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Modelling the Spatial Interactions of Biophysical Factors Associated with the likelihood of wildfires in the Sunyani West District of Ghana

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ABSTRACT

In Ghana fire accounts for one of the major causative agents responsible for reducing productivity and depleting the genetic diversity of forests. Forest fires in Ghana have been estimated to cause an annual loss of 3% of GDP during the past years. They are anthropogenic in origin and can be prevented to a large extent if local people are effectively educated on the threats forest fires pose to their environment.

This paper develops a wildfire risk model through the study of the spatial dimensions of interacting factors associated with the likelihood of wildfires. GIS system is used effectively to combine different forest-fire causing factors (Anthropogenic and physical). TM image cover of the study area was classified into five different land fuel types using supervised classification method to an overall accuracy of 83%. The development of the fire risk model was divided into four sub models namely; fuel risk sub model, ignition sub model, detection risk sub model and response risk sub model. The final fire risk model expressed as the weighted sum of all the sub models reflects both the likelihood of ignition and the risk of spreading. The model was validated by mapping recently burnt areas and overlaying with the final model and sub-models. According to the model, 39% of the project area falls within the high to very high fire risk zones.

Results from the study shows that the major constituent factor to forest fire in the project area is the high fuel content and human activities. Controlling the fuel index by reducing fuel content thus enhancing the land cover, will greatly reduce the vulnerability of the area to forest fire. An introduction of integrated approaches focusing on controlling the high risk of ignition, reducing the high fuel risk content as well as sustaining and enhancing local livelihood is important in controlling forest fire in the district.

Key Words: *Fire Risk Model, Spatial Analysis, Forest Fire and Wild Fire*

1. INTRODUCTION

Forest fires cause great loss to the forest ecosystem, diversity of flora and fauna, and economic wealth (Ghosh and Kimothi, 2008). Forest fires annihilate large tracts of virgin forests and cause irreparable damage (ibid). Globally, wildfires contribute significantly to environmental degradation including global warming (Zhengxi et. al., 2007). Fire is a significant cause of environmental degradation destroying forest cover leading to loss of biodiversity as well as exposing the underlying soil to erosion and nitrate leaching from agricultural lands (Burgess, 2011).

In Ghana, forest fire is seen as the most important agent responsible for reducing productivity and depleting the genetic diversity of forests. Forest fires in Ghana have been estimated to cause an annual loss of 3% of GDP during the past years (FORIG, 2002). The use of fire is closely linked to livelihood activities. These activities are farming, palm wine tapping, and hunting. Fire has always been used as a tool for land management and plays a central role in the maintenance of many natural ecosystems, as well as in the practice of agriculture and rangeland management. Many indigenous communities use fire for small-scale land clearance and elimination of debris in their traditional slash and burn agriculture, which has been practiced since time immemorial, taking advantage of the annual dry season.

Conducting risk assessment studies to identify fire-prone areas has the greatest potential for protecting human lives, property, and natural resources (Caetano et al., 2002). The forest fire risk prediction is very important for fire management and fire protection strategies planning (Zhang et al., 2011). Forest fire risk mapping enables the manager to analyze the risk and uncertainty due to forest fires, and assess the expected losses that fires may cause (González et al., 2007).

The diversity of factors that affect the beginning and spreading of a forest fire dictates the use of an integrated analysis approach. A Geographic Information System (GIS) can be used effectively to combine different forest-fire causing factors for demanding the forest fire risk zone map (Erten et al., 2004). Considering the intrinsic dynamism of this phenomenon, remote sensing imagery is also very valuable for these kinds of studies. It provides a quick evaluation of the vegetation status, as well as a survey of the effects of fire on the environment. In dealing with forest fire modeling, GIS can improve the integration of satellite information with other geographical hazard variables, such as vegetation, topography and fire history (Caetano et al., 2002).

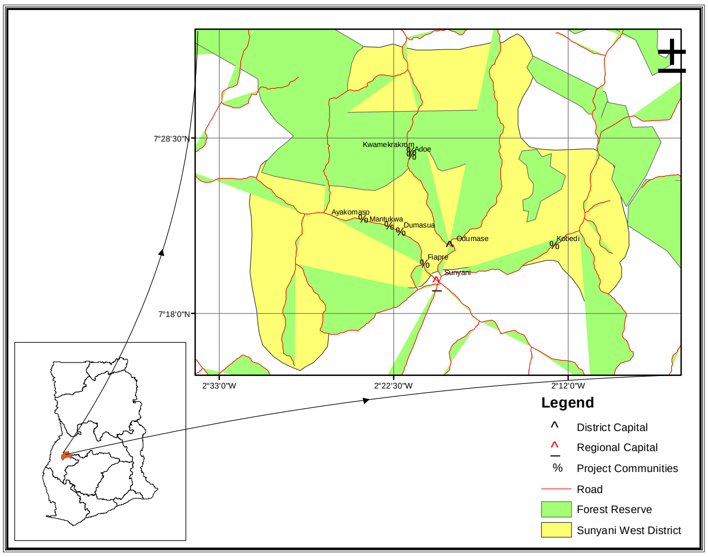
In the last decades, several GIS models have been developed to improve the spatial analysis of fire danger indices. Jaya et al., (2007) described the use of GIS and Remote Sensing technology for developing forest fires risk model and post-fire evaluation. The forest fires models considered human activity as well as environmental factors to derive a single index expressing forest fires prone. Zhang et al., (2011) also presented an overview on the status of detecting forest fire hot spots and fire areas by using satellite sensors in China over three decades, and analyze a few developed algorithms used for detecting fires with greater accuracies. GIS techniques have proven to be powerful tools for the assessment of forest fire risk (Roy, 2003).

This paper uses spatial (GIS) application and techniques to develop a forest fire risk model through the study of the spatial dimensions of interacting factors associated with the likelihood of wildfires.

2. METHODOLOGY

2.1 The study area

The Study area is Sunyani West District at a latitude of 7°28' N and Longitude 2°22' W in the Brong Ahafo Region of Ghana.



2.2 Fire Risk Mapping

Physical and anthropogenic factors are considered in the forest risk mapping. The Fire risk model is divided into four sub models namely; fuel risk sub model, ignition risk sub model, view exposure risk sub model (detection risk) and response risk sub model..

2.2.1 Fuel Risk Sub model

The fuel risk sub model is considered as one of the most important models and it includes vegetation type, slope, aspect and elevation. In this Sub model, TM image cover of the study area was classified into 5 different fuel types using Maximum Likelihood supervised classification method to an overall accuracy of 83% in Erdas Imagine. The various fuel types were assigned corresponding fire risk values based on Community scoring on inherent characteristics of the flammability and literature (Marsland et al., 2001; Mohammed, 2008). Standard topographic maps at a scale of 1:50 000 were digitized and the DEM (Digital Elevation Model) slope and aspect parameters were extracted for the study area using the Spatial Analyst tool of ArcGIS. The topographic parameters and the fuel map was all summed up in the GIS environment to generate the final Fuel Risk Model

2.2.2 Anthropogenic Ignition Risk Sub-Model

The ignition model is related with human activities like careless use/disposal of cigarettes, fireworks, and campfires (Orozco, 2008 ; Erten et. al., 2004; Jaiswal, 2002). Human settlement areas and agricultural areas where slash and burn farming practices occur were identified as the firebrand. The closer the fuel to the firebrand the higher the ignitions risk. The anthropogenic ignition risk model was created using the fuel map and distance from firebrands map. The firebrands (communities, roads) were buffered at 30, 60, and 90 meters and each buffer region weighted 3, 2, and 1 respectively, with 0 being the value for all areas > 90 meters.

2.2.3 Detection Risk Sub model

Detection risk refers to the visibility of a fire from certain viewpoints (Hussin et. al., 2000). This sub-model considers the visibility of a fire from settlements and roads. For this purpose, a viewshed analysis was carried out using the extension 3D Analyst from the ArcGIS. The settlement and road layers were used independently as input in ArcGIS viewshed analysis. Two viewshed maps were produced which were added in GIS to produce a final detection risk map. The final detection map was classified into 2 classes' i.e. Blind spot and Non-blind spot with respect to visibility of fire from roads and settlement. The visible areas were assigned low fire risk value (value 1) and invisible areas high fire risk value (value 5).

2.2.4 Response Risk Sub model

Distance and time are the major criteria for a good fire response and their interrelation is dependent on slope, cover type and elevation (Hussin et al., 2000 ; Mohammed, 2008). The total friction map was calculated as a sum of all the physical impediments (slope, elevation and land cover) of response and used as an accumulative cost surface map for calculation of response to fire. Distance (cost distance) from the settlements and road map was generated as response distance time map by using the total friction map as a cost raster surface in the ArcGIS environment.

2.3 Final Fire Risk Model

The fuel risk sub-models; ignition risk sub-model, detection risk sub-model and response risk sub-model thus produced were combined in map calculation option in ArcGIS giving appropriate weight for each map to produce the final fire risk zone map. The fire risk model was generated using the formula:

$$Final\ fire\ risk\ model = 5(Fuel\ risk) + 3(Ignition\ risk) + (Detection\ risk) + 2(Response\ risk)$$

The values 5, 3, 2 and 1 are weight factors based on the degree of influence of the various sub-model have on fire occurrence, indigenous knowledge and literature. The final grid was then reclassified using Five Jenks/Natural-Breaks classes(Very Low, low, Moderate, High, and Very High) in ArcGIS.

2.4 Model Validation

Model verification was done to evaluate the accuracy of the model. This was done by mapping recently burnt areas (burnt scares) on the field. With the help of the some community members, five different burnt scares (1302 Ha) were mapped using GPS survey. The burnt scares map was then overlaying with the final model for analysis.

3. RESULTSAND DISCUSIONS

The fire risk model (figure 1) reflects both the likelihood of ignition and the risk of spreading. According to this model, thirty nine percent (39%) of the project district is considered in the high and very-high risk values, thirty-one (31%) is categorized as moderate risk and 30% is categorized as low to very low risk (Table 1)Table 1 : The percentage distribution of the various fire risk classes

Fire Risk	Area (Ha)	Percentage
Very Low	8,604.93	9.2
low	19,330.13	20.7
moderate	28,891.16	30.9
High	24,729.88	26.5
Very high	11,824.97	12.7
Total	**93,381.07**	**100.0**

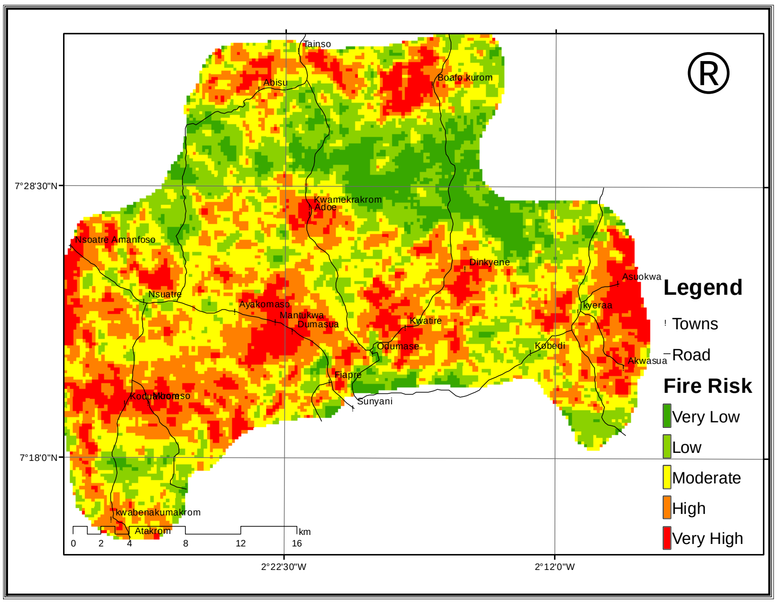


Figure 1: Final Fire Risk Model

Fuel Index risk sub model (Figure 2) shows a moderate to very high fire risk for 86.50% of the study area with the remaining 13.5% indicating low to very low fuel risk.

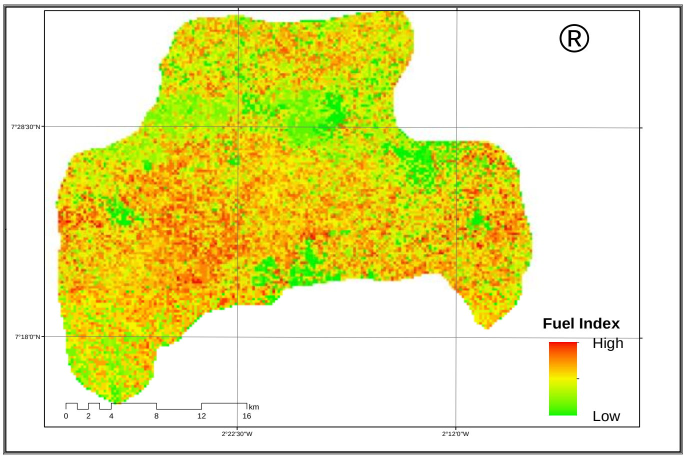


Figure 2: Fuel Risk Sub model

Ignition risk is as well high (moderate to high) for only 31.15% of the study area with the remaining 68.85% free from firebrand.

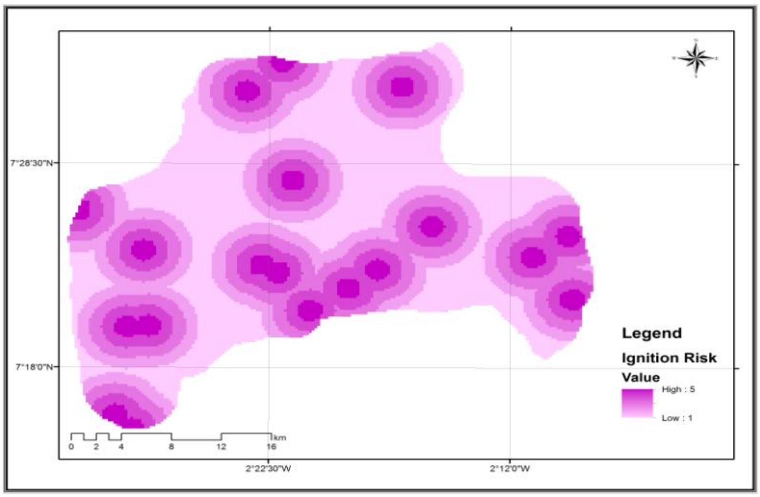


Figure 3 : Ignition Risk Sub model

Responds to fire is also very high as only 74.1% of the study area has very low to moderate fire risk and the remaining 25.9% of the study area have high fire risk. These are due to the relative flat nature of the terrain and also the relative visibility due to the land cover pattern of the area.

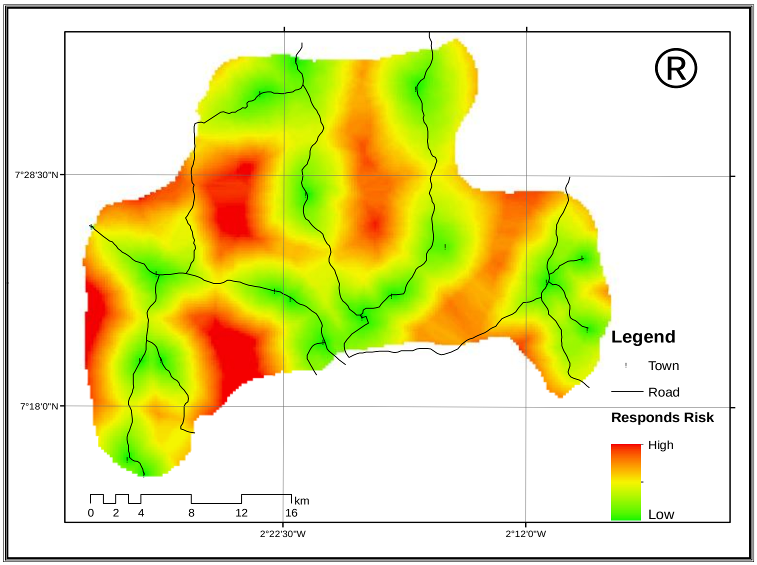


Figure 4 : Responds Risk Sub model

The detection risk sub model (Figure 4) shows that 83.53% of the total study area is visible to fire therefore fire detection within the study area is very high hence forest fire risk due to fire detection is very low.

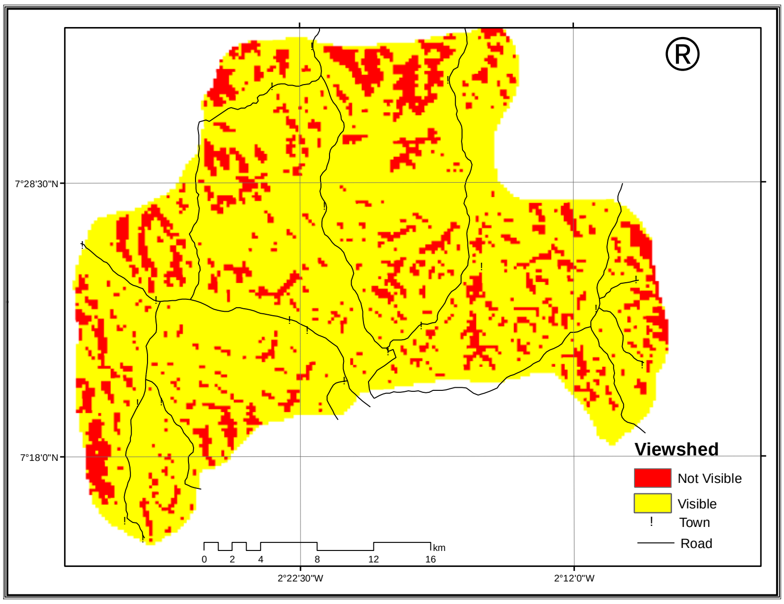


Figure 5: Detection Risk Sub model

3.1 Low Fire Risk Zone

The area of low and very low wildfire risk zone was 27,935.06 hectares representing 29.9 % of the study area. This zone is mainly stretches as a belt in the relatively flat terrain zone of the study area. In this zone, Fuel content is very low (8.6% of 13.5% total. Table 2 and Figure 5).

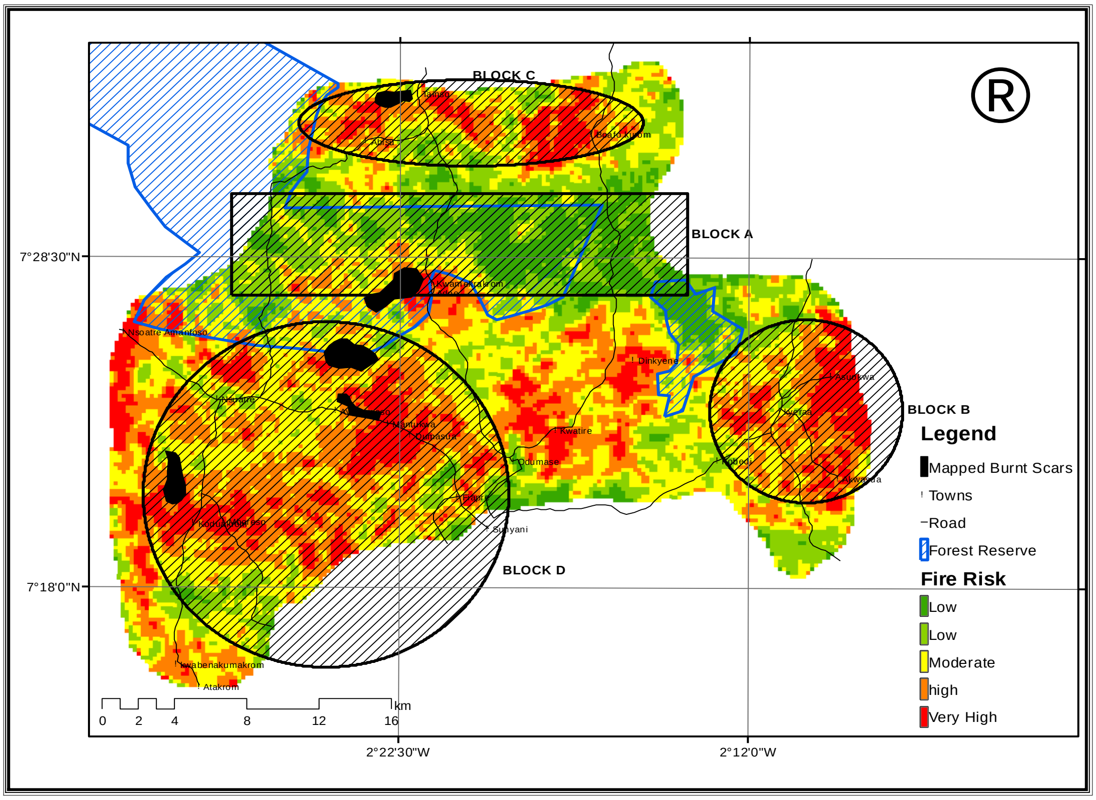


Figure 6 :Final Model showing burn scares, communities and forest reserve boundary

Table 2: Cross tabulation of Final Fire Risk Model against the Fire Risk Sub models

Sub models		Fire Risk Model					%
		Very Low	low	Moderate	High	Very High	
Fuel Risk Sub model	Low	4.4	4.2	3.1	1.4	0.4	13.5
	moderate	3.4	10.1	12.4	9.1	3.4	38.4
	High	1.0	6.2	15.6	16.5	9.0	48.1
Detection Risk Sub model	High	0.27	1.69	3.85	5.29	5.37	16.47
	Low	8.53	18.77	27.19	21.70	7.34	83.53
Responds Risk Sub model	Low	1.3	4.1	8.8	11.7	7.1	33.0
	moderate	4.9	9.5	13.3	9.6	3.7	41.1
	High	2.5	6.8	8.9	5.8	1.9	25.9
Ignition Risk Sub model	Low	8.41	18.05	23.69	14.34	4.36	68.85
	moderate	0.23	1.60	5.19	7.88	3.94	18.84
	High	0.12	0.80	2.15	4.79	4.44	12.31

Human activities within these zones are very low as there is no community found within hence low ignition risk. The Tain II forest reserve forms a greater portion of the zone. The common fuel types within this zone include; Remnant natural forest stand, Agricultural and some patches of degraded and shrub land.
The moderate wildfire risk zone covered approximately 28,891.16 hectares or 31 % of the study area, which was mostly spread out between the high and low fire risk zones.

The high wildfire risk zone covered approximately 36,554.85 hectares or 39 % of the study area. It was mostly situated in the south-western hilly zones (Figure 5; BLOCK D) of the study area mainly of agricultural activities, degraded and shrub land with high ignition risk (9.2% of the 12.3%, table 2). This zone it evidently shows that the areas closer to human settlements had very high potential to wildfire starting. Prevalence of human activities such as slash and burn, grass cutter hunting and charcoal burning has contributed to high fire risk within this zone. A high fire risk zone is also located in the Eastern sections of the district (Figure 5; BLOCK B). The low lying northern zones of the study area (BLOCK C) also have high fire risk mainly due to the dominance of shrub and agricultural activities hence very high fuel risk (25.5% of the 48% total, table 2).

One major constituent factor to forest fire in the study area is the fuel index. Controlling the fuel index by reducing fuel content thus enhancing the land cover will greatly reduce the vulnerability of the district to forest fire. Also, from table 2, 21.05% of the 31.15% (67.6%) high ignition risk zones areas, fell into the high and very high fire risk zones of the study area. These supports the arguments that most of the fire occurrences is as a result of high human activities (FORIG, 2002). During an open discussion, members of the community explained that the district has seen massive influx of migrant farmers. These farmers have replaced the perennials tree crop with annual crops mainly cassava and maize due to land tenure issues. These they normally cultivated on a large scale and the cheapest means of clearing the land is through the use of fire and weedicides. They further explained that the migrant farmers have replaced the traditional composting system with slash and burn.

Most of the burnt areas (Figure 5) were located in the high and very high-risk zones (61%) predicted from the model with the remaining 39 percent in the low and medium fire risk zones (See table 8).

Table 3 Burnt scares against final fire risk model

Fire Risk	Burnt Area (Ha)	Burnt Area (%)
Very low	0	0.00
Low	24.769	1.90
Moderate	485.482	37.26
High	604.376	46.39
Very high	188.248	14.45
Total Area	**1302.875**	**100.00**

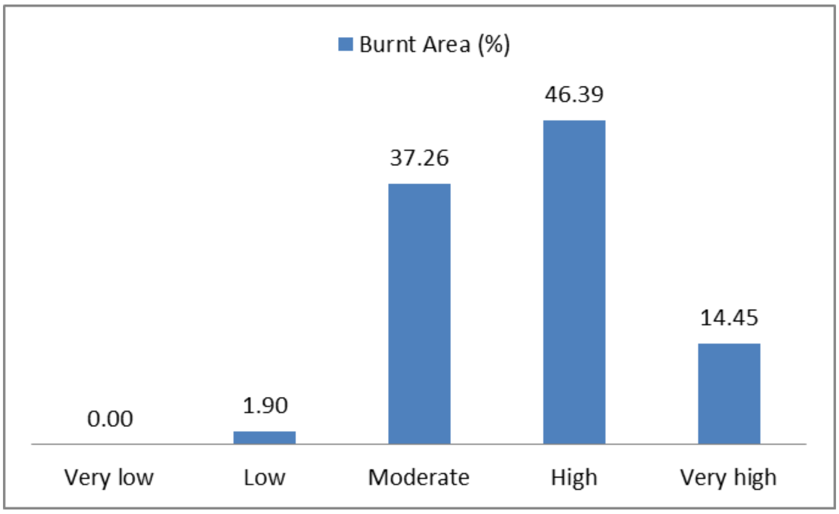


Figure 7: Percentage of burnt scares in the different fire risk classes

On the other hand, the detection model shows that ninety percent (90%) of the burnt areas were visible (table 9). This is due to the high number of settlements and the complex road network within the study district and the generally low nature of the topography.

Table 4 Results of overlay of burnt scares and detection sub-model

Visibility (Fire Detection Risk)	Fire Risk	Burnt Area (Ha)	Burnt Area (%)
Non-vissible	High Fire risk	133.755	10.27
Vissible	Low Fire Risk	1169.121	89.73

The distribution of the burnt scares in the response model shows that 65 percent (65%) burnt areas (table 10) were located in the most accessible (high responds to fire) areas. This coincides with the fact that the nearest places to roads and human settlements are the areas with more percentage of burnt scars because fires are mainly associated with human activities.

Table 5 Results of overlay of burnt scares and responds sub-model

Responds to Fire	Fire Risk	Burnt Area (Ha)	Burnt Area (%)
High	Low fire Risk	842.17	64.64
Moderate	Moderate Fire Risk	351.73	27.00
Low	High Fire Risk	108.99	8.37

4. CONCLUSION

The objective of the study was accomplished since the final model appropriately identified the low, moderate and high fire risk areas. The model shows distinct relationship between forest fire and the variables associated with it (fuel load, elevation parameters and proximity to fire brands). The models will provide resource managers with a number of tools and applications, including predictive regions of wildfire risk and identification of regions that may be candidates for fuel reduction and other interventions.

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