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Research Article

Multi-Spatial Criteria Modelling of Fire Risk and Hazard in the West Gonja Area of Ghana

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Abstract: About 30% of the West Gonja Area (WGA) of Ghana is occupied by three major forest reserves, which have rich array of plants and animals. The ecosystem in the WGA has been experiencing changes as a result of activities such as lumbering, farming, poaching and ritual bush burning as well as wildfire. Of particular concern is wildfire which has devastating effect on the ecological system and the rural livelihood in the WGA. Therefore, prevention and control of wildfire in the WGA is important to the sustainability of the natural resources. This paper uses multi-spatial criteria technique to model fire risk and hazard in order to enhance the WGA ability to prevent and control wildfires in the fragile ecosystem. The input data included: topography (slope, elevation, aspect); vegetation (fuel quality, fuel size and shape); weather (rainfall, temperature, humidity, wind); land cover/use map; landform; accessibility data; fire history; culture; and population density of the WGA. Fuel risk, detection risk and response risks were modeled and used as inputs to model the final fire risk and hazard for the WGA. From the model, forest, agricultural lands and shrubs cover types were identified as the major fuel contributing loads whereas water bodies, roads and settlements were considered as minor fuel contributing loads. Steeply sloping areas, areas facing the sun, low lying areas and long distances of forests from the fire service stations were found to be more susceptible to fire. The fire risk and hazard model will assist decision makers and inhabitants of the area to know where there is the highest possibility for fire outbreak and adopt prudent ways of preventing, and managing incidences of, wildfires in the WGA.

Keywords: Hazard, multi-spatial, risk

INTRODUCTION

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. Wildfires eradicate forests, burn the infrastructure and may result in high human death toll near urban areas. Wildfires are inevitable companions of forests and foresters across the world.

The spread of wildfire revolves around four main factors:

(a) The state and nature of the fuel, i.e., proportion of live or dead vegetation compactness, morphology, species, density, stratification and moisture content
(b) The physical environment, i.e., weather conditions and topography
(c) Causal factors (human-or naturally-related)
(d) Prevention and suppression means

Fire hazard is defined by both (a) and (b) and has two types of variations: a spatial and long-term one, related to fuel types and topography and a temporal and short-term one, related to fuel moisture content and weather conditions, whereas fire risk accounts for (c) and (d) (Chuvieco and Martin, 1994). It is pertinent to point out that the road network within the forest acts as man-made fire line. Simultaneously the road network also enhances the approachability within the forest areas thus making it more prone to fire incidence.

The issue of wildfire 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 origins have been affecting the forest ecosystems in the country adversely. The natural fire regimes have been altered and the ecosystems are no more natural but biotically disturbed leading to irreversible damage. For example between 1984 and 1985, Ghana had a total of 1005 incidence of wildfires, with the Northern Region recording 145 representing 14.43% of the reported cases (Gyabaah, 1997). Although wildfires 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 affecting the environment compared to

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tropical deforestation and desertification which have received considerable attention in environmental discussions. Like many hazardous phenomena, which occur occasionally, wildfires which appear as headlines in mass media reports during the dry season seem to b forgotten when the risk disappears with the onset of the rains. Consequently, there is very little in the form of published data and information concerning early detection, preventive measures, the frequency, intensity, duration and effects of wildfire on the environment and human welfare in Ghana (Gyabaah, 1997). The effects of wildfire on rural livelihoods and on the ecosystem in Ghana are increasingly becoming extensive and damaging. However, it has been difficult to reduce or completely eliminate wildfires due to the fact that in some cases fires are part of the forest ecosystem and they are important to the life cycle of indigenous habitats. The increasing biotic pressure on the forests due to increased resource dependency has led to the manifold increase in fire incidence. 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. The difficulties of eliminating wildfires completely means that there is the need for a clear modelling of forest fire risk hazard and its effects with respect to forestry, arable agriculture, soil and wildlife conservation. Such a 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 on the linkages between wildfires and ecological systems goes back to the early discovery which indicated that natural disturbances were a recurrent phenomenon in ecosystems and, as such, required an understanding of their effects on ecosystem structure and function. However, connecting wildfires to ecological systems has proceeded slowly. This is probably because forestry and ecology, the two fields primarily interested in effects of wildfires on ecosystems, have been side-tracked by their traditional approach to studying ecological systems. Foresters are mostly interested in extinguishing or eliminating wildfires 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. The approach that has been taken to investigate these issues, has, in general, involved describing patterns of fire effects and correlation of 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 wildfires in the fragile ecosystems which are threatened by drought and desertification.

Preventing a small fraction of these fires would account to significant savings in the natural and human resources of Ghana. Apart from preventive measures, early detection and suppression of fires are means to minimise 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 (Fleming and Robertson 2003).

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 (Breejen *et al*., 1998; Khrt *et al*., 2001). 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 may not be cost effective; 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 fire risk and hazard spatially using Remote Sensing and Geographic Information Systems approach in order to enhance the country's ability to prevent, control and completely eliminate wildfires in fragile ecosystems.

THE STUDY AREA

The study area is the WGA, which comprises Central Gonja and West Gonja Districts. WGA is located in the Northern Region of Ghana. It lies on longitude $0°45^1$ and $2°15^1$ West and Latitude $8°32^1$ and $10°02^1$ North (Fig. 1) It shares boundaries in the north with the Tamale Municipality, the Kintampo North District of the Brong-Ahafo Region in the south, East Gonja District in the East and Sawla-Tuna-Kalba District in the West. The WGA has total land area of 17 570.64 Km^2. This represents about 24% of the total land area of the Region (Anon., 2011). Temperatures are generally high with the maximum (42°C) occurring in the dry season, between March/April and are lowest (18°C) between December/January. The mean monthly temperature is 27°C. The dry season is characterised by the Harmattan wind, which is dry, dusty and cold in the morning and very hot at noon. Evapotranspiration is very high (1690-1695 mm), causing soil moisture deficiency. Humidity is very low, causing dry skin and cracked lips to people.

The mean annual maximum and minimum relative humidity values are 85% and 52%, respectively. The

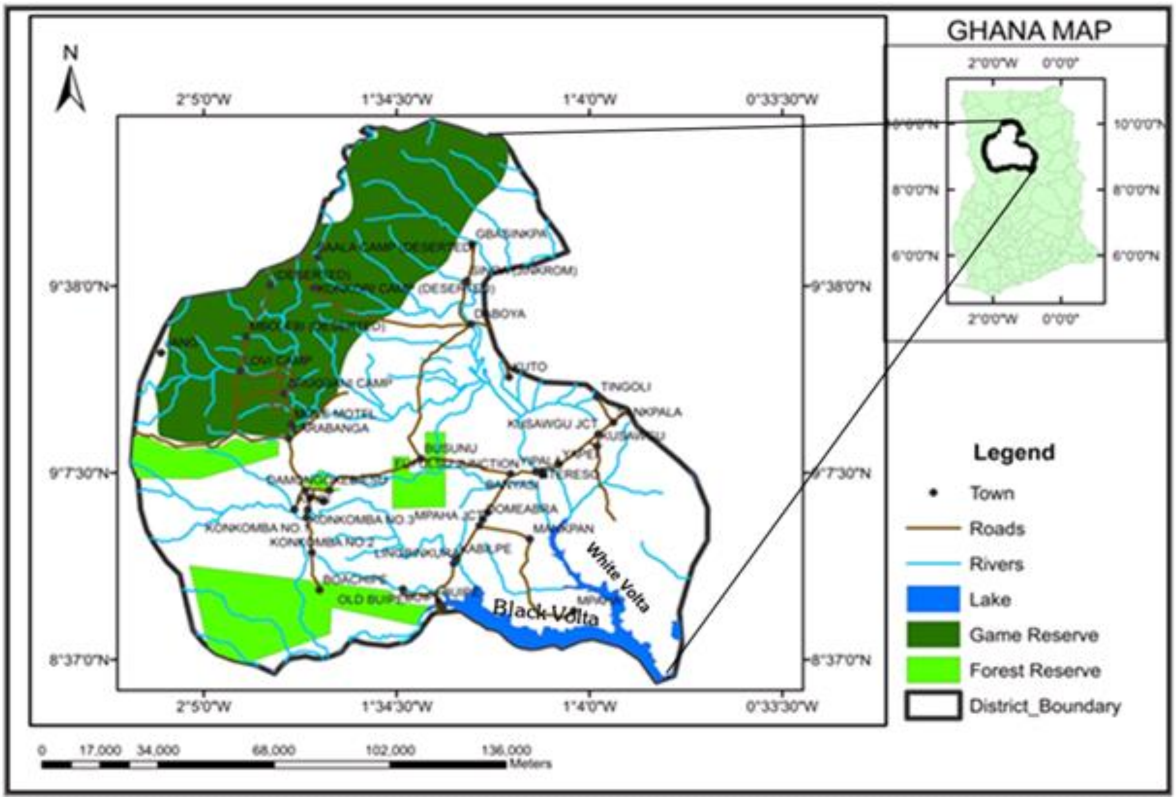

Fig. 1: Map of West Gonja Area (WGA)

climate is influenced by the movement of two air masses: Northeast Trade Winds and the Southwest Monsoons (Anon, 2008; Dickson and Benneh, 2004). These air masses converge at the inter-Tropical Boundary (ITB) which, depending on the season, determines the rainfall pattern over the WGA.

MATERIALS AND METHODS

The Materials and methods employed in this paper are discussed in the following sections.

Materials: The datasets used for the modelling of fire risk and hazard in WGA included: land use/cover map of WGA from satellite image downloaded from the internet; a digital topographical map of WGA at a scale of 1:50 000 from the survey and mapping agency of Ghana; coordinates of selected road intersections as well as the location of the headquarters of the fire service department. Garmin hand-held GPS 62cxs was used for mapping. Weather data was obtained from the meteological service department. All maps were generated using ILWIS and ArcGIS softwares.

Methods: The fire risk model (Fig. 2) was calculated using three sub-models namely, fuel risk sub-model, view exposure risk sub-model (detection risk) and response risk sub-model.

The variables (data layers) chosen for the creation of the sub-models, were comprehensively recognised as

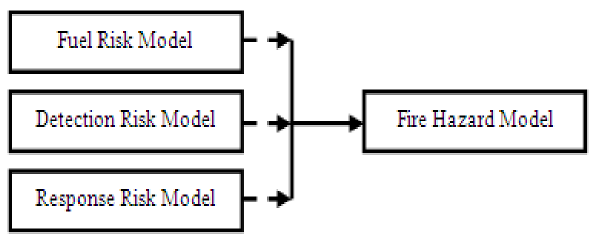

Fig. 2: A flow chart of the fire hazard model

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.

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 head quarters of the fire service department. Finally, these sub-models were combined; assigning proper weight

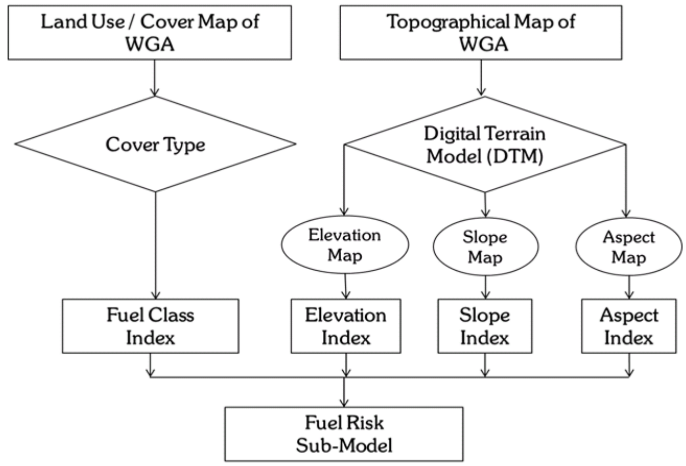

Fig. 3: Flow chat of the fuel risk sub-model

factors evaluated using pairwise comparison method to get to the fire risk model.

- **Evaluation of weights using pairwise comparison method:** There are several methods of assigning weights to evaluation criteria. This include: Ranking Method, Rating Method, Pairwise Comparison Method and Trade-Off Analysis Method.
  This study adopted pairwise comparison method in evaluating weights for the various criteria (fuel risk, slope, aspect and friction types). Inverse ranking (least important = 1to most important = n) was initially used to assigned weights before using pairwise comparison method. The pairwise comparison method was developed by Saaty (1980), in the context of the Analytic Hierarchy Process (AHP). This method involves pairwise comparisons to create a ratio matrix.
  It takes as an input the pairwise comparisons and produces the relative weights as output. Specifically the weights determined by normalising the eigenvector associated with the maximum eigenvalue of the reciprocal ratio matrix. The weights are evaluated by the following three steps:

  - Development of the pairwise comparison matrix.
  - Computation of criterion weights.
  - Estimation of the consistency ratio.

The weights are usually normalised to sum to 1. In this case of n criteria, a set of weights is defined as:

$$W = (w_1, w_2, w_3, \ldots, w_n) \text{ and } \sum w_i = 1 \quad (1)$$

The weights were manually computed from the various comparison matrices. As a means of validation; a spreadsheet program written by Goepel (2012) was also used to compute for the weights. Based on the weights obtained, the Consistency Ratios (CR) for various criteria were calculated and found to be less than 0.10 ($CR<0.10$). This ratio indicates a reasonable level of consistency in the pairwise comparisons; if, however, $CR \geq 0.10$, the values of the ratio are indicative of inconsistent judgments. In such cases one should reconsider and revise the original values in the pairwise comparison matrix (Jacek, 1999).

Pairwise comparison method has been tested theoretically and empirically for a variety of decision situations, including spatial decision making and it has proven to be effective (Jacek, 1999).

The organisation of data and methods used for the production of all the sub-models are discussed in the following subsections.

- **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. 3).
  The following conditions were taken into account:
  - Certain fuel types (tree species or grasses) burn easier than others do. Example a forested area will burn easier than a moist area of agricultural land.
  - 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.

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. 1). A very flammable area was assign 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

Table 1: Fuel risk types and corresponding fire risk values

Class Name	Fire risk value	Cover type
No fuel risk	0.13	Road and water
Very low fuel risk	0.14	Settlement
Low fuel risk	0.15	Agricultural land
Moderate fuel risk	0.17	Shrub land
High fuel risk	0.19	Plantation
Very high fuel risk	0.22	Natural Forest

Table 2: Slope types and corresponding fire risk values

Slope type (S)	Class name	Fire risk value
Flat to gently slopping (S≤ 5˚)	Low	0.19
Slopping (15°≤ S>5°)	Moderate	0.21
Moderately steep (30°≤ S>15°)	High	0.25
Very steep (90°≤ S>30°)	Very high	0.35

Table 3: Aspect types and corresponding fire risk values

Aspect type	Class name	Fire risk value
West	None	0.13
North-West	Very low	0.14
South	Low	0.15
South-West	Moderate	0.17
North	High	0.19
North-East	Very high	0.22

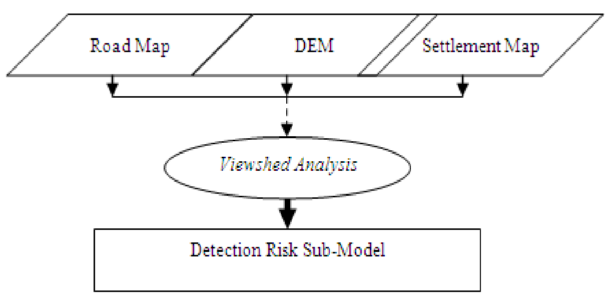

Fig. 4: Flow chart of detection risk sub-model

index and a natural forest a high risk index (Table.1). The Pairwise comparison matrix was developed and the weights evaluated and validated.

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 (Rathaur, 2006). 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. 2).

Aspect, the direction in which a slope faces, also relates to the amount of exposure of the slope to the sun. 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 more moist 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. 3).

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.

- **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 viewshed 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. 4).
- **Response risk sub-model:** Fire response (Fig. 5) 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 (Rathaur, 2006). Response to a fire situation is further subjected to two considerations i.e., transport surface and friction offered. Thus in this study, these two

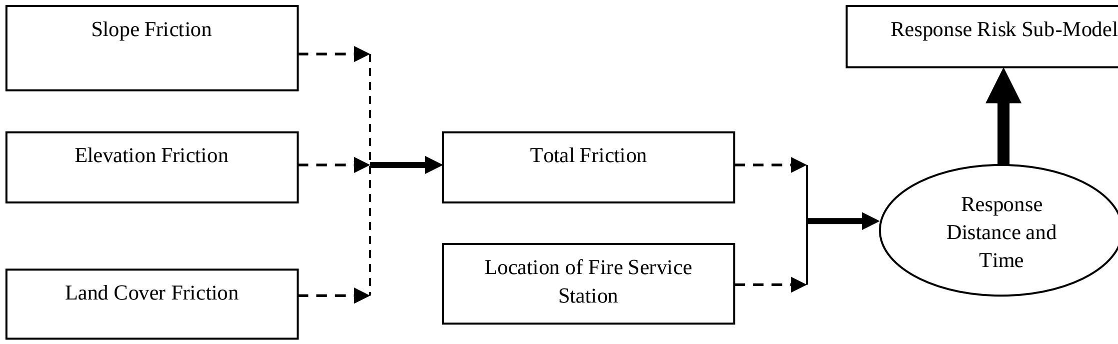

Fig. 5: Flow chart of the response risk sub-model

Table 4: Friction (difficulty of travel) of different land cover types

Land cover type	Class name	Friction value
Road	No friction	0.06
Settlement	Very low friction	0.07
Agricultural land	Low friction	0.08
Shrub land	Moderate friction	0.11
Plantation	Medium friction	0.15
Natural forest	High friction	0.26
Water	Very high friction	0.27

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.

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.

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 (Table 4).

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. 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 head quarters of the fire department. This is due to the fact that a normal distance calculation from the head quarters 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 head quarters 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.

- **Fire risk model (final):** The final fire risk and hazard model was generated through the addition of the fuel risk, detection risk and the response risk models (Fig. 4 to1) in a logical sequence using the following equation:

$$FFRM = (0.66x\ FRS)+(0.19x\ RRS)+(0.15x\ DRS)$$

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

It was done in the *MapCalc* facility of ILWIS. The sub-models weights were evaluated and compared with literature on the risk priorities of the sub-models. From fire behavioral point of view, the fuel risk sub-model is the most significant in terms of hazard area identification. Evaluated weight for the fuel risk was 0.66. The response risk sub-model, 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 WGA area will probably include discovery, report and dispatch and not modern fire fighting techniques. The fighting technique is still done by means of fire beating using the local flora and few unsophisticated tools. The weight evaluated for response risk sub-model was 0.19. The detection risk sub-model, although important, does not really serve the purpose unless special arrangements for detection, watch and communication are available. It was realistic that the weight for the detection risk sub-model was the lowest (0.15). The MapCalc operation was then used to carefully combine the sub-models to obtain the final fire risk and hazard model.

RESULTS AND DISCUSSION

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 and hazard model have been presented.

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. 6) obtained, field validation was done to match the cover types.

Fuel risk sub-model: The fuel risk map generated (Figure 7) shows the various areas with the minimum to high possibility of fire spread with respect to the land cover type (Figure 6). One of the main reasons for this can be due to the high area under natural forest, Agricultural land and shrubs which cause high fuel load in the 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 (Figure 6) and the Fuel Risk map (Figure 7) also support the reasoning that areas under natural forest correspond to medium to high fuel risk zones. Minimum to low fuel risk are mainly found around settlement and water bodies since they have least fuel load.

Response risk sub-model: The response risk model (Fig. 8) was arrived at by generating two sub models. One pertaining to the response resistance risk model 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 model considering road types, settlements and vegetation types which would weigh the risk in terms of distance from the head quarters 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 model. Majority of the area falls under moderate to medium response risk. These areas are evenly spread out across the entire study area and are predominately agricultural land, forest as well as settlements with good road types. Low to very low response risks occupy the outskirts of the study area which is predominately forest. This can be attributed to rugged terrain, high elevations and undulating topography due to which the response time towards fire may be enhanced.

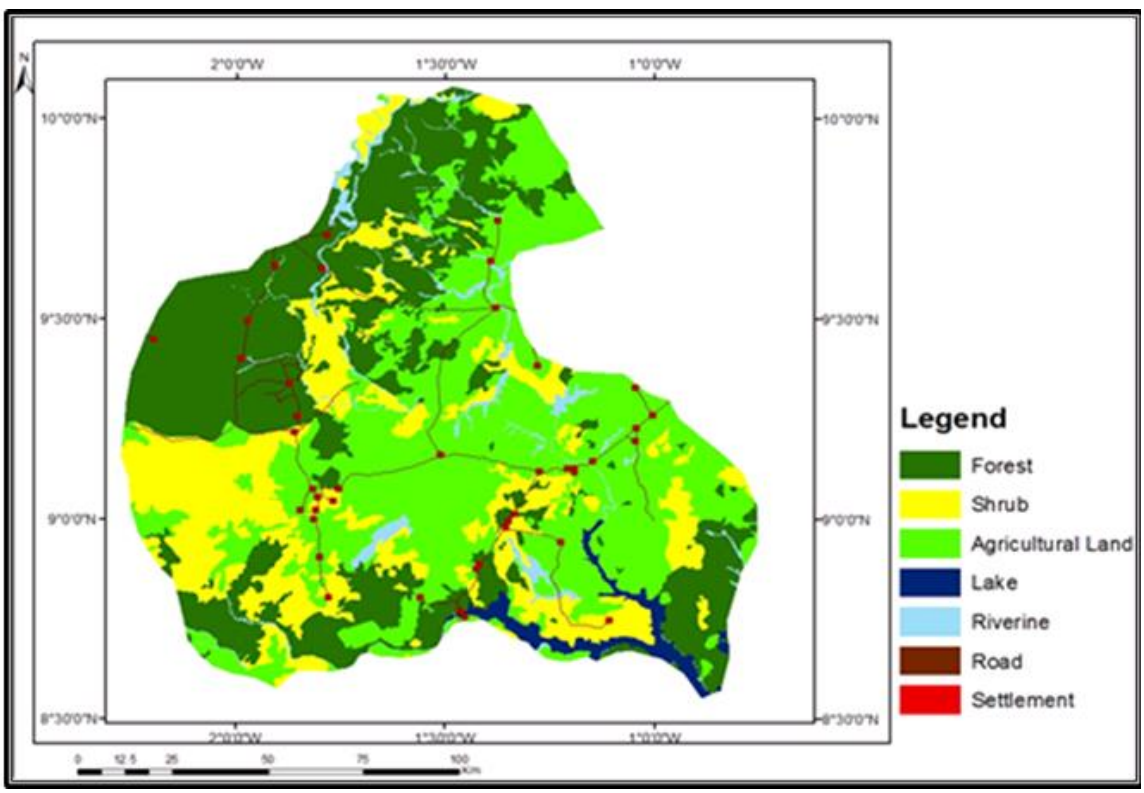

Fig. 6: Land cover map of area

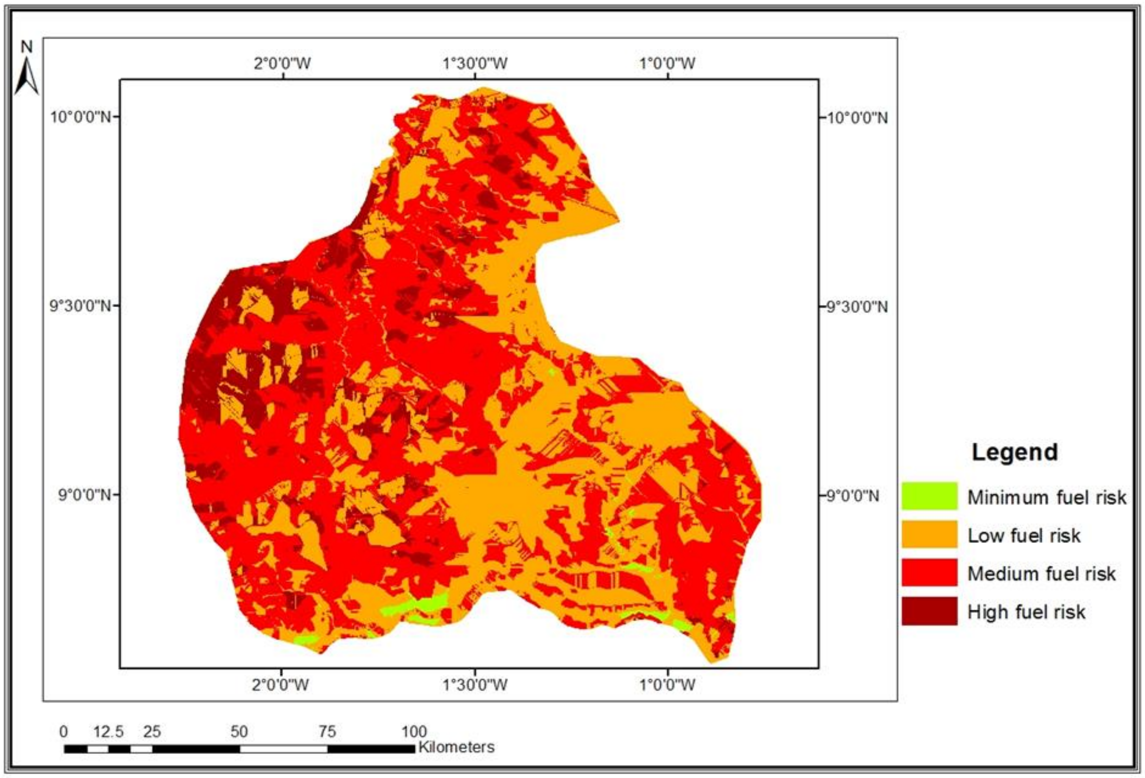

Fig. 7: Fuel risk model

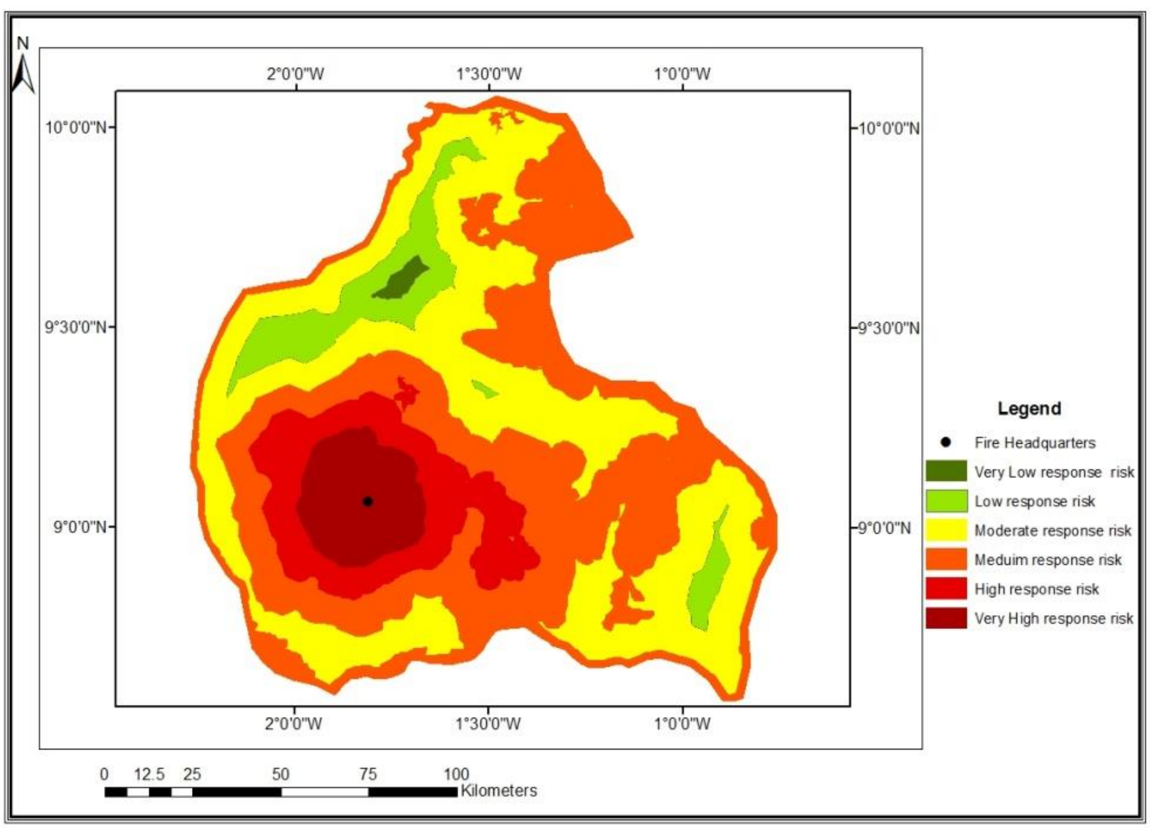

Fig. 8: Response risk model

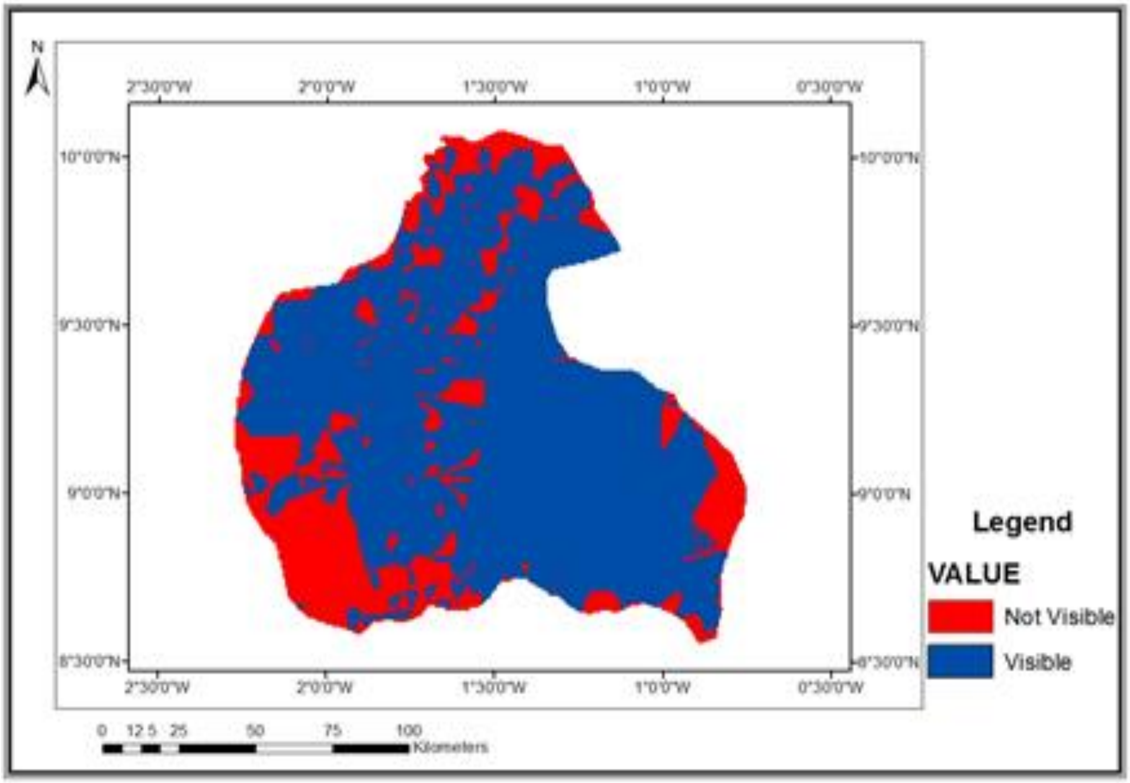

Fig. 9: Detection risk model

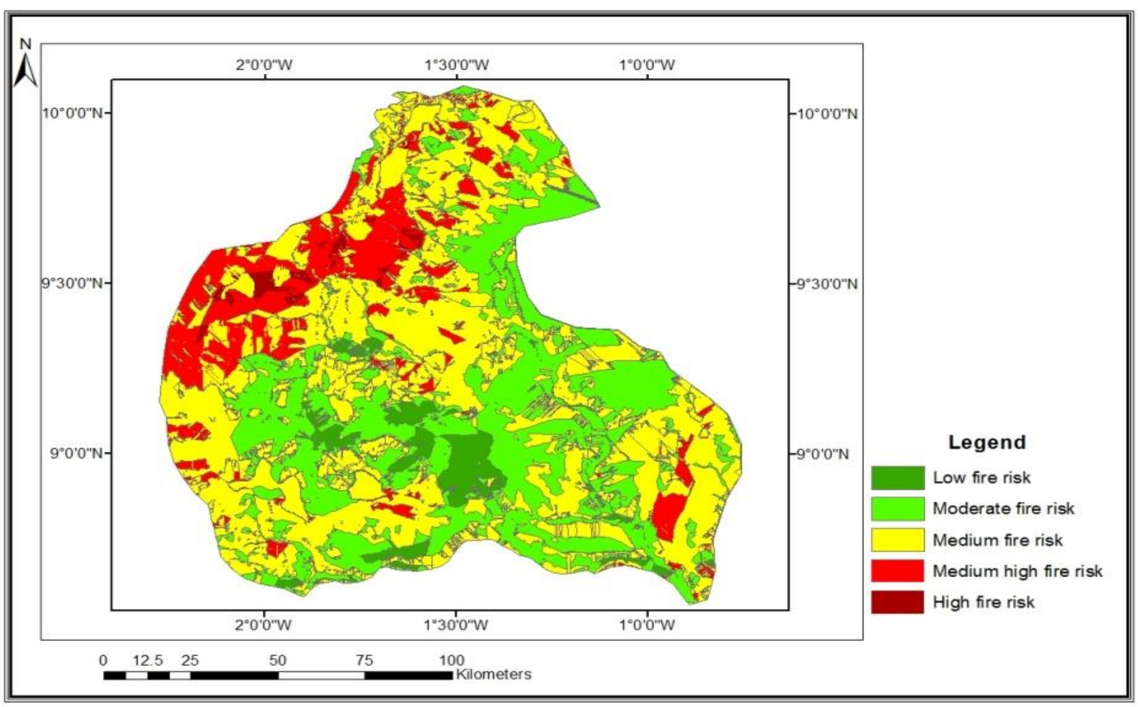

Fig. 10: Fire risk and hazard model

Detection risk sub-model: In the case of the detection risk map (Fig. 9), visual (viewshed) 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 get 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.

Final fire risk and 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. 10). The medium to maximum fire risk are found mostly in the north-eastern and the south eastern portions of the study area. Careful comparisons of the land cover map (Fig. 6) and the final fire risk and hazard model (Fig. 10) 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. Wildfires have been the cause of degradation in especially the moist semi-deciduous forest zone and dry semi-deciduous fire zones in recent years (Hawthorne and Abu-Juam, 1993). 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.

Low to moderate fire risk is 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 believe 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. 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. Hawthorne and Abu-Juam (1993), 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 wildfires in the country.

CONCLUSION

- In this study, land cover types within the area are predominately agricultural land, shrub land and natural forest representing. Natural forest, agricultural lands and shrubs cover types were identified as the major fuel contributing loads where as water bodies, roads and settlements were considered as minor fuel contributing loads.
- 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.
- Steeply slopping areas, areas facing the sun, low lying areas and distance of natural forests from the fire station were found to be more susceptible to wildfire.
- The fire risk and hazard model generated will assist decision makers and inhabitants of the area to know where there is the highest possibility for fire outbreak and adopt effective methods to prevent and control incidences of, wildfire.

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