Application of GIS in Flood Detection for Road Infrastructure Planning in North-Eastern Corridor of Northern Ghana

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Abstract

This study used GIS to identify flood risk areas on the proposed Wapuli and Kpalba roads to help policy makers take a firm decision on which road to link Yendi, Saboba, Chereponi and Gushiegu districts in Northern Ghana. The aim was to identify and measure floodable areas on the proposed roads. Factors influencing flooding in the area are identified and reclassified to flood risk values based on their suitability to retain waters, and then combined using weighted overlay tool in ArcMap to generate flood prone areas. The results showed that Wapuli road has lesser passage through flood risk areas. The study, thus, reveals how road planners can identify flood risk areas to aid in designing mitigations. The study concludes that flood risk areas should not be the sole factor in road planning, but rather multi-factors, including cost of construction, access to people and economic activities and the ability to ease trade.

Keywords: flood detection, flood risk, GIS, road planning, weighted overlay

Introduction

Ghana is located in West Africa and shares boundary to Togo at the east, Burkina Faso (north), Cote d'Ivoire (west) and the Atlantic Sea to the south (Fig. 1). The transport system in the country is dominated by roads, which carries 94% of freight and 97% of passenger traffic (Republic of Ghana, 2002). In terms of spatial distribution of roads, the southern sector is well linked than the northern sector. The study area includes four districts in north-eastern corridor of Northern region. The districts are Yendi, Saboba, Chereponi and Gushiegu. The area is strategic for the Northern region because of its agricultural potential (Ghana Statistical Service, GSS, 2005).

Nevertheless, transport infrastructure in the area is in poor condition – mainly paved roads with potholes, and thus presents serious bottlenecks on mobility within the districts themselves and with the surrounding districts (GSS, 2005). The road networks are also hampered by seasonal flooding in the area. Thus, the recent national development plans such as National Development Policy Framework have focused on investment to improve roads in these districts. The plan is also for the roads to be devoid of inundation after construction.

However, the choice of which road to link Yendi to the other three district capitals has not been an easy decision to make. One of the proposed options is to link a road from Yendi through Wapuli to Chereponi and from Wapuli to Saboba, then finally from Sakpeigu to Gushiegu as shown in Figure 1b (referred as *Wapuli road*). Its total length is 170km. The second option is to link a road from Yendi through Kpalba and Saboba to Chereponi, and then a separate road from Yendi through Sakpeigu to Gushiegu (referred as *Kpalba road*) – Figure 1c. Kpalba road has a total length of 169km. The last two decades witnessed a changing of focus on which of these two options to link the area.

The change of focus is usually based on the amount of flood risk associated with each road. The goal of the districts is to construct the road with lesser flood risk. But which of the proposed road has lower flood risk? Providing answer to this question will help policy makers take a firm decision on which road to upgrade.

This study uses Geographic Information System (GIS) to incorporate flood risk consideration in providing answer to the above question. Such application of GIS has been done elsewhere, and found to be more accurate and useful to planners than the manual method (Dawod et al, 2011, Thilagavathi et al, 2011, Bera et al, 2012).
The main aim of this study is to identify and measure the floodable risk areas on the two proposed roads to link Yendi, Saboba, Chereponi and Gushiegu districts. The specific objectives are;

- To generate flood risk layer for the study area.
- Identify the floodable areas on the two roads.
- Measure the length of each road within flood risk areas.

The study used GIS to provide answers to the above objectives.

Hypothesis

The study hypothesises that *Kpalba road has lesser length passing through flood risk areas*, based on the fact that that road is shorter than its counterpart. But is the premise valid?

Expected results

The study is expected to produce floodable layer for the study area to be used to assess the roads. This output is expected to help stakeholders take a firm decision on appropriate road to link the districts and/or design appropriate mitigation measures to reduce the risk.

Outline of the study

After introduction section, in that order, is literature review, brief characteristics of the study area, the methodology and the results of the study. The results include the identification of flood risk areas and measuring of length of the roads within flood risk areas. After that, a SWOT analysis of the proposed roads is provided. Finally, the study ends with a discussion and recommendation for the districts and for further research.

Literature Review

This section reviews literature on the use of GIS for flood detection and zonation. GIS has emerged as an essential tool in flood mapping and analysis, particularly because it enables preparation of maps of inundated areas and estimation of damages (Bera et al, 2012). GIS technique has also been utilised as efficient tools in flood risk assessment (Saleh and Al-Hatrushi, 2010). Dawod et al (2011) developed a GIS-based methodology by incorporating topographic, geological, metrological, and land use/cover datasets in GIS, that utilises the Curve Number (CN) method of flood modelling; and found that the expected flood volume will reach 172.97 million m^3 over Makkah metropolitan area.

The author noted that precision, cost-effectiveness, digital outputs, and its ability to be re-run in other conditions are the advantages of the developed methodology. Others have applied GIS to study the time-based relationship between flood hazards and land use changes (Chang et al, 2009) and to test a GIS model, which consists of a storm-runoff model and an inundation model for modelling flood hazards (Chen et al, 2010). Karmakar et al (2010) also proposed a methodology to assess flood risks, involving exposures of land use and soil type to flood water, vulnerability to flood and flood probability of occurrence.

Thilagavathi et al (2011) used GIS to demarcate the flood hazard prone areas in the Papanasam Taluk, and Qiang and Zhu (2009) showed how elevation, hydrological conditions, rainfall intensity, soil and river network features can be used to make flood forecasting model in GIS, and concluded that elevation was the most important factor. Thus, when an area is below a given point in height, it is likely to fall within the reach of flood waters. To sum up, the literature review shows that GIS can be used to identify flood areas in the study area. With its overlay functions, ability to store, manipulate and analyse data, GIS can perform effective flood risk determination for road planning.

The Study Area

The study area consists of four administrative districts in north-eastern part of Northern region (Fig. 1). These are Yendi, Saboba, Chereponi and Gushiegu districts – all named after their respective administrative capitals. The road network concerned in this study is to link these districts capitals.

Though, the newly created Karaga district (out of the former Gushiegu-Karaga district) is part of the study area, the proposed road development to link Gushiegu and Karaga is undisputed (in fact only one feasible option exist); and it is therefore not considered in this study. The study area has fairly gentle slopes and undulating lowlands with few rock outcrops underlain by Voltain rocks. Elevation ranges from about 50m at valley bottoms to about 300m at plateaux surfaces. Generally, the eastern border of the study area along River Oti drainage system has the lowest heights. Relatively higher heights are along strips of small ridges from Yendi through to Gushiegu. The area is drained by three main perennial rivers, Oti, Daka and Nasia.

The vegetation is grassland interspersed with guinea savannah woodland. The districts have 349,781 people with an average density of 28 persons per sq/km. The existing roads linking Yendi to Saboba, Chereponi and Gushiegu are either trunk or paved roads (Fig. 2a), many of which are unmotorable in all sections due to potholes and flood waters during rainy seasons (Kursah, 2009; 2010). The government intend to upgrade these roads to a tarred status (Figure 2b). The powerline from Yendi to Saboba and the planned extension to Chereponi is along Kpalba road. To sum up, the physical features of the districts are important components to consider in identifying factors to determine flood risk areas for road planning.

Methodology

This section deals with the choice of method, data sources and the process of determination of flood risk areas.

Choice of method to generate flood risk areas

Several methods and tools could be used to generate flood risk areas. These include *weighted overlay, multi-criteria evaluation* (MCE) and the *raster calculator*. However, the *weighted overlay* was chosen at the expense of others because it is more convenient than other methods (or tools) to work with in a *ModelBuilder* – a model showing all the tools and datasets used in each stage of the analysis. Using *ModelBuilder* is worthwhile because it allows one to make adjustments or change parameters and then re-run (Dawod et al, 2011) the entire model in a single window without the need to run each individual modules/tools again (Eastman, 2001) and makes it much easier to identify errors in the process.

It also makes it possible to transfer models between researchers or for future use in similar researches – either in the same region or in another geographic area. For comprehensive understanding of these tools, refer to Eastman (2001). On the basis of the above discussion, *weighted overlay* method is used in this study.

The requisite datasets and sources

Several factors influence the level of floodability in an area. This depends on the local conditions of the area. These factors include, but not limited to, elevation, landcover, watercourses, soil types, geology, rainfall amount and slope – as seen in the literature review section. Thus, the following datasets were acquired; 1) digital elevation layer (with 90m resolution), 2) watercourses such as rivers and streams, 3) rainfall pattern, 4) soil layer, and 5) landcover layer. Also, datasets showing road networks, district administrative boundaries and settlements location were acquired. The elevation and rainfall layers were in *raster* format, while the rest were vector layers. There were two sources of the GIS data; 1) Centre for Remote Sensing and Geographic Information Services (CERGIS), University of Ghana, and 2) CGIAR-CSI[1]. The source of the 90m digital elevation model (DEM) is CGIAR-CSI, and this was chosen due to its quality and because it was unclassified and show more details. Using DEM that is already classified means some heights may be masked out and grouped into a larger class – Example 45m and 50m may have been classified into one class.

Data Preparation

The soil, landcover and watercourses layers were converted to raster format using *feature to raster conversion* tool in ArcMap with a cell size of 15m (metres), while the cell size of the 90m DEM was reduced to 15m using *resampling* tool.

[1] CGIAR-CSI Consortium for Spatial Information: http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp

Field work and choice of factors

The study aims at identifying the road with lesser passage within flood risk areas. To produce flood risk map/layer of the study area, a test field work was undertaken during the rainy seasons in 2011 and 2012 in the area to identify the flooded points using Garmin Oregon 450 GPS. The survey sampled flooded spots along the two proposed roads (Fig. 3). The attributes of the flood spots, location and heights, were taken and inputted in ArcMap. Residents and concerned stakeholders were then asked if such areas regularly get flood during rainy season. Also, the researcher – having travelled along these roads over several years, made use of personal observation in identifying these flooded points.

Some of the flood spots identified during the field work include; 1) the location of Kpalba bridge, 2) at Garimata, 3) mid-way between Sanguli and Gbangbanponi, and 4) the location of Gbenja bridge (Wapuli bridge) as shown in Figure 3 – names of the settlements are more visible in Appendix 1. Areas without flood waters were also identified and its location and heights inputted in ArcMap, so as to be able to categorise the whole area based on its floodability. These points were overlaid on elevation, soil, landcover, slope, watercourses (rivers and streams) and rainfall layers, and geostatistics tool used to find out the relationship between flooded points and these layers. It turns out that flooded points had high correlation between elevation and soil classes – flooded areas were also close to river valleys but this is a function of elevation since river valleys are in lowlying areas.

The others factors had no correlation in determining floodability in the area, as there is no much variation in landcover types, rainfall pattern and slopes in the areas. Though, these factors could be important in identifying flood risk areas in another geographic region, they did not account for floodability in the study area and were left out. The flooded points were overlaid on soil and elevation layers to identify which soils and heights were highly associated with these points. The characteristics of these points were used as basis for reclassifying the study area according to its floodability. These flood points have similar characteristics; 1) found in areas less than 120m high; and this further strengthens Qiang and Zhu (2009) assertion that elevation is the most important factor in determining floodability, 2) close to rivers valleys, and 3) the soil are fluxisol and planosol –

It is not surprising since these soils have slowly permeable subsoil with considerably more clay and seasonal waterlogged and form in clayey alluvial and colluvial deposits with oxygen deficiency in wet seasons (IUSS Working Group, 2007). Having identified the key factors influencing floodability in the area, elevation and soil; the next step is to reclassify the layers to flood risk values based on susceptibility to retain flood water.

Assigning of weights or flood risk values

To give a broader approach to the weighting system; two groups, made up of five persons each were chosen from the area to assist in assigning weights or flood risk values on a scale of 1–10. The first group comprised experts in engineering, construction and planning (referred as *Group I*) and the second group were made up of people without or with very little education (referred as *Group II*). Each group assigned weights to the respective variables and the outcome compared with those of the other group and the researcher's own weighting. *Group II* was chosen to find out whether variation of educational levels has any influence on the weights one assigns to the factors. The outcome was interesting; varying educational backgrounds did not significantly influence the weights assigned by the groups. In few occasions where the groups' assigned weights were slightly different, the average value was used. Thus, at any point in time, the variables used could be modified then run the ModelBuilder to generate a new output.

Reclassifying elevation layer to flood risk values

Elevation layer was reclassified based on its susceptibility to retain flood waters. From the flood points taken during the survey, areas that were less than 120m in height and made of fluvisol and planosol were found to contain the flood spots. It was also found that areas that were above 260m have not experienced any flood waters. Thus, elevation layer was reclassified with heights less than 120m (being the most suitable areas to retain flood waters) having the highest flood risk value of 10 (on a scale of 1–10) and the highest peaks (261-290m) given the lowest value of 1, since that was the most unsuitable area to retain flood waters.

Other heights ranges were assigned intermediate values as follows; 120-140m (8), 141-170m (6), 171-200m (4), 201-230m (3) and elevations between 231-260m got a value of two (2).

Reclassifying soil layer into flood risk values

Soil layer was also reclassified based on suitability to retain flood waters. The characteristics of the soil classes in Table 1 form the basis in which the two groups and the researcher assigned the flood risk values. As such, the most suitable soil to retain flood waters (fluvisol) was assigned the highest flood risk value of 10 and plinthosol being the least suitable soil to retain flood waters was assigned the least flood risk value of 1. Other soil classes between the two extremes got the intermediary values based on their susceptibility to flooding as follows; planosol (8), acrisol (6), lixisol (4) and leptosol got a value of 2. After reclassifying elevation and soil layers into flood risk values, the next step is to combine the two layers into one thematic flood risk layer using weighted overlay tool.

Deriving a composite flood risk layer

Weighted overlay tool was used to combine flood risk values from elevation and soil layers into one composite flood risk layer (Fig. 4) – and the ModelBuilder shown in Figure 5. The flood risk value from elevation and soil layers were inputted as *first image file* and *second image file* in weighted overlay tool respectively – however their order of entering does not affect the output. Both layers were given the same *percentage of influence* (weight) of 50% each to generate levels of floodability as shown in Appendix 2. Since the levels of floodability represented suitability for flood ranging from 1 to 10, it was further reclassified for enhanced view. Floodability values between 9 and 10 were found to be the floodable zones, and classified as such. Values of 8 and 7 were considered as less floodable areas, 6 and 5 (unlikely to get flooded), 4 and 3 (very unlikely to get flooded) and finally values of 2 and 1 were considered as not floodable – these areas have the highest heights and made of plinthosol – soil type that is generally not found in flood areas (IUSS Working Group, 2007).

Results

This section presents and analyses results of the study. Figure 6 depicts flood risk zones in the study area. The output is overlaid on elevation layer in a 3D view for better visualisation. However, only the floodable zones (with floodability risk values between 9 and 10) are used in the discussion since it is the zone that was observed to have effects on road planning – will demand embankments, culverts or even bridges, hence likely to influence the cost of road construction. The various levels of floodability are shown in Appendix 2. Sampled ground-truth checks showed that the other levels of floodability do not have effects on road development in the area. The floodable areas generated in this study were checked with residents in the area to see the reliability of the categories and it turned out to conform to ground-truth.

Measuring road length within flood risk area

Figure 6 shows that flood risk zones are found in lowlying areas close to river valleys and areas made up of fluvisol and planosol soils. However, some river valleys, especially River Daka (west of Yendi) are not flood prone areas, due to the height of the surrounding areas. This reveals the contribution of heights to floodability in the area, thus confirming Qiang and Zhu (2009) argument that elevation is the most important factor determining floodability. The flood zones on Kpalba road are located at; 1) about 2km from Kpalba through Kutuli to about half a kilometre to Kunkunzoli, 2) less than a kilometre from Garimata to about half a kilometre to the junction of the two roads near Saboba, 3) from Saboba to about a kilometre after Kuwani with the exception of the hilly spot in Kuwani, 4) between Sanguli to the location where the first tributary of River Oti crosses the road, 5) there are also 5 other flood spots after Gbangbanponi towards Chereponi. Appendix 1 shows the location of these settlements.

On the contrary, there are only 4 flood zones on Wapuli road. These are; 1) around Gbenja bridge, 2) the one near Nashegu Sosong, 3) one near Buriburni, and 4) after Hilltop (DCE village) to about one kilometre to Saboba. Also, the flood zones on Wapuli road are generally narrower compared to those on Kpalba road. The measurement tool in ArcMap was then used to measure the length of each road passage within the flood risk zones to determine which road has longer distance passing through flood prone areas. In total, 20km of Kpalba road lies in areas that are flood prone, while about 5km of Wapuli road lies in floodable zones. Thus, a longer part of Kpalba road is prone to flood risk compared to Wapuli road.

SWOT analysis

SWOT represents **S**trengths, **W**eaknesses, **O**pportunities and **T**hreats. Table 2 lists the strengths, weaknesses, opportunities and threats of Wapuli and Kpalba roads. This will help policy makers to easily compare the roads to aid in their decision making process. To sum up, the analysis above show that Wapuli road has lesser flood risk compared to Kpalba road.

Hypothesis confirmation

With 5km span of floodable areas for Wapuli road and 20km for Kpalba road, the results did not confirm the hypothesis of the study that *Kpalba road has lesser length passing through flood risk areas*, due to its relatively shorter distant. Its passage in relatively lower heights, closer to river/stream channels and soil that are fluvisol and planosol in nature made it flood prone road than Wapuli road which avoided much of these features.

Discussion

This section discusses the findings and method of the study, and makes recommendations to both policy makers in the districts and for further research. The study assessed Wapuli and Kpalba roads based on the length of passage within flood risk areas. Even though Wapuli road is longer, its environmental and topographic advantages made it the lesser prone one compared to Kpalba road. Thus, the analysis of results did not confirm the hypothesis that Kpalba road has lesser passage through flood risk areas. Whether the choice should be Wapuli road or Kpalba road should be based on what the districts want to achieve. If the districts are solely concerned about the road without much flood risk, then Wapuli road is the appropriate option.

However, if the districts for some other reasons will want to develop the Kpalba road instead, then the districts must explore ways to mitigate the 20km of its length within flood risk areas. However, choosing Kpalba road will be a high *risk-taking* option. The use of elevation layer with a 90m resolution means that minor rock outcrops or hilly highlands, though could have been about floodable heights, may still be masked out and grouped below its real heights. Hence, little rock outcrops of land will still fall within floodable limits. Two of such outcrops were found around Kuwani. A 30m resolution or at best a 15m resolution would have been better, but availability and cost make such dataset inaccessible.

The study area is not isotropic plain, but one which humans have already modified its natural stage (farming, settlements, among others), thus planning roads in such area demand inclusion of multiple factors, and not just flood risk consideration. Other factors such as access to the greater number of people and socio-economic activities, and the ability to facilitate trade and interaction should be considered before any appropriate choice of which road to upgrade is made. Personal observation shows that the flood areas identified in the area are not high enough and can be mitigated by embankment, culverts and bridges; therefore Kpalba road could still be a viable option should these other factors mentioned above favour it. This study is, as far as I know, the first of its kind concerning these roads in the area. It is expected to stimulate further discussion towards inclusion of more factors for assessing these roads.

Conclusion

The study identified flood risk areas on the proposed Wapuli and Kpalba roads that link four districts in Northern region. The analysis revealed that Wapuli road, though longer, has lesser passage through flood risk areas compared to Kpalba road. The study also calls for inclusion of multiple factors such as access to the greater number of people and economic activities, and the ability to facilitate trade and interaction before any choice of which road to upgrade is made. Therefore, making decision based on only flood risk is inadequate.

Recommendation

Personal observation reveals that the argument about which road has more flood risk in these districts came from manual planning method. It is recommended that GIS be used in the planning process. There are free *open source* GIS softwares such as GRASS, SAGA-GIS and DIVA-GIS that can be used to make modern and more reliable plans and forecasting. So even if the districts cannot afford to buy the mainstream GIS softwares such as ArcGIS and IDRISI, then these *open source* ones can be good substitute. It is also recommended that a study be conducted to include multiple factors such as access to the greater number of people and economic activities, and the ability to facilitate trade and interactions in the area.

Acknowledgement

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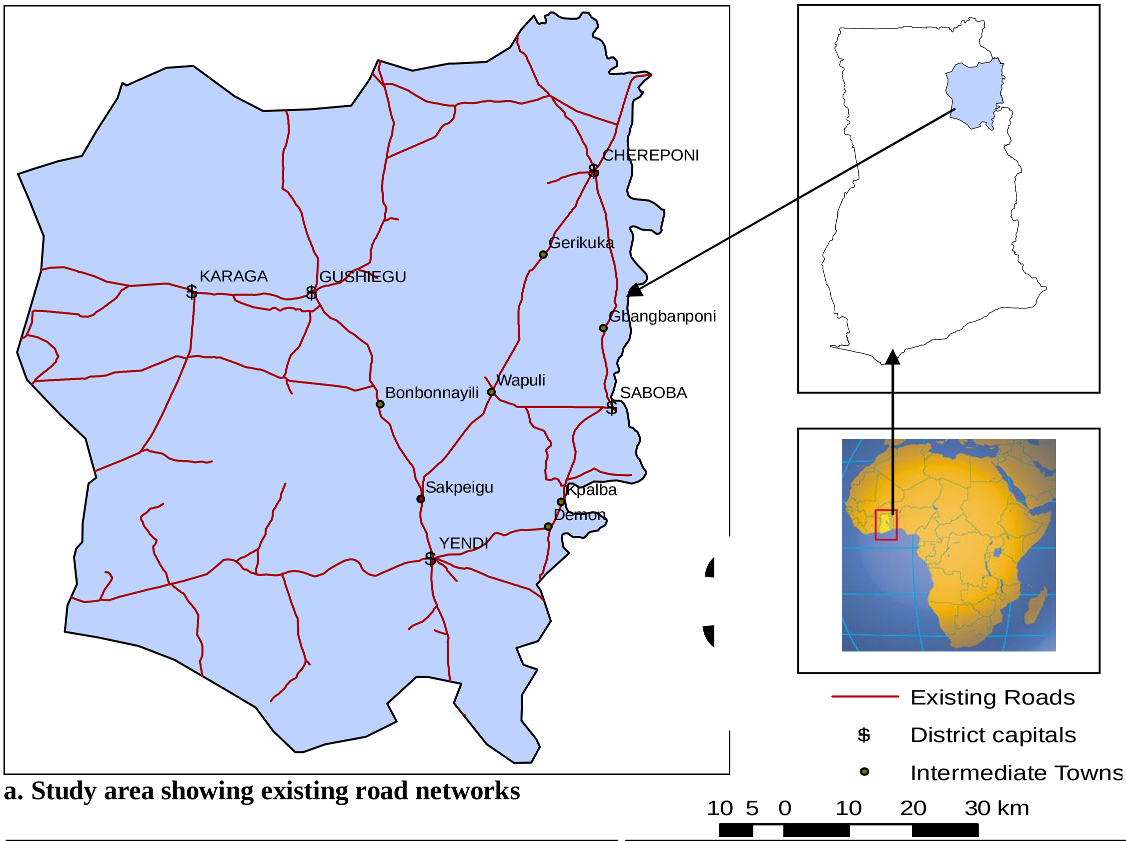
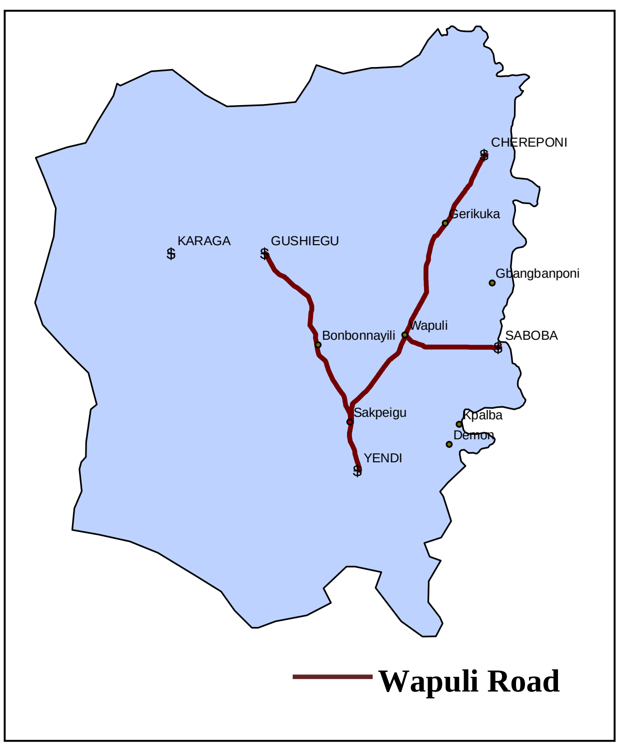
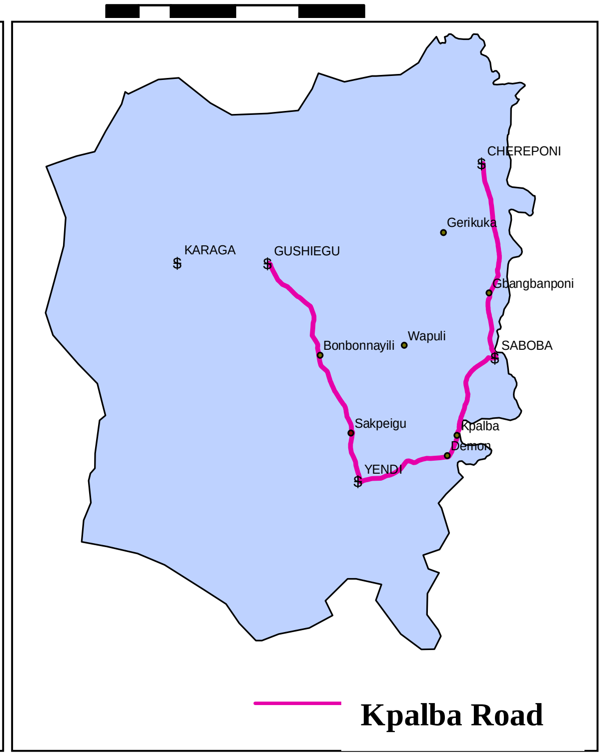


a. Study area showing existing road networks



b. Wapuli road option



c. Kpalba road option

Fig. 1: Maps showing existing roads (a) and the two proposed Wapuli road (b) and Kpalba road (c)

a. Section of Saboba-Wapuli road. Notice potholes and water at the far end.

b. Intended road after upgrading

Fig. 2: Sample of existing roads (a) and the intended road after construction (b). The "b" is a section of the 3km road constructed in Saboba Township

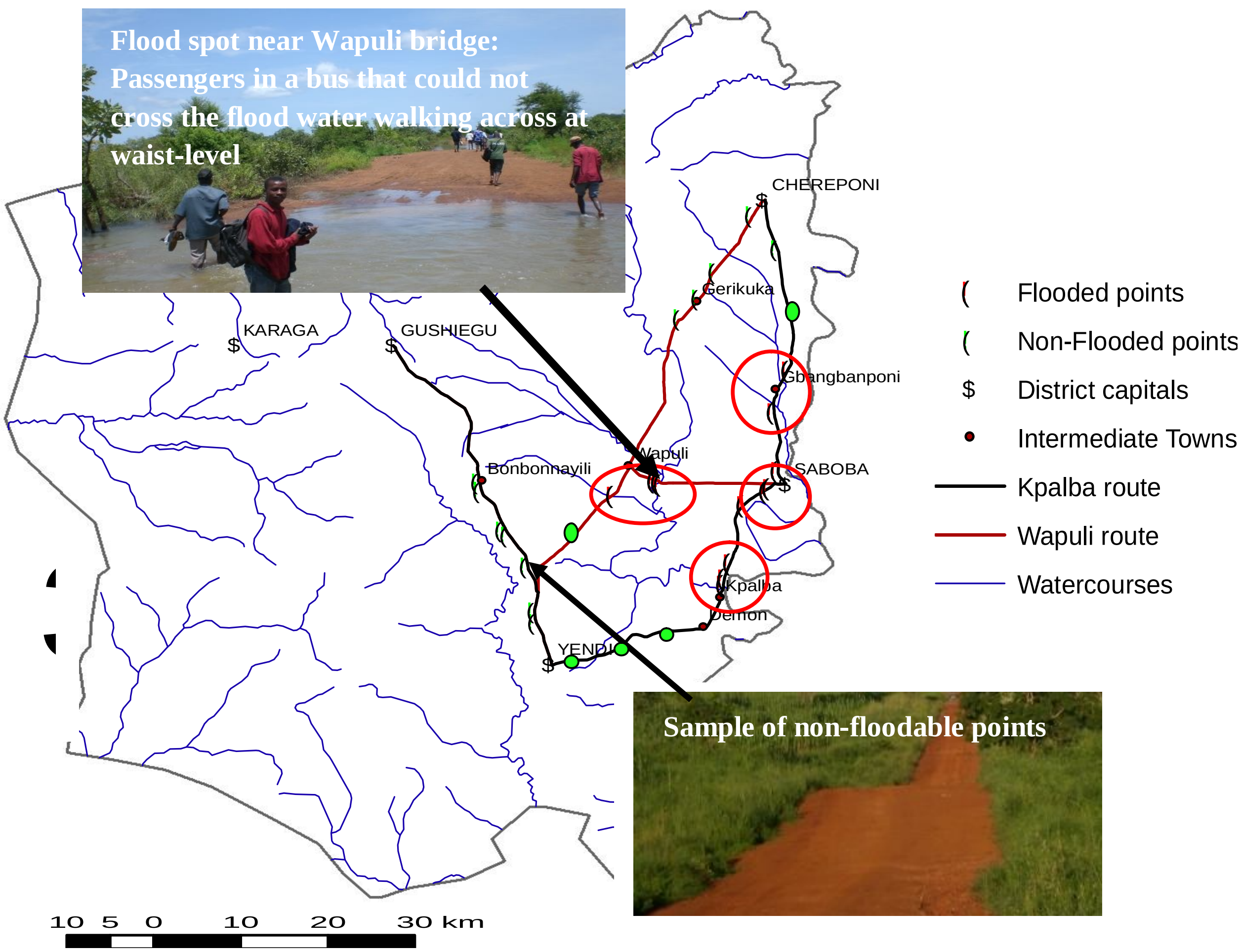


Fig. 3: Flooded and non-floodable points from the field survey

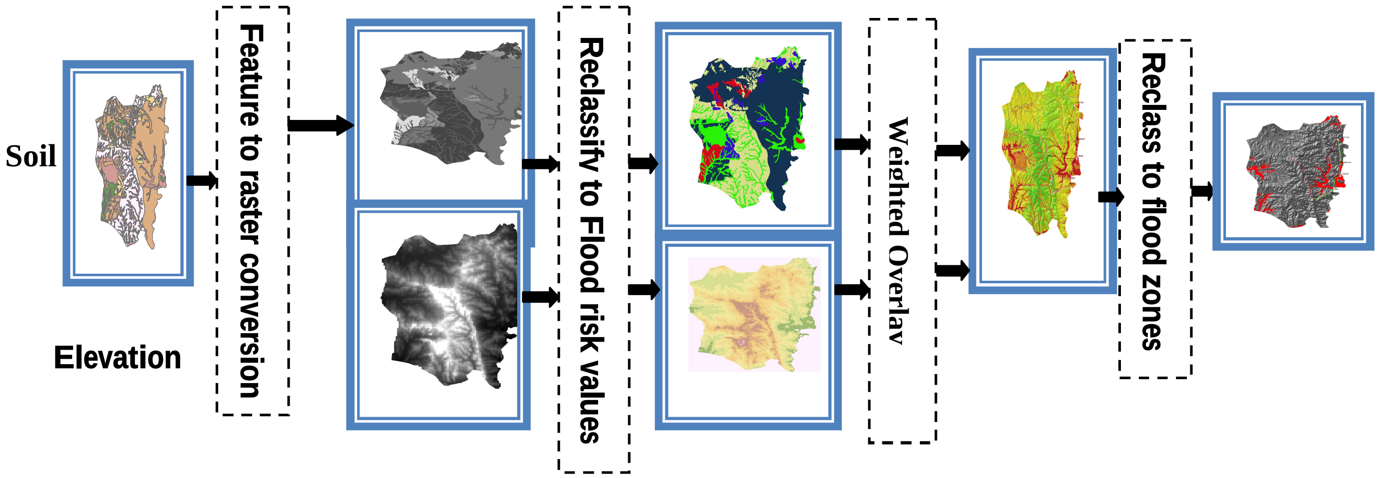


Fig. 4: A flow diagram showing GIS tools used in generating flood areas and the outputs

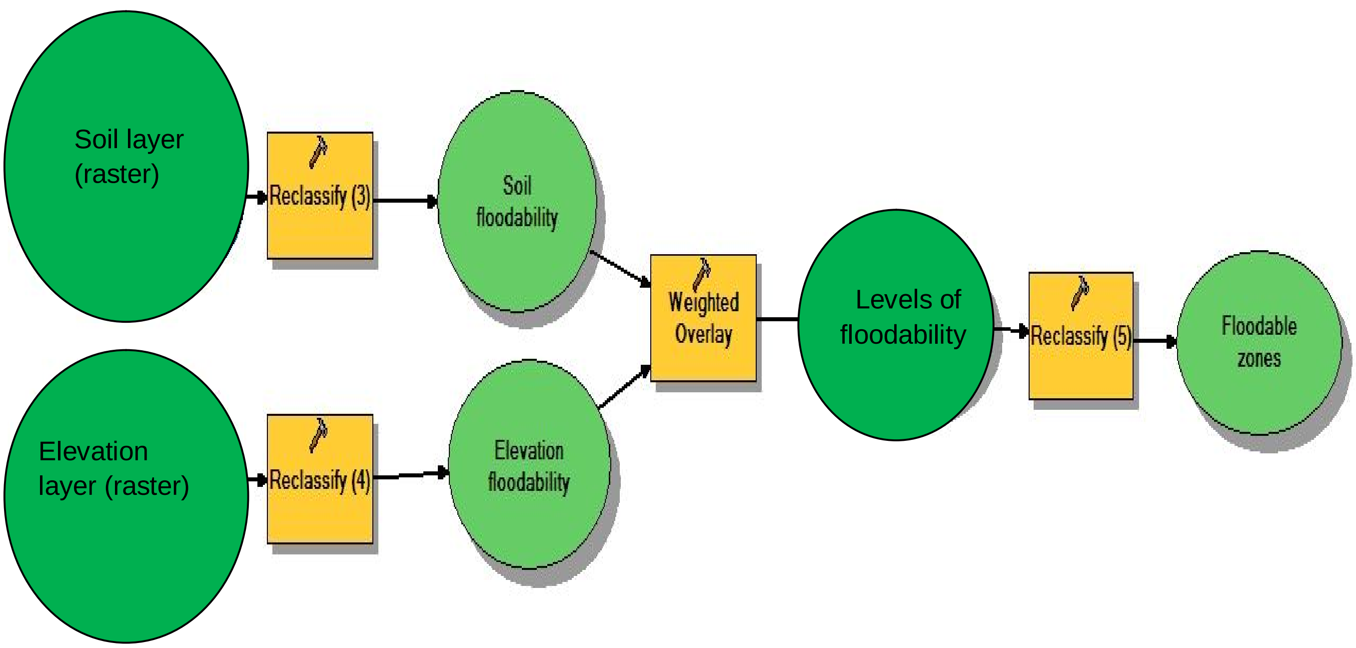


Fig. 5: The ModelBuilder showing the layers and tools used to identify food risk zones

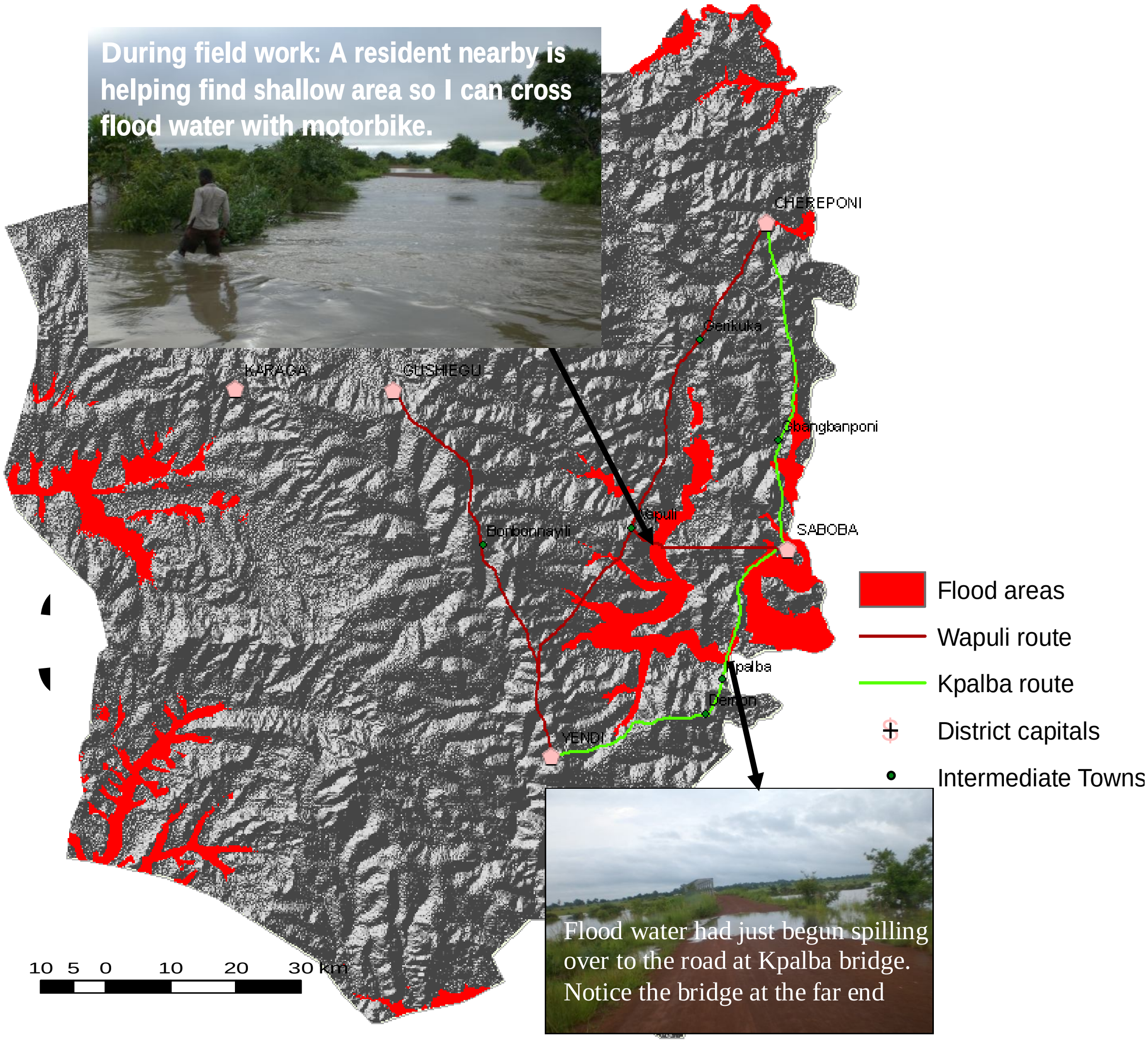


Fig. 6: Flood risk zones overlaid on elevation layer (3D view)

Table 1: The flood risk values and the weights assigned to the different soil classes

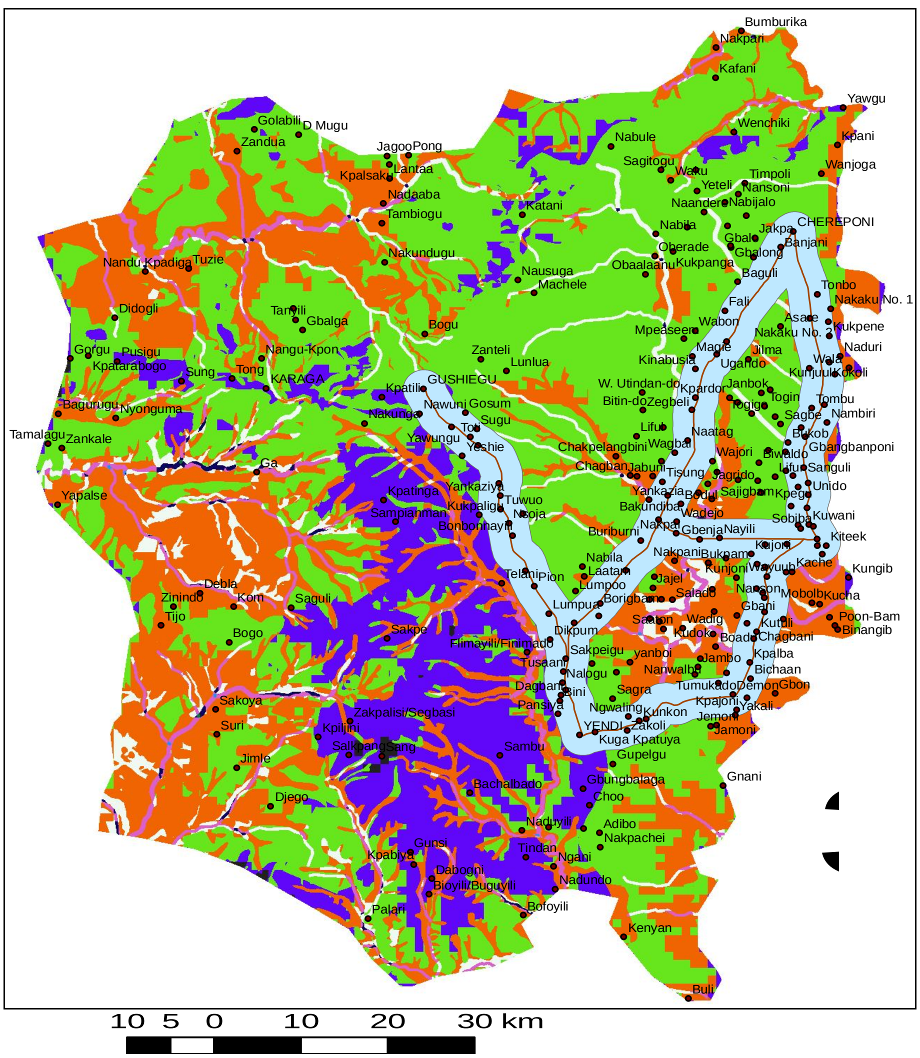
Factor	Attributes	Characteristics (based on IUSS Working Group, 2007)	Cost value	Weight
Soil Classes	Plinthosol	Wet soils with an irreversibly hardening mixture of iron, clay and quartz in the subsoil. The hardened plinthite has value as subgrade material for roads	1	50%
	Leptosol	Shallow soil over hard rock or highly calcareous material, extremely gravely and/or stony. Unattractive soils for agriculture	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 and susceptible 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	8	
	Fluvisol	Genetically young soil in alluvial deposits, river plains, valleys and tidal marshes and periodic flooding. Low pH-values, toxic aluminium levels and high concentrations of salts.	10	

Table 2: SWOT analysis of Wapuli and Kpalba roads

	Name of Road	
SWOT	**Wapuli Road**	**Kpalba Road**
Strengths	1. The road already exist 2. It has lesser flood risk (only 5km)	1. The road already exist 2. Has shorter total distance (169km)
Weaknesses	1. Longer distance coverage (170km).	1. It has the most flood risk (20km) 4. Chereponi will have longer distance to Yendi, a difference of 10km compared to Wapuli road
Opportunities	1. Opportunity of making Wapuli township an important node in the area 2. Shorter distance between Chereponi and Yendi – 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. Possibility to encourage trade relation between Saboba and Chereponi 3. Can facilitate trade links with neighbouring Republic of Togo
Threats	1. Susceptible to major flooding around Gbenja bridge.	1. Flooding is possible within 20km of its length. Its counterparts have less. 2. Susceptible to flooding in and around Kpalba bridge and Gbangbanponi

Appendix

Appendix 1: Map of the study area showing location of settlements



Appendix 2: Levels of floodability in the study area