is based on the manual planning method, and sometimes even guess work. It is recommended, therefore, that GIS be used in the planning process. If the *ESRI* and *IDRISI* software packages are unaffordable, then free*, open source GIS* software such as *SAGA-GIS* and *GRASS* can be a good substitute. We suggest that government agencies and policy makers adopt this powerful technique for reliable and well integrated road planning and assessment. It is also recommended that the feasibility of including more criteria, such as flood risk and access of roads to people and socio-economic activities in the area, be examined.

6. Conclusion

This study made a GIS-based assessment of the proposed Wapuli and Kpalba roads using cost values derived from geo-environmental factors. The analysis revealed that the Wapuli road, though longer, is cheaper to construct due to its relatively favourable geo-environmental factors. The study has, therefore, contributed to different perspective by using GIS to determine least-cost road from pre-defined or existing roads.

Acknowledgement

Much gratitude goes to the members of the two groups who assigned the weights that were used in this study.

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