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Using Multi Criteria Evaluation in Forest resource conservation in Ghana: spatially identifying vulnerable areas

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Abstract

The importance of forest resources to the socio-economic development of countries cannot be over-emphasized. A lot of research has been conducted in areas relating to forest management and protection in Sub-Saharan African. This paper discussed and illustrated the use of Spatial Multicriteria Decision Support System (SMDSS) to identify factors that make forest and game reserves vulnerable to rampant human induced depletion of forest resources by assessing risk factors of slope, roads and settlement data in Ghana. The model structure is aimed at understanding the critical vulnerable factors that threatens the survival of forest resources to deforestation, and draws on data from the Forestry Commission, CERSGIS and the Ghana Statistical Service. This paper incorporates multiple criteria and rank risk factors. In the end spatial maps are produced that identifies vulnerable areas for each ecological zone, so that specific policy interventions can be targeted by government to safeguard same. The research attempts to propose technology in managing scarce forest resources through the use of GIS techniques. It contributes to the discourse on forest management, ecological mapping and inventory of forest resources in Ghana. It provides an information base to tackle the threat of deforestation on a location by location basis. We conclude that spatial information is critical to forest resource management although spatial data is virtually unavailable in most developing countries. There is therefore the need by government to ensure acquisition and access to spatial data if forest resources are to be managed effectively.

***Keywords*—Forest, Conservation, Vulnerability, GIS and RS, SMDSS, Ghana**

1. INTRODUCTION

The need to protect and preserve our natural environment is one of the key topical issues in the twenty first century (Sunderlin et al., 2008, 2005). This need has come about as a result of rampant human induced depletion of these resources without ensuring that they are replaced (Alo and Pontius, 2008; Mayaux et al., 2005). We need to be mindful that the natural environment essentially provides resources that support our

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very existence (Boahene, 1998). If we consider these resources as a factor of production then there is the need to adequately consider conservation techniques to help perpetuate same. This is so because it is our store and source of wealth creation.

There are various legislations enacted to protect and manage these resources. These include the Forest Protection Act, 1972 (NRCD 243); Timber Resources Management Act, 1997 (Act 547); Forest and Plantation Development Act, 2000 (Act 583); Forest Protection (Amendment) Act, 2002 (Act 624); Forestry Commission Act, 1999 (Act 571); and Wildlife Resources (Amendment) (Declaration of Game Reserves) Regulations, 1976 (L.I. 1085). Even in the colonial past, ancestors enacted laws to preserve sacred grooves and virgin forests, these seen in the light of today were all conservation measures put in place. Resources are classified as fund, flow or composite.

Forest resources have been under the risk of human induced activities, many of which deplete the stock of these resources (Angelsen and Kaimowitz, 1999). There are a number of techniques that are used to monitor, model and analyze the changes to land cover at various scales of aggregation and disaggregation (Achard et al., 1998; Downton, 1995; Lambin, 1997; Mertens and Lambin, 1997; Stéphenne and Lambin, 2001). This relationship has been enjoyed over the centuries and exploited to realize capital for many countries across the globe. Deforestation is catching up fast on many forests in sub Saharan Africa (Achard et al., 2002; Rudel, 2013). Many primary forests are non-existent now. Now the current fear is that our forest resources are fast depleting. In sub-Saharan Africa a trend has emerged (and Ghana is no exception); deforestation has set in and we are losing much of our forest resources through human-induced activities. Attempts by governments over the years in Ghana have seen the planting of trees in community afforestation programmes. These programmes are not coordinated and at times are targeted at certain areas just to fulfill manifesto promises. The phenomenon of urbanization brings with it expansion in settlements, road networks among other services. This threatens our ecosystems to a large extent and makes them easily prone to deforestation if a stock of vulnerable areas is not assessed and measures put in place to safeguard forest resources.

Geo-Information Science (GIS) and Remote Sensing (RS) techniques are a Decision Support Tool that offers a platform to integrate both spatial and non spatial data in various formats that can be visualized spatially in a map form. Its overlay functionality provides analysis of data to meet specific research needs. Recent advances in spatial research provide tremendous opportunities to model forest resources and analyze same (Kennedy et al., 2009; Panta et al., 2009; Songer et al., 2009).

Ghana's total land mass of 239,460 square kilometers lies between latitude 11.5°N and 4.5°S and longitude 3.5°W and 1.3°E. The forest area covers an approximate area of about 39 per cent of the total land mass. Forest resources are fast depleting due to rapid urbanization. Over the last 3 decades the forestry sector in Ghana has had to grapple with deforestation degradation of reserves. Unsustainable human induced activities threaten the survival of forests. These are discussed later in the research.

The focus of this paper is to spatially examine vulnerable forest resources in ecological zones in Ghana and map out risk areas for targeted policy interventions.

2. METHODOLOGY

A database containing all areas compiled and classified as forests by the Forestry Commission of Ghana is employed in this research. The dataset is shape-file containing all areas classified as forests and to which ecological zones they belong to. Various layers of spatial information are employed to examine and identify 'vulnerable' forests within Ghana's ecological zones. The specific locations are identified so that appropriate interventions by policy can be targeted.

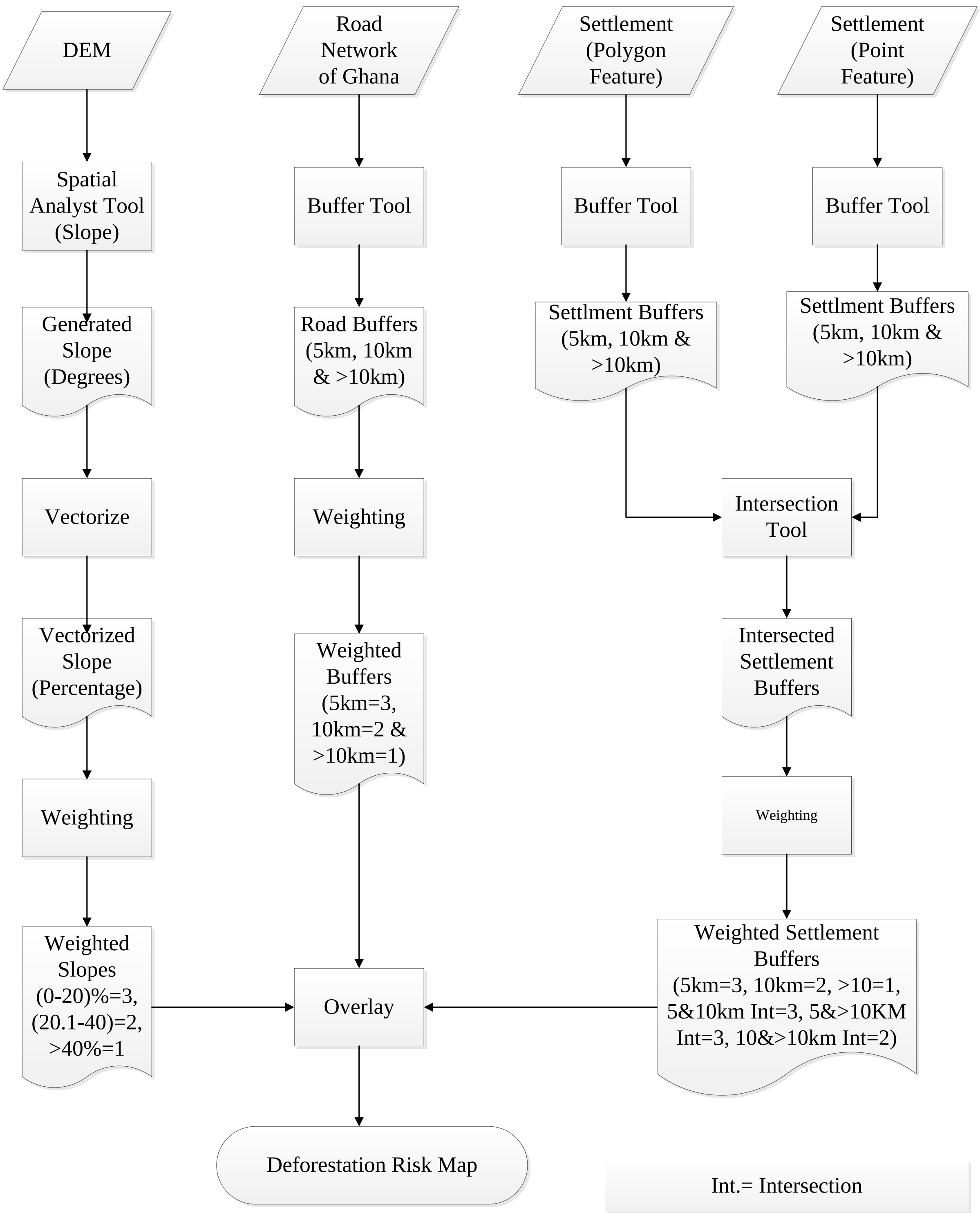
A number of processes were used to generate various layers of information for the final analysis. These involve the creation of a Digital Elevation Model (DEM), Slope Settlement and Road layers to create what the researchers term a Forest Conversion Risk Map. The details are provided in the paragraphs that follow. Figure 1 outlines the detailed processes employed to arrive at the Deforestation Risk Map.

2.1 Creation of Forest Conversion Risk Map

Forest management has become very important in the era of climate change. Governments with forest resources are being encouraged and given incentives to protect and conserve them. In order to achieve this, those countries would have to monitor their forest resources by examining associated risk factors that these resources are susceptible to, to enable targeted responses from deciding authorities. Based on this the researchers created what they called a Forest Conversion Risk Map. The researchers examine in subsequent paragraphs the reasons for risk factors considered and how the data was prepared.

Although there are several factors to consider in the creation of a Forest Conversion Risk Map, however, for this research 3 factors (Slope, Road and Settlements) were considered in the spatial analysis due to the limitations in available data.

Figure 1: Detailed processes of the Deforestation Risk Map



Slope

The slope of a line or an area describes its steepness or inclination. A higher slope value indicates a steeper inclination. The line may be practical - as defined by walking, set by a road surveyor - or in a diagram that models a road.

The people who cause destruction to forest resources do so by moving either by walking or driving a vehicle. The perception is that they will use more energy to traverse the distance to the resource if the slope is higher since the rise or fall of a road between two points is the difference between the altitudes of the road at those two points, say y1 and y2. In other words, the rise or fall is;

$$(y2 - y1) = \Delta y \qquad (1)$$

This therefore means that it will be more attractive to visit the forest resource to cause destruction when the slope is relatively flat as compared to when it is steeper.

Road

Roads are often a causal agent in the degradation of forest resources. Roads can allow uncontrolled extraction of natural products and landscape conversion. Roads provide the means by which much degradation occurs in Ghana. Road was considered as a risk factor because the availability of a road (paved access) provides accessibility which makes it easy for people to reach the forest resources to cause destruction. Studies have established a link between transportation infrastructure investment and economic development which is positive (Banister and Berechman 2001; 2003). However, for example timber operators rather use the road as an access to degrade forest resources. The more “good” roads are provided in the forest areas, the more accessible and vulnerable the forest resources become. This also implies that roads cause more danger to the forest resources as far as degradation and deforestation are concerned.

Settlements

Settlements also play a critical role in the degradation of the forest resources. It does that both in its establishment or construction and the attitude of the people living in it. Forest destruction to meet the agricultural productive land requirement of the steadily growing population is perhaps the most important deforestation threat in the developing countries. The growing population pressure for food and space is pushing some of the remaining specialized and sensitive flora and fauna of developing countries to local extinction. These countries rely more on extensive farming methods through shifting cultivation with very short fallow periods. The short duration of the fallow never allows trees to thrive again or if they do, they are removed at seedling stage. The land subsequently is with time left to be barren.

Two (2) different types of settlements data were used. These were the point settlement and the polygon settlement datasets (extracted from the 2010 classified ALOS satellite imagery).

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3. RESULTS AND DISCUSSION

3.1 Analyzing the Risk Factors for Creating Deforestation Risk Map

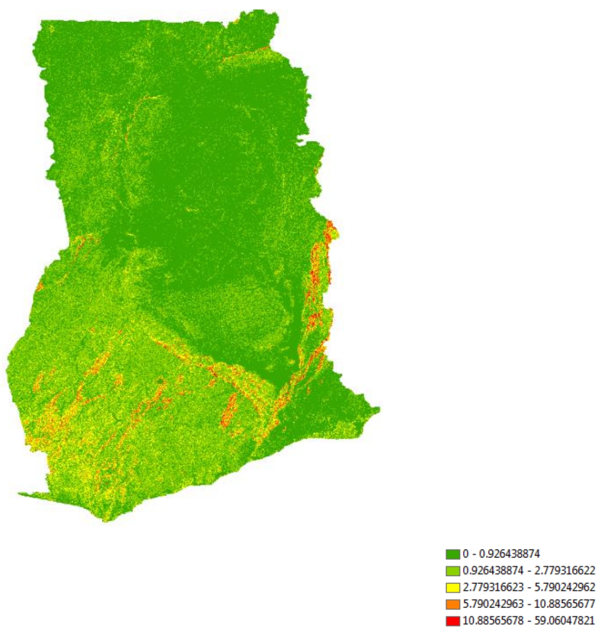
The slope was created with the 3D analyst tool in the ArcGIS software by using the Digital Elevation Model (DEM) of 90 meter cell size from SRTM dataset, which has been used to ortho-rectify the ALOS satellite image.

The resulting slope information was classified into 3 classes (see table 1) and a weight ranging from 1 - 3 was applied to each class. A weight of 1 refers to low risk factor whiles 3 refers to the highest risk factor. In the light of this, a gentle slope was weighted 3 because of the easy accessibility it imposes to forest lands whiles a steep slope is weighted 1 for the reserve reason. Figure 2 shows the generated slope with the legend indicating the value of elevation in percentage. It can be deduced that the slope over the entire country (Ghana) ranges from 0 – 60%, with the majority of the areas falling within the slope of 0 – 6% (gentle sloping areas)

Table 1: Slope classification

Slope class	**Name**	**Weight assigned**
0.00 – 20.00%	Gentle slope (flat)	3
20.01– 40.00%	Medium slope	2
>40.01	Steep slope	1

Figure 2: Slope layer generated from DEM



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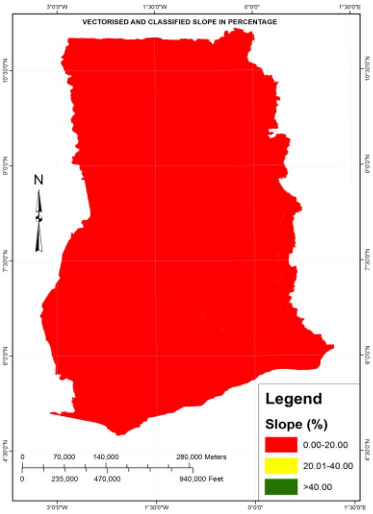
The resultant slope map as shown in figure 1 was then vectorized, and re-classified into the three classes as specified in table 1, ie, 0% – 20.00%, 20.01% – 40.00% and > 40.00%. The resulting map is shown in figure 3.

Figure 3: Vectorized and Classified slope



The existing GIS road data from across the country from the Centre for Remote Sensing and GIS (CERSGIS) and the Ghana Statistical Service (GSS) was used. Using the ArcGIS software, buffers were created for three (3) sets of distances: 0 – 5.00 km, 5.01 – 10.00 km and > 10.00km. These distances were considered with reference to the road network. The distances were then named and weighted as shown in table 2.

Table 2: Road network classification and weightings

Classes	**Name**	**Weight assigned**
0.00 – 5.00 km	High Vulnerable Zone	3
5.01 – 10.00 km	Medium Vulnerable Zone	2
>10.00 km	Low Vulnerable Zone	1

The reason considered for weighting these buffers is that forested lands within a buffer of 5 kilometers from a road network stand the risk of being degraded easily because of its proximity to the resource. Therefore a weighting of 3 applied to forest areas within a very close proximity to a road network, while those found beyond 10 kilometers network distance imposed a lesser risk and thus a weight of 1 was assigned. Figure 4 below shows the resultant road buffers performed which was later re-classified as per table 2.

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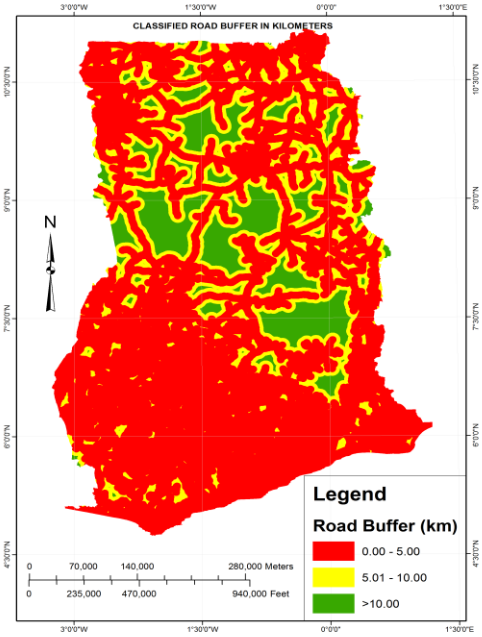
Figure 4: Classification of the road buffers



The entire polygon settlements data created from Task 8 of the Forest Preservation Programme (FPP) project was used in the analysis. This was complemented by the existing point settlement GIS data collected from CERSGIS. These two (2) settlement layers (polygon and point layers) were used and buffer of 5 kilometres, 10 kilometres and above 10 kilometres were created for each layer. The three (3) buffer zones were named and weighted as shown below in table 3.

The areas of intersection between two buffers either from the point or polygon or both settlements were assigned the highest weight among the two intersecting buffers. See the figure 5 for the combined buffers from the points and polygon datasets.

Table 3: Settlement classification and weightings

Classes	**Name**	**Weight assigned**
0.00 – 5.00 km	High Vulnerable Zone	3
5.01 – 10.00 km	Medium Vulnerable Zone	2
>10.00 km	Low Vulnerable Zone	1

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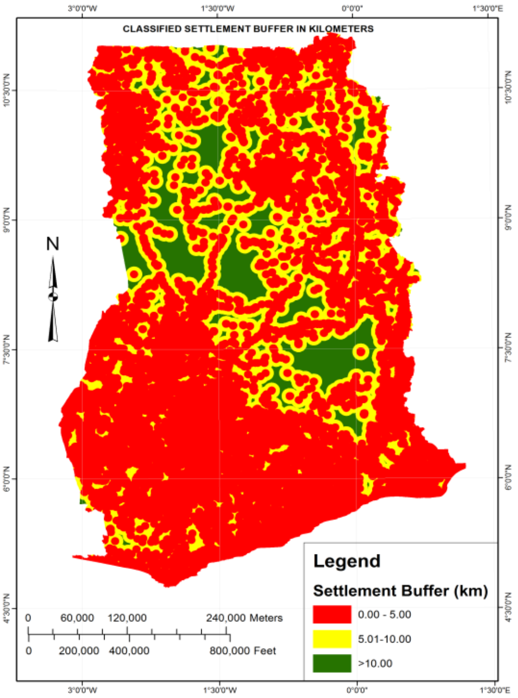
Figure 5: Classification of the settlement buffers



3.2 Overlay and interpretation of results of Deforestation Risk Map

The final deforestation risk map was obtained by overlaying the figures 3, 4 and 5 using the ArcGIS Analysis Tool and the Union function. The final classification of overlaid result of all above factors with their assigned weights (maximum of 3) was re-classified into 5 classes as shown in table 4.

Table 4: Deforestation risk classifications

Classes	Name
2.61 - 3.00	Very High Risk Zone
2.26 - 2.60	High Risk Zone
1.91 - 2.25	Medium Risk Zone
1.56 - 1.90	Low Risk Zone
1.20 - 1.55	Very Low Risk Zone

These classes were visualized by considering equal interval within the range of total accumulated points as shown in figure 6. The equal interval classification was used to generate the 5 classes including very low risk, low risk, medium risk, high risk and very high risk areas. In response to this classification, figure 7 shows the forest and game reserves that are vulnerable to the risk of human induced deforestation. It can be seen from figure 7 exactly which of these forests are vulnerable and the extent of vulnerability.

Figure 6: Deforestation Risk Map

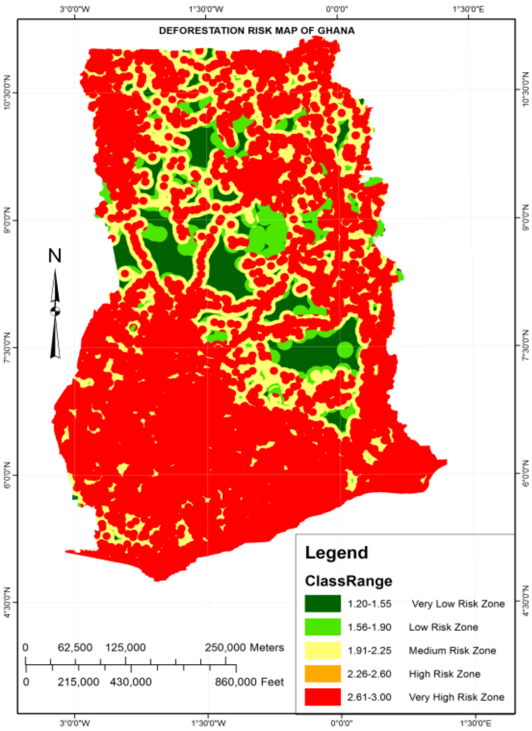


Figure 7: Vulnerability of Forest and Game reserves to human-induced deforestation

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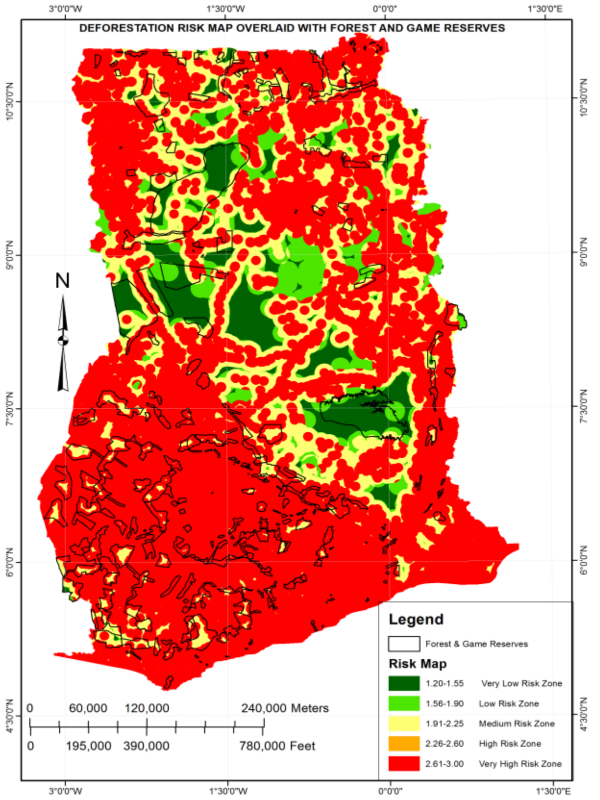

Table 5: Vulnerable forest and game reserves within ecological zones in Ghana

Ecological zone	**Risk Class/ Zones (Area in sqkm)**					**Total (Area in sqkm)**
	Very Low Risk	**Low Risk**	**Medium Risk**	**High Risk**	**Very High Risk**	
Dry semideciduous (fire zone)	36	106	2,328	1,910	1,734	6,114
Dry semideciduous (inner zone)	0	14	802	726	646	2,188
Moist evergreen	0	1	4,905	4,180	4,014	13,100
Moist semideciduous (north west subtype)	0	5	3,778	3,375	3,190	10,348
Moist semideciduous (south east subtype)	0	0	2,435	2,311	2,199	6,945
Savannah	5,417	2,516	10,962	6,486	4,915	30,298
Southern marginal	0	0	62	62	62	186
Upland evergreen	0	0	278	253	254	784
Wet evergreen	52	44	2,018	1,443	1,074	4,631
Total	**5,505**	**2,685**	**27,568**	**20,748**	**18,089**	**74,595**
Standard deviation	1,802	832	3,358	2,085	1,717	9,293
Average	612	298	3,063	2,305	2,010	8,288

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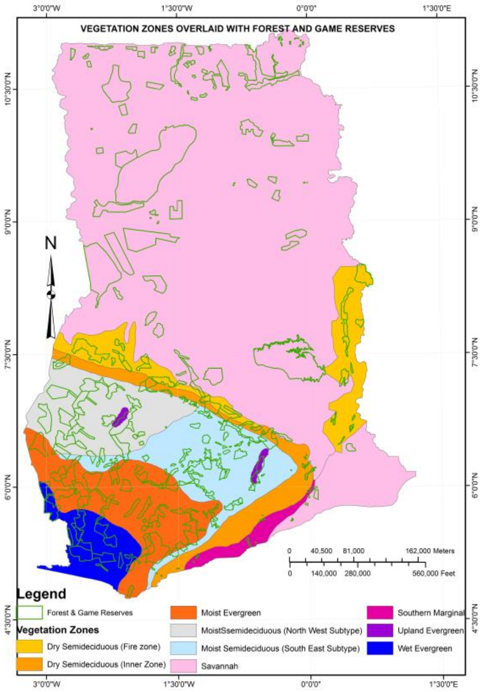
Figure 8: Forest and Game Reserves in Ecological zones of Ghana



In terms of quantifying vulnerable areas within the country, the analysis is done based on 9 classified ecological zones of Ghana. Figure 8 shows the ecological zones showing where the forest and game reserves are located. It can be realized that a good number are located towards the south western part of the country, which is the forest zone of the country.

Table 5 gives a summary of forests that are vulnerable in each ecological zone. For example within the moist evergreen forest zone, out of a total of about 13,100sqkm of forest and game reserves about 8,200sqkm is at a high risk of deforestation. The table quantifies these statistics for all ecological zones. Our prediction is that with the rate of urbanization and the expansion in settlement and road infrastructure, the vulnerability of these resources will increase. There is the need to manage land uses to protect these forest resources.

4. CONCLUSION

The results here present how spatial data can be used to model vulnerable areas as far as forest resources are concerned. These techniques help to easily visualize various scenarios and how these affect forest resources. Governments and decision makers are encouraged to base their interventions on afforestation programmes based on some of these factors to ensure judicious use of funds. The analysis sheds light on the need to examine scenarios that threaten forest resources and to target specific land use policy interventions to protect same. If vulnerable areas can be spatially identified it serves as base information to ensure strict compliance to land use planning to safeguard protected forest and game reserves.

Further, a national geo-database of vulnerable forest resources can easily be created to promote and raise awareness so that sound management of these resources can be achieved. This information will serve a Spatial Decision Support Tool in forest resources management.

We conclude that spatial information is critical to forest resource management although spatial data is virtually unavailable in most developing countries. There is therefore the need by government to ensure acquisition and access if forest resources are to be monitored effectively. The advantage of using GIS techniques is that we can cover a wider area than field sampling, which saves time and cost.

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