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Modelling Forest Fire Risk in the Goaso Forest Area of Ghana: Remote Sensing and Geographic Information Systems Approach

Bernard Kumi-Boateng, Issaka Yakubu

***Abstract*—**Forest fire, which is, an uncontrolled fire occurring in nature has become a major concern for the Forestry Commission of Ghana (FCG). The forest fires in Ghana usually result in massive destruction and take a long time for the firefighting crews to gain control over the situation. In order to assess the effect of forest fire at local scale, it is important to consider the role fire plays in vegetation composition, biodiversity, soil erosion, and the hydrological cycle. The occurrence, frequency and behaviour of forest fires vary over time and space, primarily as a result of the complicated influences of changes in land use, vegetation composition, fire suppression efforts, and other indigenous factors. One of the forest zones in Ghana with a high level of vegetation stress is the Goaso forest area. The area has experienced changes in its traditional land use such as hunting, charcoal production, inefficient logging practices and rural abandonment patterns. These factors which were identified as major causes of forest fire, have recently modified the incidence of fire in the Goaso area. In spite of the incidence of forest fires in the Goaso forest area, most of the forest services do not provide a cartographic representation of the burned areas. This has resulted in significant amount of information being required by the firefighting unit of the FCG to understand fire risk factors and its spatial effects. This study uses Remote Sensing and Geographic Information System techniques to develop a fire risk hazard model using the Goaso Forest Area (GFA) as a case study. From the results of the study, natural forest, agricultural lands and plantation cover types were identified as the major fuel contributing loads. However, water bodies, roads and settlements were identified as minor fuel contributing loads. Based on the major and minor fuel contributing loads, a forest fire risk hazard model with a reasonable accuracy has been developed for the GFA to assist decision making.

***Keywords*—**Forest risk, GIS, remote sensing, Goaso.

I. INTRODUCTION

FOREST fires, also known as wildfires, are uncontrolled fires occurring in wild areas and cause significant damage to natural and human resources. Such fires are common in almost all type of forests barring some wet evergreen patches. Forest fires eradicate forests, burn the infrastructure, and may result in high human death toll near urban areas. Fires are inevitable companions of forests and foresters across the world and revolve around four main factors. These factors are:

(i) The state and nature of the fuel, (i.e. proportion of live or dead vegetation, compactness, morphology, species, density, stratification and moisture content);
(ii) The physical environment, (i.e. weather conditions and topography);
(iii) Causal factors (human-or natural-related); and
(iv) Prevention and suppression means.

Fire hazard is defined by the physical environment, the state and nature of the fuel. However, it varies in relation to the fuel type and moisture content, weather conditions and topography [1], [2]. On the other hand, fire risk accounts for the causal factors, prevention and suppression of fire [1], [2].

It is pertinent to point out that the road network within forest acts as man-made fire line. Simultaneously the road network also enhances the approachability within the forest areas thus making it more probabilistic for the occurrence of the fire incidence.

The issue of forest fire appears as a central theme in forest management because forest burning is one of the challenging 'man versus environment' conflicts in Ghana. Frequent fires of anthropogenic origin have been affecting the forest ecosystems in the country adversely. The ecosystem within the GFA has been biotically disturbed leading to irreversible damage to the natural forest belt. For example, between 1984 and 1985, Ghana had a total of 1 005 incidence of forest fire with the GFA alone recording 110 representing 10.95% of the reported cases [3].

Although forest fires have played some part in agricultural production and in accelerating environmental degradation especially in the fragile savanna ecosystem, this issue has largely been ignored in decisions. The situation has affected the environment compared to tropical deforestation and desertification which have received considerable attention in environmental discussions of FCG. Like many hazardous phenomena which occur occasionally, forest fires appear as headlines in mass media during the dry season. Then, it seems to be forgotten when the risk disappears with the onset of the rains. Thus, there is very little in the form of published data and information concerning its detection, prevention, frequency, intensity and duration [3]. The effects of forest fire on rural livelihoods and on the ecosystem in GFA are increasingly becoming extensive and damaging. However, it has been difficult to reduce or completely eliminate forest fire due to the fact that in some cases fires are part of the forest ecosystem. They are also important to the life cycle of indigenous habitats. The increasing biotic pressure on the

Bernard Kumi-Boateng is with the University of Mines and Technology, P O Box 237, Tarkwa, Ghana (phone: +233262817778, e-mail: kumi@umat.edu.gh).

Issaka Yakubu is with the University of Mines and Technology, P O Box 237, Tarkwa, Ghana.

forests due to increased resource dependency has led to an increase in fire incidence in the GFA. Hence, there arises the need for generating greater amount of information with regard to ecosystems and the likelihood of forest fire so that prompt and immediate action is possible whenever there is a fire outbreak. In order to eliminate forest fire completely, there is a need for a novel methodology to model forest fire risk and its effects. Such a model must take into account the forestry, arable agriculture, soil and wildlife conservation. The model will also help in devising preventive measures so that valuable resources are not lost routinely. Modern tools and technology along with traditional knowledge can be of immense importance in preventing, controlling and managing forest fires.

Research [1], [2], [8], [10] on the linkages between forest fire and ecological systems goes back to the early discovery that natural disturbances were a recurrent phenomenon in ecosystems. This linkage requires an understanding of forest fire effects on ecosystem structure and function. However, connecting forest fire to ecological systems has proceeded slowly. This is probably because forestry and ecology, the two fields primarily interested in the influence of forest fire on ecosystems, have been side tracked by their traditional approach to studying ecological systems. Foresters are mostly interested in extinguishing or eliminating forest fire in managing burns to produce certain effects in the forest (e.g., reduced competition between certain trees or creation of wildlife habitat). Ecologists have been interested in how fires change the composition and structure of ecological systems. In an attempt to link forest fire and ecological systems, some researchers [3], [5], [8], [10], in general, describe the patterns of fire effects and correlate these to environmental factors. This approach does not directly lead to research towards studying the mechanism of interaction between fire processes and ecosystem processes. This factor undoubtedly undermines the country's ability to prevent, control and completely eliminate forest fire in the fragile ecosystems which are threatened by drought and desertification.

Preventing a small fraction of the fires would account to significant savings in the natural and human resources of Ghana. Apart from preventive measures, early detection and suppression of fires is the only way to minimize the damage and casualties. Systems for early detection of forest fires have evolved over the past decades based on advances in related technologies. Traditionally, forest fires have been detected using fire lookout towers located at high points. A fire lookout tower houses a person whose duty is to look for fires using special devices such as Osborne fire finder [4].

Due to the unreliability of human observations in addition to the difficult life conditions for fire lookout personnel have led to the development of automatic video surveillance systems [5], [6]. The accuracy of these systems is largely affected by weather conditions such as clouds, light reflection, and smoke from industrial activities. Automatic video surveillance systems cannot be applied to large forest fields easily and cost effectively, thus for large forest areas either aeroplanes or Unmanned Aerial Vehicles (UAV) are used to monitor forests. Aeroplanes fly over forests and the pilot alerts the base station in case of fire or smoke activity. UAVs, on the other hand, carry both video and infrared cameras and transmit the collected data to a base station on the ground that could be up to 50 km away. The problem with the UAVs is that they are very expensive to operate in a developing country such as Ghana. Thus, this paper seeks to develop a methodology to model forest fire hazard spatially using Remote Sensing and Geographic Information Systems approach in order to enhance the country’s ability to prevent, control and completely eliminate forest fire in the fragile ecosystem using the Goaso district as a case study.

II. THE STUDY AREA

Goaso is the district capital of Asunafo district located on the western corridor of Brong Ahafo region of Ghana. The population of the district is estimated to be about 188143 at a growth rate of 2.6% per annum. It lies on latitude 6˚48'00"N and on longitude 2˚31'00"W. The topography is gently undulating lowland and it is drain by three major rivers namely; *Tano, Ayum* and *Go* [7]. The climate is hot and humid and receives an annual rainfall of between 1500 mm and 1750 mm and mean monthly minimum and maximum temperatures varying between 26 ˚C and 29 ˚C. There are two rainfall seasons; the major season occurs from April to July with a short dry season in August. The minor season begins in September and ends in October with a long dry season between December and March [7]. Relative humidity is generally high ranging between 70% in the dry season and 80% in the rainy season [8]. The total land area of the district is 2 187.5 km^2 with the forest reserves covering 779.4 km^2.

The GFA lies between latitudes 6˚27'00"N and 7˚00'00"N and longitudes 2˚23'00"W and 2˚52'00"W. Goaso is a rural community that is typical of biophysical and socio-economic conditions pertaining in most of the fragmented forest agro-ecosystem in the moist semi-deciduous high forest zone of Ghana [7]. A total area used for this study is approximately 216.79 km^2. The major land use is mainly forest and rain-fed agriculture, with cocoa as the major cash crop, and mixed cropping of cassava, maize and plantain for subsistence and commerce.

III. SOURCE OF DATA AND ORGANISATION

The source of data and methods employed in this paper are discussed in the following sections.

A. Source of Data

The datasets used for the calculation of the Forest Fire Hazard Model included: Land use/cover map of Goaso from the forestry commission in Kumasi; a digital topographical map of Goaso at a scale of 1:50 000 from the survey; and mapping agency of Ghana as well as the location of the headquarters of the fire service department was mapped using Garmin hand-held GPS. All maps were generated using ILWIS and ArcGIS software.

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B. Data Organisation

The fire risk model (Fig. 1) was calculated using three sub-models namely, fuel risk sub-model, view exposure risk sub-model (detection risk) and response risk sub-model.

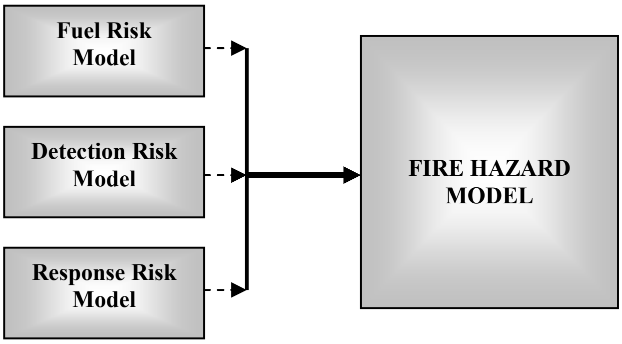

Fig. 1 A Flow Chart of the Fire Hazard Model

The variables (data layers) chosen for the creation of the sub-models were comprehensively recognized as determining factors in forest fire prevention and suppression. In order to assess the data layers in each sub-model, linkages of different locality variables like fuel type, elevation, slope, aspect; land features etc. were evaluated and established, as a primal imperative. Then, variables of every sub-model were given quantitative fire risk values depending upon their capacity to promote a fire situation. For example, in the fuel risk sub-model, fuel type (the different species of trees which can burn) is given a higher weight (besides its fuel risk value), followed by slope, aspect and elevation, respectively.

The detection risk sub-model has roads and habitation view exposure, as its components. The response risk sub-model evaluates the friction offered by different land features and terrain to travel over them, as a response in distance units, from the headquarters of the fire service department. Finally, these sub-models were combined, imparting proper weight factors, to get to the fire risk model. The organisation of data and methods used for the production of all the sub-models are discussed in the following subsections

1. Fuel Risk Sub-Model

In order to model the fuel risk, different factors such as; Elevation, Slope, Aspect, and Land cover type that may stimulate the spread of fire were identified and mapped (Fig. 2).

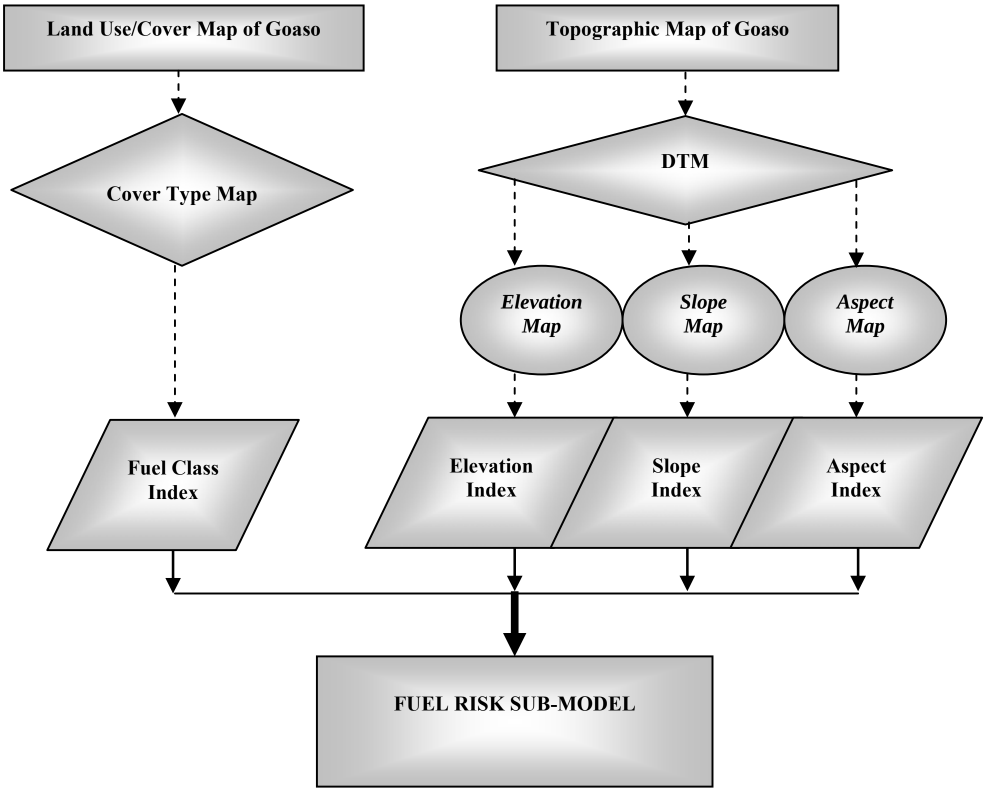

Fig. 2 A Flow Chat of the Fuel Risk Sub-model

The following conditions were also taken into account:

- Certain fuel types (tree species or grasses) burn easier than others do (e.g., forest area burns easier than a moist agricultural area).
- A fire will spread more easily and quickly on an upward sloping hill than on a flat area.
- Areas facing the sun will be drier and hotter and thus more susceptible to fire.
- Certain elevation heights will also be more susceptible to fires. An area that is very high above sea level will be less receptive to a fire than a lower laying area where there is more oxygen.

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In developing the fuel class index map, the inherent characteristics of plants and other land cover types were considered. The land cover types were classified into different classes of fuel risk levels (Table I). A very flammable area was assigned a high value, while a non-flammable area was given a low value; a river will hardly burn relative to a natural forest. Thus, for the fuel class index, water bodies were assigned a low risk index and a natural forest a high risk index (Table I).

TABLE I
FUEL RISK TYPES AND CORRESPONDING FIRE RISK VALUES

Class Name	Fire Risk Value	Cover Type
No fuel risk	1	Road and Water
Very low fuel risk	2	Settlement
Low fuel risk	3	Agricultural Land
Moderate fuel risk	4	Shrub Land
High fuel risk	5	Plantation
Very high fuel risk	6	Natural Forest

Topographical factors have a large effect on the spreading speed of a fire. The steepness of slope has a big influence on the spreading speed of a fire. The spreading speed of a fire front on a flat (0%-8% slope) surface can be expected to double on an 18% slope, and double again on a 36% slope. It is expected that a moderately burning fire doubles the rate of spread as it burns up a steep (40-70%) and again doubles as it burns up a very steep slope (70-100%). Later a ten percent increase in slope may double the spreading speed of a fire [9]. In generating the slope index map, the various classes of slope in the study area were assigned risk indices according to their fire risk levels (Table II).

TABLE II
SLOPE TYPES AND CORRESPONDING FIRE RISK VALUES

Slope Type	Class name	Fire risk value
Flat to gently slopping (≤ 5˚)	Low	1
Slopping (≤ 15˚)	Moderate	2
Moderately steep (≤ 30˚)	High	3
Very steep (≤ 90˚)	Very high	4

Aspect which is defined as the direction in which a slope faces was estimated. These estimates relate to the amount of exposure of the slope to the sun making the fuels on them warmer. In the study area, northern slopes are exposed to sun. Slopes to the south and east are oriented most parallel to the sun's rays. They are shaded during most of the day, and the fuels (trees that can burn) on them remain moister and cooler than the fuels on slopes in other directions. Northern and north-western slopes are nearly perpendicular to the rays of the sun. They are exposed to the sun for a longer time during the warmest part of the day. The fuels on them become warmer and drier and burn more intensely and completely than the fuels on slopes in other directions. They also allow the radiant heat to transfer fire across slopes easier than broad canyons or valleys do. These conditions usually increase fire spread rates faster than normally would be expected.

The different classes of aspect in the study area were given risk indices to indicate their supportiveness to fire. An aspect that faces the sun directly will get a high risk index while aspects in the shadows of fuels and mountains will get a lower risk index (Table III).

TABLE III
ASPECT TYPES AND CORRESPONDING FIRE RISK VALUES

Aspect Type	Class name	Fire risk value
South – south - west (≤ 225˚)	None	1
East – south - east (≤ 135˚)	Very low	2
North east – east (≤ 90˚)	Low	3
West – north - west (≤ 315˚)	Moderate	4
North – north - east (≤ 45˚)	High	5
North west – north (≤ 315˚)	Very high	6

The elevation of an area above sea level affects the length of the fire season and the availability of the fuels. Relatively lower areas have longer fire seasons. As the elevation rises the availability of the fuels becomes lesser after a certain limit. The fact also remains that fire spreads quicker uphill than downhill. The phenomenon of rolling fires occurs after a comparatively higher elevation. The study area was classified into low and high lying areas and their corresponding risk index assigned. Lower elevations were assigned low risk and high risk index to highlands.

The total fuel risk sub-model was calculated using the *MapCalc* operation in ILWIS by adding the fuel class index, elevation index, slope index and the aspect index maps together.

2. Detection Risk Sub-Model

Part of the fire risk model is the detection risk sub-model. This refers to the visibility of a fire from certain viewpoints. A fire that cannot be seen will cause more damage to forests as it can continue burning without being stopped. Areas that are not visible to people from certain areas will thus have a higher fire risk than areas that can be seen. When somebody sees a fire, the risk that the fire will cause more havoc is smaller. This means that, areas that are visible from certain viewpoints have a smaller fire risk. In the case of this sub-model, the view shed analysis (to identify visible and invisible areas from certain viewpoints) was done using the roads and settlement maps as input maps since majority of people who are likely to see fires, will be in the community or on a road (Fig. 3).

3. Response Risk Sub-Model

Fire response (Fig. 4) involves not only the reaction to a fire situation by reaching the place but it includes the activities after detection and also includes communication, dispatching and getting to the fire [9]. Response to a fire situation is further subjected to two considerations i.e. transport surface and friction offered. Thus, in this study, these two factors were calculated as a distance from the headquarters of the fire service department i.e. place of dispatch. Distance and time are the major criteria for a good fire response and their interrelation is dependent on slope, cover type, off road and on road travel and barriers.

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Slope offers resistance to travel. Increasing slope has a prominent effect on response interval. It is considered that for first marginal slopes of 0-10% (in a slope percentage map) there will be little effect on response interval, while any increase of slope thereafter proportionally increases the response time, to a limit of maximum 110-120% slope, after which the slope becomes inaccessible to human beings. In a fire situation or from management point of view, conditions become even more intense, owing to urgency of the situation. A slope percentage map was generated and reclassified into a map with response friction values. A steep slope was given a high response friction value, while a flat area was given a low response friction value.

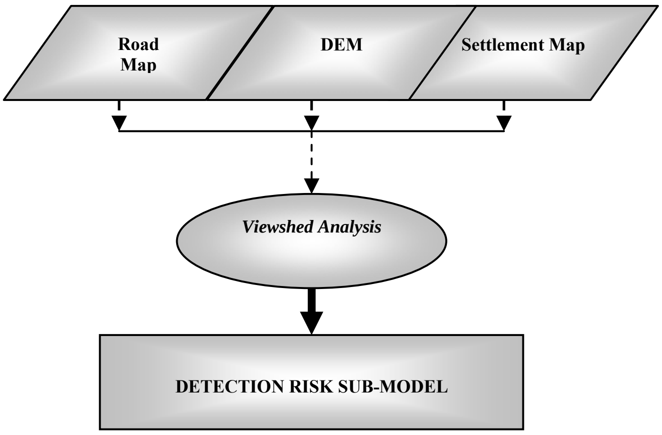

Fig. 3 A Flow Chart of Detection Risk Sub-model

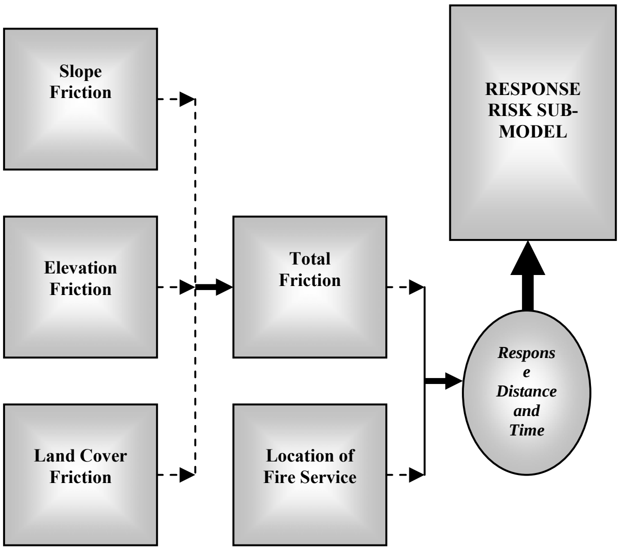

Fig. 4 A Flow Chart of the Response Risk Sub-model

The response to a fire mainly depends on speed of travel. Friction is the sum total of all the factors responsible for retarding the speed of response. It includes the cover type, road type, rivers etc. Thus, in generating the friction map, the land cover map was used. Every land cover type was given a friction value corresponding to the difficulty of traveling over that area.

Studies of inertia indicate that with a subsequent rise in elevation, the capacity to do work decreases. Many factors including the structure of human body, reduced supply of oxygen, high rate of caloric combustion, raised centre of gravity, principal load of body along with equipments are of importance in this case. The elevations map (DEM) was reclassified into classes of friction caused by elevation.

TABLE IV
FRICTION (DIFFICULTY OF TRAVEL) OF DIFFERENT LAND COVER TYPES

Land cover type	Class name	Friction value
Road	No friction	1
Water	High friction	10
Settlement	Very low friction	2
Agricultural land	Low friction	3
Shrub land	Medium friction	5
Plantation	High friction	8
Natural forest	High friction	8

The three friction maps (slope friction, elevation friction and land cover friction) generated were subsequently combined using the *MapCalc* operation in ILWIS to determine the total friction map.

Although the total friction map created tells how difficult it is to travel through a certain area, it was also important to know how far these areas are from the headquarters of the fire department. This is due to the fact that, a normal distance calculation from the headquarters will not take into account the difficulty to travel through a certain area. However, it was possible in ILWIS to calculate the distance from the headquarters to all points in the map while taking into account the difficulty to travel through all the areas. In the distance calculation operation of ILWIS, the total friction maps created was used as a weight map.

4. Fire Risk Model (Final)

The final fire risk model was generated through the addition of the fuel risk, detection risk and the response risk maps (Fig. 1) in a logical sequence using:

$$\text{FFRM} = (4 \times \text{FRS}) + (2 \times \text{RRS}) + (\text{DRS}) \tag{1}$$

where: FFRM = Final Fire Risk Model, FRS = Fuel Risk Sub-model, RRS = Response Risk Sub-model, DRS = Detection Risk Sub-model.

The submodels were given weights depending upon their risk priority. The fuel risk submodel, being the most significant in terms of hazard area identification as well as from a fire behavioral point of view, was given a weight factor of 4. The response risk submodel, being part of the overall fire suppression plan, was also assessed to be given a high weight factor. It was at the same time, however, considered that fire response activities in the Goaso area will probably include discovery, report and dispatch and not modern firefighting techniques. The fighting technique is still done by means of fire beating using the local flora and few unsophisticated tools. The response risk submodel was therefore given a value of 2. The detection risk submodel, although important, does not really serve the purpose unless special arrangements for detection, watch and communication are available. It was realistic not to provide weight factor to the detection risk submodel. The MapCalc operation was done using (1) and the value map obtained reclassified using Table V.

TABLE V
RECLASSIFIED VALUES FOR THE FINAL FIRE RISK MAP

Reclassified Value Ranges	**Class Name**
0 – 8	Minimum fire risk
9 – 12	Low fire risk
13 – 16	Moderate fire risk
17 – 20	Medium fire risk
21 – 24	Medium high fire risk
25 – 28	High fire risk
29 – 32	Very high fire risk
33 – 36	Maximum fire risk

IV. RESULTS AND DISCUSSIONS

The results obtained from the study are discussed in the following sub-sections. The results of each of the sub-models and the final fire risk hazard map have been presented along with the area statistics for each.

A. Land Cover Map of the Study Area

Available satellite data of the study area obtained from the forestry commission was used for preparing the fuel risk sub-model. In order to ascertain the accuracy of the cover maps (Fig. 5) obtained, field validation was done to match the cover types.

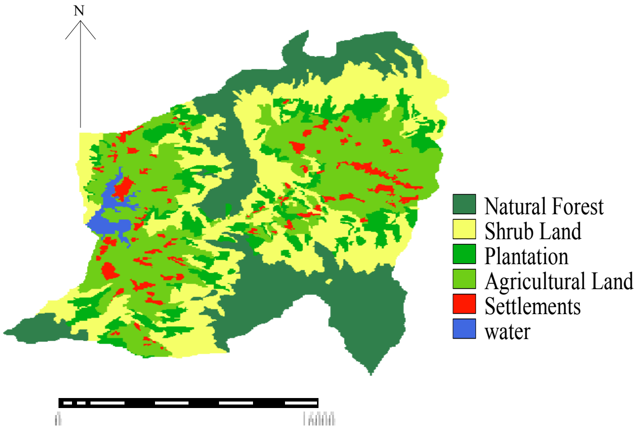

Fig. 5 Land Cover Map of Area

TABLE VI
AREAS OF THE LAND COVER TYPES

Cover Type	**Area**	
	km^2	**(%)**
Natural Forest	58.28	26.88
Shrub Land	61.12	28.19
Plantation	24.07	11.10
Agricultural Land	63.46	29.27
Settlement	5.90	2.72
Water	3.97	1.83
Total Area	216.79	100.00

It was detected that agricultural land forms the major land cover type in the area with 63.46 km^2 representing 29.27% of the total area under study (Table VI). Natural forest which is 58.28 km^2 representing 26.88% is found mainly at the outskirt of the area while settlement occupies a total area of 5.90 km^2.

B. Fuel Risk Sub-Model

The fuel risk map generated (Fig. 6) shows the various areas with the minimum to maximum possibility of fire spread with respect to the land cover type (Fig. 5). The area under medium to maximum fuel risk covers approximately 176.96 km^2 representing 81.63% (Table VII) of the study area. Fuel load is a significant factor in its contribution to the fuel risk zones. A spatial visual analysis between the forest cover type map (Fig. 5) and the Fuel Risk map (Fig. 6) also support the reasoning that areas under natural forest correspond to maximum Fuel Risk zones. Minimum to low fuel risk are mainly found around settlement and water bodies since they have least fuel load.

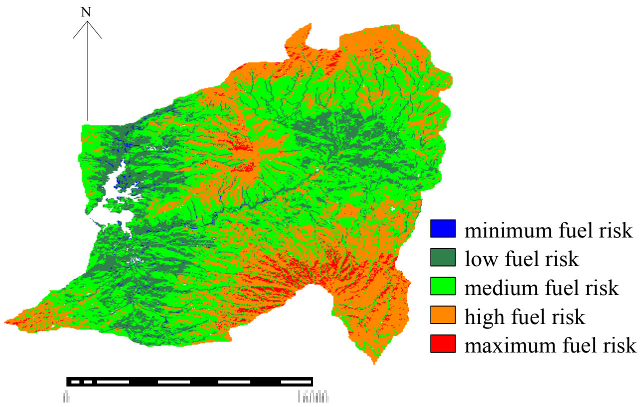

Fig. 6 Fuel Risk Map

TABLE VII
AREAS OF FUEL RISK SUB-MODEL

Risk Level	**Area**	
	km^2	**(%)**
Minimum Fuel Risk	2.00	0.92
Low Fuel Risk	37.82	17.45
Medium Fuel Risk	101.08	46.63
High Fuel Risk	71.01	32.76
Maximum Fuel Risk	4.87	2.25
Total Area	216.79	100.00

C. Response Risk Sub-Model

The response risk map (Fig. 7) was generated by estimating the total friction from the land cover, slope, elevation and the location of the fire service. One pertaining to the response resistance risk map considering factors such as land cover type, slope and elevation where factors which would resist movement of fire control were also considered and the other is the response distance map considering road types, settlements and vegetation types which would weigh the risk in terms of distance from the headquarters of the fire service to the point of fire. These maps were then combined using the Raster Calculation facility in ArcGIS resulting into a fire response risk map. Majority of the area falls under moderate to very quick response risk and constitute a total area of 206.61 km^2 being 95.30% of the study area (Table VIII). These areas are evenly spread out across the entire study area and are predominately agricultural land as well as settlements with good road types. Slow to very slow response risks occupy the outskirts of the study area which is predominately natural forest. This can be attributed to rugged terrain, high elevations and undulating topography due to which the response time towards fire may be enhanced.

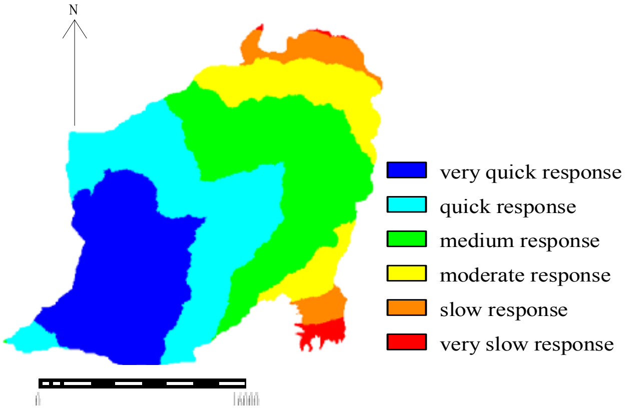

Fig. 7 Response Risk Map

TABLE VIII
RESPONSE RISK SUB-MODEL

Response Levels	Area	
	km^2	(%)
Very Quick Response	48.34	22.30
Quick Response	51.35	23.69
Medium Response	83.90	38.70
Moderate Response	23.02	10.62
Slow Response	5.19	2.40
Very Slow Response	4.97	2.29
Total Area	216.79	100.00

D. Detection Risk Sub-Model

In the case of the detection risk map (Fig. 8), visual (view shed) analysis (to identify visible and invisible areas from certain viewpoints) was done using the DEM, roads and settlement maps as input maps since majority of people who are likely to see fires, will be in the community or on a road or may be on a high land. It was evident that the view/visibility gets significantly reduced due to obstructions from forest cover types. Detection risk corresponds to the risk generated due to early or late detection of the fire. If the fire is detected early there are better chances of combating it. Detection on the other hand has a direct correlation to visibility, which was addressed by viewshed analysis spatially. In all visible areas constitute a total area of 182.76 km^2 representing 84.30% (Table IX).

E. Final Fire Risk Hazard Model

The resultant map (Fire Risk Hazard Map) was generated as a combination of all the sub-models (Fuel Risk, Detection Risk and Response Risk) developed using appropriate weights depending upon their risk priority (Fig. 9). The medium to maximum fire risk are found mostly in the north-eastern and the south eastern portions of the study area and constitute a total area of 149.50 km^2 representing 68.96%. A careful comparison of the land cover map (Fig. 5) and the final forest fire risk map (Fig. 9) reveals that the maximum fire risk areas consist mainly of natural forest. The vegetation cover here is moist semi-deciduous high forest zone and thus has a high oxygen content which contributes greatly to fire spread. Forest fire have been the cause of degradation in especially the moist semi-deciduous forest zone and dry semi-deciduous fire zones in recent years [10]. The maximum fire risk observed could also be due to the differences in elevations as low lying areas are prone to fire than highlands; the distance from the fire scene to the rescue station which is an important factor in the control and suppression of fire outbreak of the study area. Another significant reason that could lead to the high risk levels may be the ability for a fire to be detected. An invisible fire would be difficult to detect. A fire outbreak far away (as is in this case) from the fire station would blaze up for quite a longer time because of the barriers that are likely to be encountered on and off road.

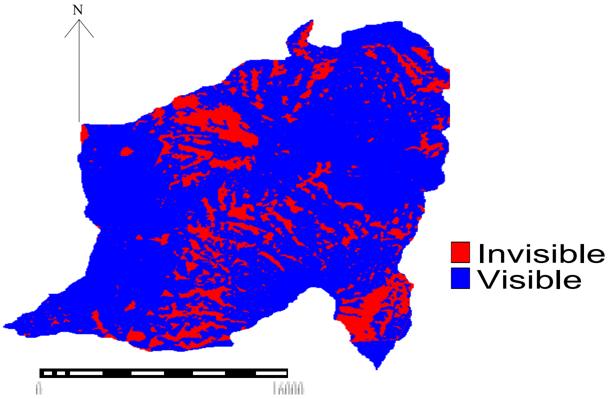

Fig. 8 Detection Risk Map

TABLE IX
DETECTION RISK AREAS

Detection	Area	
	km^2	(%)
Invisible	34.03	15.70
Visible	182.76	84.30
Total Area	216.79	100.00

Minimum to moderate fire risk are predominately in the central and southern portions of the study area and constitute 67.29 km^2 being 31.04% (Table X) of the total area under study. The minimum fire risk levels were mostly dominated by settlements and water bodies. Although houses can burn, there are usually some people in the vicinity to stop the fire. The moderate fire risks observed were predominately agricultural lands. This could be due to the belief by some farmers that better yields are obtainable from spots where heaps for stubble are burnt. Others also believe that bushes habour evil or provide cover for wild animals that can only be flushed out with fire. Hunting, charcoal production and inefficient logging practices have been identified as major causes of wild fires, threatening the survival of the forest especially drier forest in the country [10]. Inefficient logging practices have compounded the problem making the forest more susceptible due to the heavy fuel loads from logging residues which become more combustible in drier conditions. Reference [10] cautioned that the continued exploitation of timber and the reluctance of the Forest Services Division to reduce timber yield in the fire prone areas are major challenges in dealing with forest fire in the country.

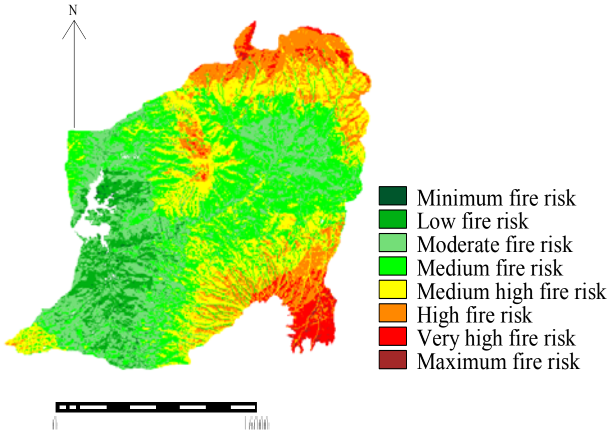

Fig. 9 Forest Fire Risk Hazard Map

TABLE X
FOREST FIRE RISK HAZARD AREAS

Risk Level	Area	
	km^2	(%)
Minimum Fire Risk	0.62	0.29
Low Fire Risk	17.78	8.20
Moderate Fire Risk	48.89	22.55
Medium Fire Risk	67.98	31.36
Medium High Fire Risk	52.13	24.05
High Fire Risk	28.83	13.30
Maximum Fire Risk	0.56	0.26
Total Area	216.79	100.00

V. CONCLUSIONS

From the analysis of this study, the following conclusions are made:

- The land cover types within the area are predominately agricultural land, shrub land and natural forest representing 29.27%, 28.19% and 26.88% respectively.
- A fire risk model based on fuel risk, detection risk and response risk with reasonable accuracy has been developed using remote sensing and geographic information systems techniques.
- A steeply slopping area, areas facing the sun, low lying areas and locations such as natural forest far from the fire station were revealed generally to be more susceptible to fire.
- Finally, a novel forest fire risk methodology has been developed to generate map that will assist decision makers and inhabitants of the GFA to know where there is the highest possibility for fire outbreak and to manage not fires but the factors leading to fire.

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