Revista Brasileira de Cartografia (2014) N^0 66/7 - International Issue: 1551-1566
Sociedade Brasileira de Cartografia, Geodésia, Fotogrametria e Sensoriamento Remoto
ISSN: 1808-0936

METHODOLOGICAL DEVELOPMENT FOR FOREST FIRE HAZARD MAPPING IN NEPAL

Desenvolvimento Metodológico para o Mapeamento de Incêndio Florestal no Nepal

Nirmal Raj Sharma[1], Pedro José Farias Fernandes[2] & Jiba Raj Pokharel[1]

[1]Tribhuvan University
Institute of Engineering
Pulchowk Campus, Pulchowk, Lalitpur - Nepal
{er.nirsharma;jibaraj}@gmail.com

[2]Fluminense Federal University - UFF
Physical Geography Laboratory (LAGEF)
Av. Gen. Milton Tavares de Souza s/n -Instituto de Geociências - Niterói – RJ - Brazil
pj_fernandes@id.uff.br

Received on July 19, 2014/ Accepted on January 23, 2015
Recebido em 19 de Julho, 2014/ Aceito em 23 de Janeiro, 2015

ABSTRACT

In Nepal, annually due to uncontrolled forest fires, lots of valuable forests and biotic and abiotic resources are being destroyed. There is no effective and actionable forest fire hazard zoning map available in Nepal so far. The objectives of this research is to develop a methodology (equation) using Analytical Hierarchy Process (AHP) and incorporating the selected major parameters (chosen from a review of the literature) for forest fire hazard mapping in Nepal. The various parameters have roles in the forest fire; among them due to thorough literature reviews it was found that the most important parameters for the forest fire are land use/land cover types (forest types), proximity to roads (human interference), aspect, slope and elevation. These selected five parameters were obtained and reclassified in the scale of low to very high according to their potentiality for forest fire hazard. After that the use of well-known decision making process named, Analytical Hierarchy Process (AHP) was used and the pairwise comparison between these five parameters was done along with the assignation of values from 1 to 9 from the fundamental scale of AHP. The use of AHP provided the possible weightage for each of the five parameters and one equation for fire hazard mapping was developed using those coefficients. The equation so developed was used to make the forest fire hazard map for Nepal. The reliability of the model so developed was checked with the Active forest fire data obtained from National Aeronautics and Space Administration (NASA) from the date November 2000 to December 2013. Secondly the historical data series from an online portal for disaster information, named “DesInventar” have been used. The comparison of the fire hazard model equation so developed in the study showed correlation with the historical data of fire events from above mentioned two sources. The use of AHP and Geographic Information System (GIS) in this study clearly illustrates that these two tools can be used for the forest fire hazard mapping, and decision making process for forest fire hazard mapping in large scale with accuracy.

Keywords: Forest Fire, Analytical Hierarchy Process, GIS.

RESUMO

No Nepal, devido aos incêndios florestais, áreas de florestas, recursos bióticos e abióticos estão sendo destruídos. Não há nenhum mapeamento eficaz de zoneamento de risco ao incêndio florestal disponível até o momento no Nepal. Os objetivos desta pesquisa são desenvolver uma metodologia (equação), utilizando a técnica de Processo Analítico Hierárquico (AHP), e incorporar os parâmetros desencadeadores selecionados, escolhidos a partir de uma revisão da literatura, para o mapeamento de risco ao incêndio florestal no Nepal. Vários parâmetros têm papéis no incêndio florestal, entre eles, tipos de uso e cobertura da terra (tipos florestais), proximidade de estradas (interferência humana), orientação das encostas, declividade e altimetria. Estes cinco parâmetros selecionados foram obtidos e reclassificados na escala de risco, de baixo a muito alto, de acordo com sua potencialidade de risco de incêndio florestal. Depois, foi utilizada a técnica de tomada de decisão AHP, que estabelece uma comparação aos pares entre estes cinco parâmetros, pela atribuição de valores de 1 a 9, na escala fundamental da AHP. O uso da AHP forneceu os pesos para cada um dos cinco parâmetros, e uma equação para o mapeamento de risco ao incêndio foi elaborada usando estes pesos. A equação desenvolvida foi usada para mapear o risco aos incêndios no Nepal. A confiabilidade do modelo estabelecido foi verificada com dados de incêndios florestais ativos de novembro de 2000 a dezembro de 2013, obtidos a partir da National Aeronautics and Space Administration (NASA). Posteriormente, foi feita uma avaliação a partir da série histórica de dados do portal on-line de informações de desastres DesInventar. A comparação do modelo de risco obtido neste estudo mostrou correlação com os dados históricos de eventos de fogo acima mencionados das duas fontes. O uso da AHP e de Sistemas de Informação Geográfica (SIG) na pesquisa ilustra claramente que estas duas ferramentas são eficazes para o mapeamento de risco aos incêndios florestais, e no processo de tomada de decisão para mapeamento de risco ao incêndio florestal em escala regional com precisão.

Palavras chaves: Incêndio Florestal, Processo Analítico Hierárquico, SIG.

1. INTRODUCTION

Technically, fire is defined as the rapid combustion of fuel, heat and oxygen. All these three elements are in some proportion to start and spread fire. It is a chemical reaction of any substance that will ignite and burn to release a lot of energy in the form of heat and light (RAWAT, 2003). To start a fire an external source of heat is required along with oxygen. Heat is measured in terms of temperature. Fuel is any material capable of burning. In forests, fuels are vegetation, branches, needles, standing dead trees, leaves, and man-made flammable structures.

Thus, the forest fire can be defined as an uncontained and freely spreading combustion which consumes the natural fuels of a forest i.e. duff, litter, grass, dead branch, wood, snags, logs, stumps, weeds, brush, foliage and to some extent green trees (BROWN; DAVIS, 1959). The impacts of forest fires can have global consequences: forest fires also produce gaseous and particle emissions that impact the composition and functioning of the jet stream and the global atmosphere, exacerbating climate change (GOLDAMMER et al., 1997). Tropical forest destruction, through fire, could also spiral our weather systems in new and unpredictable directions (GALTIÉ, 1999).

Forest fire is one of the major disasters in the forests of Nepal. There are many indigenous and endangered species in the forests of Nepal, which are adversely effected due to these forest fires. As per historical forest fire events, it is clear that Nepal is prone to forest fires. However, not much work has been done by researchers for identifying the vulnerability zones for forest fire hazard in Nepal. Therefore, there is an immediate need to identify the prominent forest fire hazard zones for Nepal in order to solve the problem of forest fire. There is also a lacking of sufficient and technical expertise in the field of forest fire management and planning in Nepal, hence this research could be a novel topic for forest fire management strategy for Nepal.

Geographic Information Systems (GIS) has also developed functions such as analyzing available information and using them as a decision and a support system as well as it compiles the information as a whole and stores it. In that way, GIS analysis show the spatial distribution of the observed forest condition and also may help to find cause parameters for the observed – and classified – forest decline phenomena. The link between environmental factors and an efficient forestry GIS can therefore work as a tool for an operational and practically oriented monitoring system for forest damage assessment and management. It may play an important role as a planning tool for forest and land-use affairs in a broader sense (JAISWAL et al., 2002).

In this context, the Analytical Hierarchical Process (AHP) is a decision-aided method developed by Saaty (1990), and can be used in GIS analysis, as made by Setiawan et al. (2004). AHP aims at quantifying relative priorities for a given set of alternatives in a ratio scale based on the judgments of a decision maker as well as the consistency of the comparison of alternatives in the decision making process. This method has been forced to an effective and practical approach that can consider complex and structured decision. The AHP is proposed in this research in order to assess weights for various parameters influencing the forest fire. The weights have been decided following the analytical approach suggested by Saaty (1990). A spatial process model has been developed for the decision making.

Therefore, the objectives of this research is to develop a methodology (equation) using AHP and incorporating the selected major parameters (chosen from a review of the literature) for forest fire hazard mapping in Nepal.

2. LITERATURE REVIEW

The use of GIS techniques succeeds in fire hazard mapping applications. For example, in a case study of Golestan province, in Iran, for forest fire risk mapping using GIS in northern forests of Iran was conducted by Ghobadi et al. (2012). According to the study GIS can be used effectively to combine different forest-fire causing factors for demanding the forest fire risk zone map. Parameters that affect the fire such as topography, vegetation, slope, aspect, NDVI, meteorology factors were integrated within GIS with success.

Jung et. al. (2012) conducted a research at Kolli Hills, Tamil Nadu, India, using GIS based multi criteria analysis. The factors considered for fire risk analysis were mainly three categories: topographical factors (aspect and slope), fuel type factor (forest cover) and anthropogenic factor (roads and settlements). The factors were analyzed using AHP and GIS based method and the output map were compared and cross checked with the expert's opinion. Finally, the forest fire risk map for the study area was prepared.

Sharma et. al. (2012) studied forest at Shimla forest, India, using Fuzzy AHP method for the date obtained from Remote Sensing and GPS and analyzing it with GIS. The study used six variables: fuel type, elevation, slope, aspect, distance from road and distance from settlement and derived equations and eventually map to predict areas which might suffer from severe forest fire hazard.

Vadrevu et. al. (2009) evaluated fire risk over Andhra Pradesh, India, using Fuzzy AHP method. The study classified the forest fire hazard causing parameters broadly in to four categories: topography, vegetation, climate and socioeconomic. Within these four categories there were other sub-categories also. All of the variables in sub-categories were evaluated first using Fuzzy AHP method, and then weightage calculation for the four categories was done in order to derive potential fire risk zone in the district level. The output fire risk map was cross checked with the satellite driven fire patterns with varying accuracy.

A work for integrating biophysical characters, microclimate and human factors for forest fire risk modeling, in Dhaulkhand range of Rajaji National Park, India was conducted by Saxena and Srivastava (2007) and developed a risk model. The study used the variables such as weather data, fuel conditions and human activity within the area of study. The authors integrated remote sensing data of IRS LISS III for generation of fuel map with GIS for generation of topographical gradients. The model made the use of Normalized Difference Vegetation Index (NDVI) as an input values for calculating the Relative Greenness, meteorological data for estimating the Dead Fuels Moisture Content, and a Fuel Map to estimate the fuel loads. The major fire parameters selected for fire hazard modeling were fuel variable, slope, aspect, distance to roads and distance from settlements. The weightage to each variable was given based upon subjective judgments and their potential for fire hazard. An equation was generated to calculate the fire risk index.

The model so generated was validated with the historical data of fire occurrence and it was highly correlated.

A research on fire risk assessment using satellite data in the Tenerife Island, Spain was developed by Leal et al. (2006). The parameters (thematic variables) selected for the study were slope, altitude, insolation (aspect), proximity to roads, vegetation cover and fire statistics. The integration in GIS of multiple variables related to fire risk, in different thematic layers as mentioned above generated a static index introduced as the Fire Risk Static index (FRSI).

A study with GIS-grid-based and multi-criteria analysis for identifying and mapping peat swamp forest fire hazard in Pahang, Malaysia was conducted by Setiawan et al. (2004). The study selected five variables: land cover (vegetation), distance to road, aspect, slope and elevation which were major responsible for forest fire hazard. The study used the Analytical Hierarchy process (AHP) to compare the weights of each variable and calculated a hazard equation. Combining elevation, dangerous topographic features, slope, aspect, and fuel type into one raster data set accurately the study classified the danger of forest fire hazards in the area.

Hai-wei et. al. (2004) studied forest fire at Yuying and Fendou forest farms, Tuqiang, China, using remote sensing date, GIS and AHP method in order to calculate the forest fire risk model. The research used five variables: vegetation types, distance from settlements, slope, altitude and aspect. The variables were classified internally as per their potential to create forest fire, and coefficient for each variable was calculated using AHP and one forest fire risk equation was developed. The equation so developed was used to make fire risk map with the aid of GIS software. Finally, the outcome map was cross-checked with the fire intensity map and was matched with high degree of accuracy.

Jaiswal et al. (2002) conducted research on forest fire risk zone mapping from satellite imagery and GIS in Gorna sub-watershed, located in Madhya Pradesh, India. The authors selected four variables responsible for fire hazard in that area: vegetation type, slope, proximity to settlements and distance from roads. Forest fire risk zones were delineated by assigning subjective weights to the classes of all the layers of four selected variables according to their sensitivity to fire or their fire-inducing capability using a hazard equation. The study found that almost 30% of the study area was predicted to be under very high and high-risk zones and the evolved GIS-based forest fire risk model of the study area was found to be in strong agreement with actual fire-affected sites.

A study on application of remote sensing and GIS to Forest Fire Hazard Mapping in the Mediterranean coast of Spain was conducted by Chuvieco and Congalton (1989); the work selected the five major parameters responsible for fire hazard: vegetation type, slope, aspect, distance to roads and elevation. The study generated a hazard equation with those factors. They made a comparison between the predicted hazard from the model and the actual burned area in the history and found that more than 22% of pixels with high hazard values in the whole study area were burned by the fire, while only 3.74% of those with low hazard values were actually burned.

Other research about the major forest fire types in 16 countries of Asia lying in tropical and sub-tropical regions was conducted by Goldammer (2000). Nepal was also one of the study areas and the study found that the tropical moist deciduous forest lying in Terai region of Nepal was most vulnerable to forest fire; secondly tropical wet evergreen *Pinusroxburghii* forest was also vulnerable.

3. STUDY AREA

The study area is Nepal, which is a small country located in South Asia with total area of 147 km² (Figure 1). It has the variation of the land from northern edge of the Indian Gangetic plain to the high Himalayan ridges bordering the Tibet region of China.

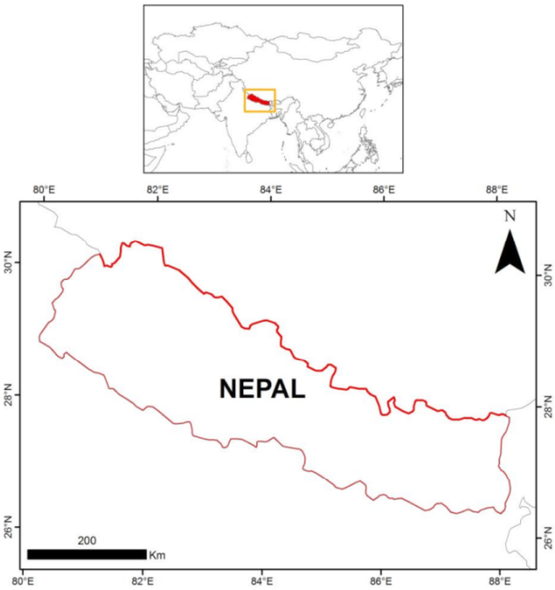

Fig.1 - Study Area (Nepal).

The country has topographic variation from 150 meters above sea level at the southern border to the highest mountain in the world (Everest at 8848 m) in the north. Due to the east-west orientation of the mountain ranges, the country has a tropical climate in the south and temperate and alpine climates in the north.

Forest fires occur annually in all the major physiographic/climatic regions of Nepal, including the Terai and Bhabar, the Siwaliks or the inner Terai, the Middle Mountains, and the High Mountains regions. The main causes of forest fires are anthropogenic due to negligence and occasionally by deliberate burning to induce succulent grass growth for domestic animals. Forest fires occur during the dry season from February to June and the nature (surface fire, crown fire, etc.) as well as the severity varies greatly depending upon fire weather, fuel conditions, and physiography. Once the monsoon is established, usually by the middle of June, the fire problem disappears. Forest fires destroy timber and non-timber forest products, although no data are available about the number of fires, severity and the amount of loss. Fires also reduce the biological diversity of the forests to a great extent. In addition, fires degrade the soil, inducing flood and landslide damage. Forest fires make the entire countryside hazy, thereby reducing aesthetic values for eco-tourism during the dry season (BAJRACHARYA, 2002).

4. MATERIAL AND METHODS

To reach the objective of the study, the methodology followed these steps in the flowchart below in Figure 2.

4.1 Material

Five parameters that are major responsible for forest fire hazard were found out: landuse/land cover (forest type), proximity to roads, aspect, slope and elevation. The land use/land cover data was downloaded from Global Land Cover Data and extracted for Nepal with the help of GIS. Similarly the digital elevation model (DEM) data developed by SRTM with spatial resolution 90 m was used for creation of aspect and slope map for Nepal. The use of road network data provided by International Centre for Integrated Mountain Development (http://www.icimod.org/) was used for calculation of proximity to road from forest area.

4.1.1 Forest Types

The forest category was taken from the land use map as presented in Figure 3 which was downloaded from Global Land Cover Facility developed by University of Maryland, USA under the finance of NASA and was downscaled from the dataset of South Asia to extract the data for Nepal using GIS software (Figure 3). Land use/land cover map so obtained classifies Nepal in to 24 different categories of land use. Land use/land cover has very important parameters for forest fire, the forest fire will be more prominent in the dense forest and where the leaves falling problem occurs during seasonal change. The forests growing in the dry weather are mainly susceptible to the frequent fire problems.

4.1.2 Proximity to Roads

Roads are an important factor in forest fire because their presence indicates human activity (JO et al., 2000). Trail and road locations are also important factors in fire hazard mapping. Two major effects can be considered. First, roads can serve as fire breaks or as pathways for the suppression of fire. In this sense, they are a factor which reduces fire hazard. Second, they are potential routes to hiking or camping areas. In this context, they increase the hazard of forest fire because of more intense human activity (CHUVIECO; CONGALTON, 1989) In this study, the road data was taken and all the roads were in Figure 4.

4.1.3 Elevation

Elevation influences vegetation composition, fuel moisture and air humidity. More than 90% of cases of forest fire occur at 100m above sea level. Most of these disasters take place in areas which are lower above sea level. Fires are less severe at higher elevations due to higher rainfall (CHUVIECO; CONGALTON, 1989). Two factors to consider are elevation above sea level and elevation changes in relation to the surrounding topography. It has been reported that fire behavior trends to be less severe at higher elevation due to higher rainfall. Step gradient increases the rate of fire spread because of more efficient convective preheating and ignition, and gradients facing east receive more ultraviolet during the day. As a consequence, eastern aspects dry faster (CHUVIECO; CONGALTON, 1989). The elevation map generated from DEM acquired by SRTM (Figure 5).

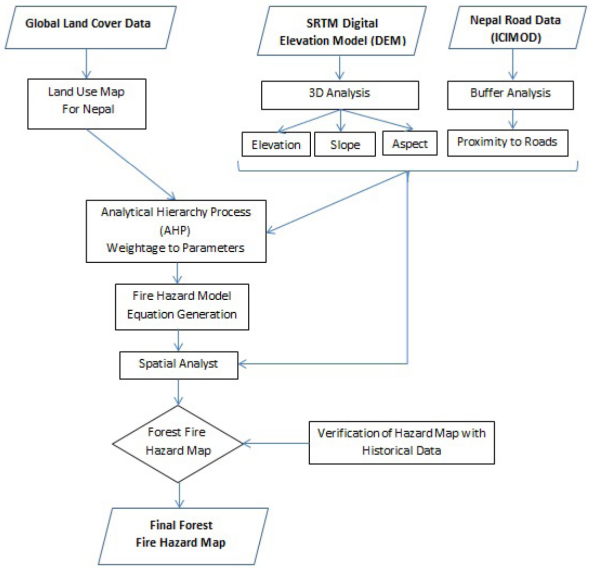

Fig.2 - The flowchart of activities.

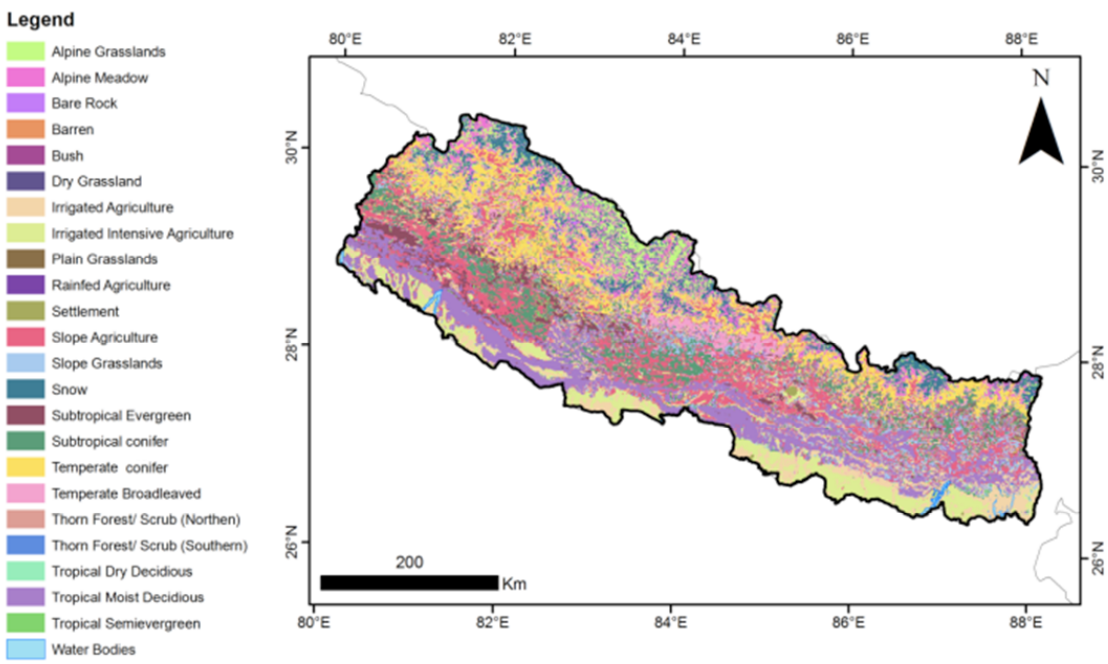

Fig. 3 - Land Use Classification of Nepal (Source: Global Land Cover Facility, USA).

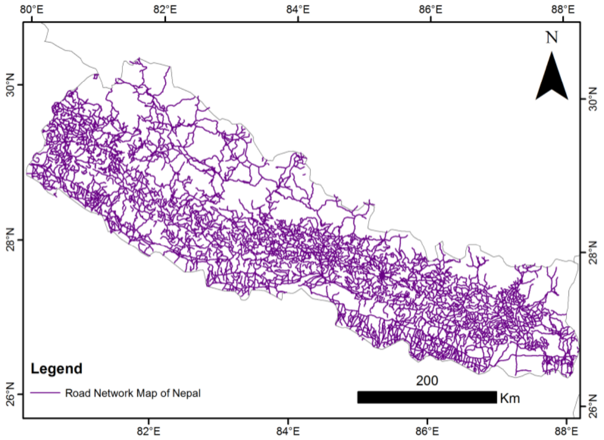

Fig.4 - Road Network Map of Nepal (Source: ICIMOD).

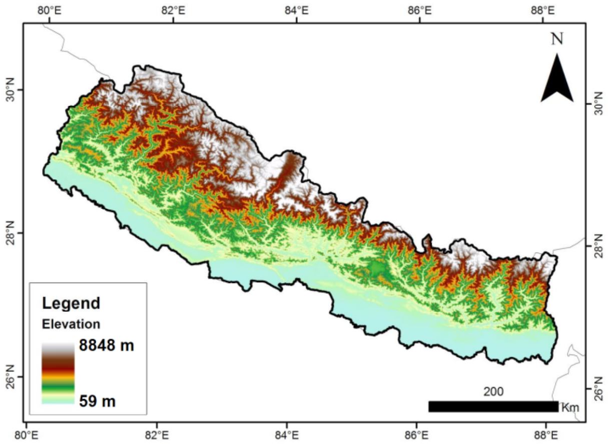

Fig.5 - Elevation Map of Nepal (Source: SRTM).

4.1.4 Aspect

Aspect is the direction the slope faces; i.e. its exposure in relation to the sun. Fire conditions vary dramatically according to aspect (Figure 6).

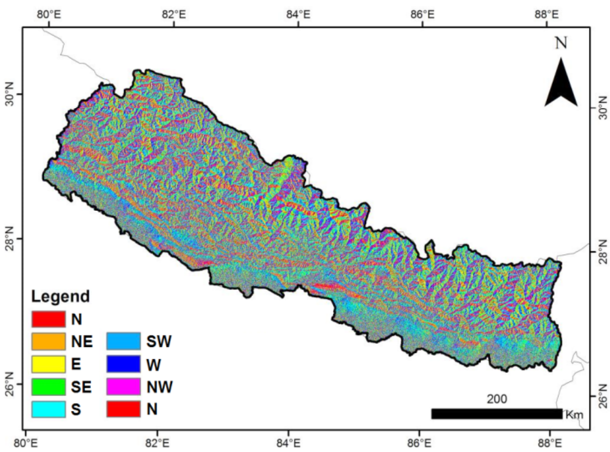

Fig.6 - Aspect Map of Nepal (Source: GIS enhanced data from SRTM).

In the north hemisphere, southern exposures suffer the greatest solar and wind influences, while northern slopes suffer the least. Generally, eastern aspects receive early heating from the sun and early slope winds, while western aspects receive late heating and transitional wind flows. Aspect is related to the amount of sunshine an area receives. In general, cases of forest fire occur more in areas of southern aspect than in areas of northern aspect, because areas of southern exposure have higher burning points (CHUVIECO; CONGALTON, 1989).

4.1.5 Slope

Slope is a critical factor in fire behavior, and aspect is clearly related to insulation and air humidity.

Typically, in the temperate zones of the northern hemisphere, south-facing slopes receive more solar radiation than north-facing slopes. Therefore South-facing slope are hotter, drier and pose greater fire hazards. More than 60% of forest fires happen on slopes of between zero and 20 degrees and in areas of southern and south western aspect (JO et al., 2000).

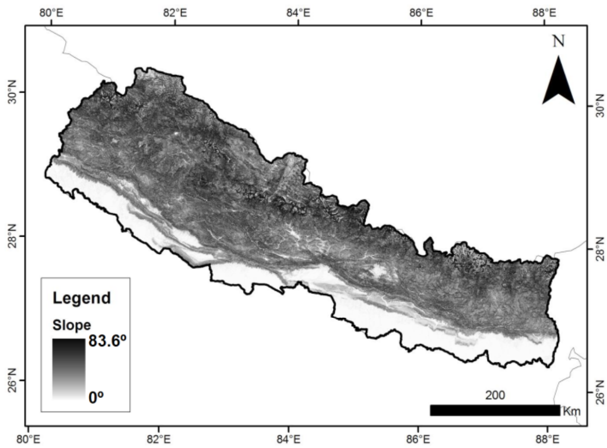

Fig.7 - Slope Map of Nepal (Source: GIS enhanced data from SRTM).

The rate of forest fires decreases remarkably as slope increases (JO et al., 2002). Slope increases fire hazard: as a surface's slope increases, so does fire hazard. The slope map (Figure 7) is created using the DEM data.

4.2 Methods

This section describes the spatial data used as input for Analytical Hierarchical Process technique, which was employed for fire hazard mapping.

4.2.1 Weightage Assigned to the Parameters

The re-classification of the selected five parameters: land use/land cover (forest type), proximity to roads, aspect, slope and elevation were done and assigned the fire risk value associated with them. The assignation of the score was done based upon thorough literature reviews made in the similar subject matters and the scenario of forest fire frequency associated with each of the five parameters.

4.2.1.1 Land use/land cover

The original land use/land cover use data was reclassified in to five categories and assigned the value from 0 to 4 (Extremely low – Very High) was assigned for land use/land cover according to the different land use patterns which have different potentiality for creating forest fire hazard as shown in Table 1. The assignation of fire hazard score for particular forest type is based upon the literature review and under the assumption that there is greater vulnerability of forest of types such as tropical and sub- tropical compared to alpine ones. For examples; (1) A study about the major forest fire types in 16 countries of Asia lying in tropical and sub-tropical regions was conducted by Goldammer (2000) where Nepal was also one of the study areas and that research found that the tropical moist deciduous forest lying in Terai region of Nepal was most vulnerable to forest fire; secondly tropical wet evergreen *Pinusroxburghii* forest was also vulnerable. (2) Dry and dense vegetation are more susceptible to forest fire (GHOBADI et al., 2012).

Table 1: The fire hazard potential weightage for different land use/land cover

Factor	Sub-Factors	Score	Fire Hazard Potential
Land use/ land cover	Tropical Dry Deciduous, Tropical Moist Deciduous, Tropical Semi evergreen, Thorn Forest N/S	4	Very High
	Subtropical Evergreen, Subtropical Conifer, Bush	3	High
	Temperate conifer, Temperate Broadleaved	2	Medium
	Alpine Grasslands, Alpine Meadow, Dry Grassland, Plain Grasslands	1	Low
	Bare Rock, Barren, Irrigated Agriculture, Irrigated Intensive Agriculture, Rain fed Agriculture, Settlements, Slope Agriculture, Snow, Water bodies.	0	Extremely low

4.2.1.2 Proximity to roads

The original proximity to road data was reclassified in to four categories and assigned the value from 1 to 4 (Low – Very High) according to their potentiality for creating forest fire hazard, as shown in Table 2. The score was given based upon the possibility of human interference intensity to crate forest fire. It is assumed that the areas lying near the day to day human interference is more vulnerable to forest fire compared to areas farther from that. And distance from the road is one of the major features indicating human interference, because people use road for various activities such as walking, taking cattle, transporting goods etc. and during that case they might do activities such as smoking or leakage of oil from tankers etc. which might cause forest fire. The assignation of fire hazard score for particular distance from the road (i.e. human interference) is based upon the literature review and under the assumption that there is higher possibility of forest fire nearer to the roads and trails compared to others. For examples; (1) Roads are an important factor in forest fire because their presence indicates human activity (JO et al., 2000). (2) Trail and road locations are also important factors in fire hazard mapping. Two major effects can be considered. First, roads can serve as fire breaks or as pathways for the suppression of fire. In this sense, they are a factor which reduces fire hazard. Second, they are potential routes to hiking or camping areas. In this context, they increase the hazard of forest fire because of more intense human activity (CHUVIECO; CONGALTON, 1989). (3) Human, animal and vehicular movement and activities on roads provide ample opportunities for accidental/man-made fires. Forests located near roads are therefore more fire prone. While collecting the leaves, people carelessly throw matches and burning ends of cigarettes, which are the major causes of forest fires (JAISWAL et al., 2002).

Table 2: The fire hazard potential weightage for different proximity to road distance

Factors	Sub-Factors	Score	Fire Hazard Potential
Proximity to Roads (m)	0-500	4	Very High
	500-1000	3	High
	1000-1500	2	Medium
	>1500	1	Low

4.2.1.3 Elevation

The original elevation data was reclassified in to four categories and assigned the value from 1 to 4 (Low – Very High) according to their potentiality for creating forest fire hazard, as shown in Table 3. The assignation of fire hazard score for altitude is based upon the literature review and based upon the fact that there is higher possibility of forest fire towards the tropical and warm weather condition. For examples; (1) Elevation influences vegetation composition, fuel moisture and air humidity. More than 90% of cases of forest fire occur at 100m above sea level. Most of these disasters take place in areas which are lower above sea level. Fires are less severe at higher elevations due to higher rainfall. Two factors to consider are elevation above sea level and elevation changes in relation to the surrounding topography.

Table 3: The fire hazard potential weightage for different Elevation levels

Factor	Sub-Factors	Score	Fire Hazard Potential
Altitude (m)	59-1000	4	Very High
	1000-2000	3	High
	2000-3000	2	Medium
	>3000	1	Low

It has been reported that fire behavior trends to be less severe at higher elevation due to higher rainfall (CHUVIECO; CONGALTON, 1989). (2) Higher elevations are related to greater rain availability. Therefore, the fires tend to be less severe at higher elevations (BROWN; DAVIS, 1959).

4.2.1.4 Aspect

The original aspect data was reclassified in to four categories and assigned the value from 1 to 4 (Low – Very High) according to their potentiality for creating forest fire hazard, as shown in Table 4. The assignation of fire hazard score for aspect is based upon the literature review and the higher possibility of forest fire towards certain faces of the slope receiving direct and more intense sunlight during day time compared to others. For example, south aspects have received more sun light and exposure in the north hemisphere, because of that, drier soil is more capable to ignition. South aspect slopes are higher temperatures, robust winds, minor humidity and lower fuel moistures because Southern aspects receive more direct heat from the sun. In the earlier day, east aspects get more ultraviolet and direct sunlight than west aspect, as a consequence east aspect drier faster. In northern hemisphere, south-facing slopes receive more solar radiation than north-facing slopes. Therefore, south-facing slope are hotter, drier and pose greater fire hazards. More than 60% of forest fires happen on slopes of between zero and 20 degrees and in areas of southern and south western aspect (JO et al., 2000).

Table 4 -The fire hazard potential weightage for different Aspect conditions

Factor	Sub-Factors	Score	Fire Hazard Potential
Aspect	Flat/S	4	Very High
	E/SE/SW	3	High
	W/NE/NW	2	Medium
	N	1	Low

4.2.1.5 Slope

The original slope data was reclassified in to four categories and assigned the value from 1 to 4 (Low – Very High) according to their potentiality for creating forest fire hazard, as shown in Table 5 .

Table 5: The fire hazard potential weightage for different Slope patterns

Factors	Sub-Factors	Score	Fire Hazard Potential
Slope (%)	>40	4	Very High
	26-40	3	High
	12-26	2	Medium
	<12	1	Low

The assignation of fire hazard score for slope is based upon the literature review and the higher possibility of spreading of forest fire at greater slope compared to flatter slope. For example, steep slopes increase the rate of fire spread because of a more efficient convective preheating and ignition by point contact. Fire travels most rapidly up slopes and least rapidly down slopes. Steep hills helps to spread forest fire rapidly (JAISWAL et al., 2002). Also, it is difficult to extinguish fire in steep areas (JULIÃO et al., 2009).

4.2.1.6 Analytical Hierarchical Process and evaluation

Once all the data were gathered/calculated, the AHP was used for the pairwise comparison between the selected five variables based upon their importance for forest fire hazard. The use of the fundamental scale for AHP (Table 6) developed by Saaty (1990) was done for the comparison.

Table 6: The fundamental scale for comparing the pairwise activities in AHP

Intensity of Importance on an absolute scale	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed

The AHP tool developed by K. D. Goepel, version 12.08.2012 (http://bpmsq.com) was used for the assignation of comparative score between the variables. The assignation of comparative score was done based on the literature review (Figs. 8 and 9).

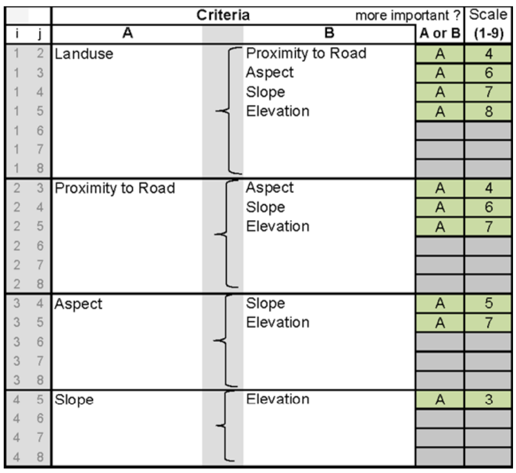

Fig. 8 - Assignation of comparative score between variables.

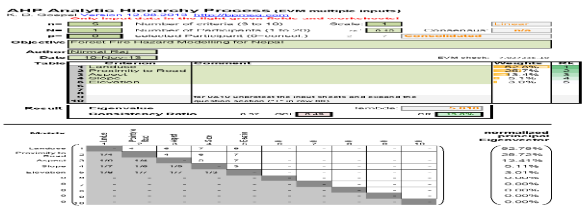

Fig. 9 - The weights obtained for equation generated by AHP.

Similarly, the equation was used in GIS raster calculator to develop the forest fire hazard map of Nepal and was cross checked for its reliability against the historical forest fire hazard data for Nepal from NASA and from Disaster Information Management System (DesInventar, http://www.desinventar.net/).

5. RESULTS

This section shows the obtained forest fire hazard map by AHP, its analysis for Nepal territory, and the map evaluation.

5.1 Forest Fire Hazard Map

The fire hazard map was developed using the AHP and GIS raster calculator. The appropriate comparison value for each pair of the five factors responsible for fire hazard was assigned in AHP and was processed in GIS environment. The weightage for each variable was calculated and the fire hazard equation model was obtained:

$$X = 0.528 * L + 0.257 * P + 0.134 * A + 0.051 * S + 0.03 * E \quad (1)$$

Where, X, L, P, A, S and E are overall hazard index, land use/land cover (forest type), proximity to roads, aspect, slope and elevation respectively. The combination of all these five classifies the danger of forest fire hazards for whole Nepal.

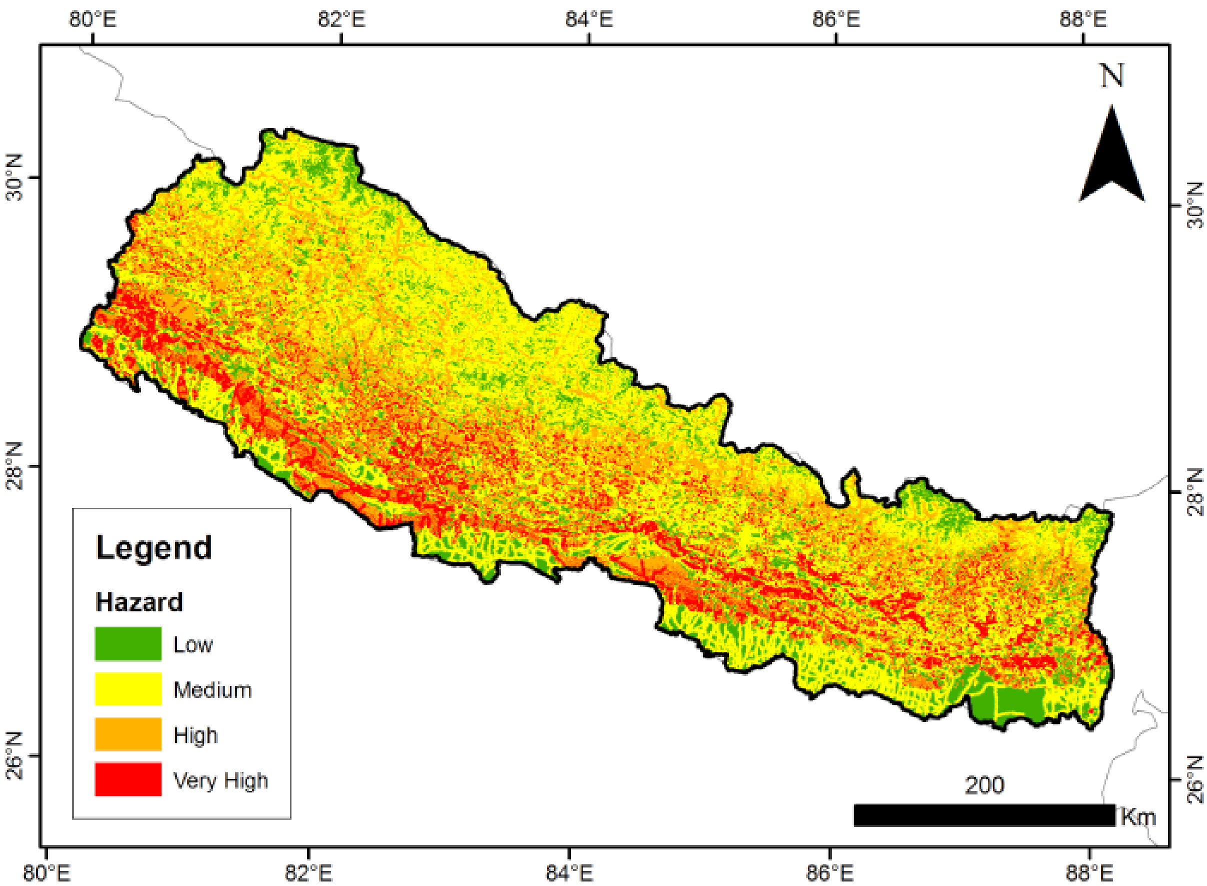

Fig.10 - Forest Fire Hazard Map of Nepal.

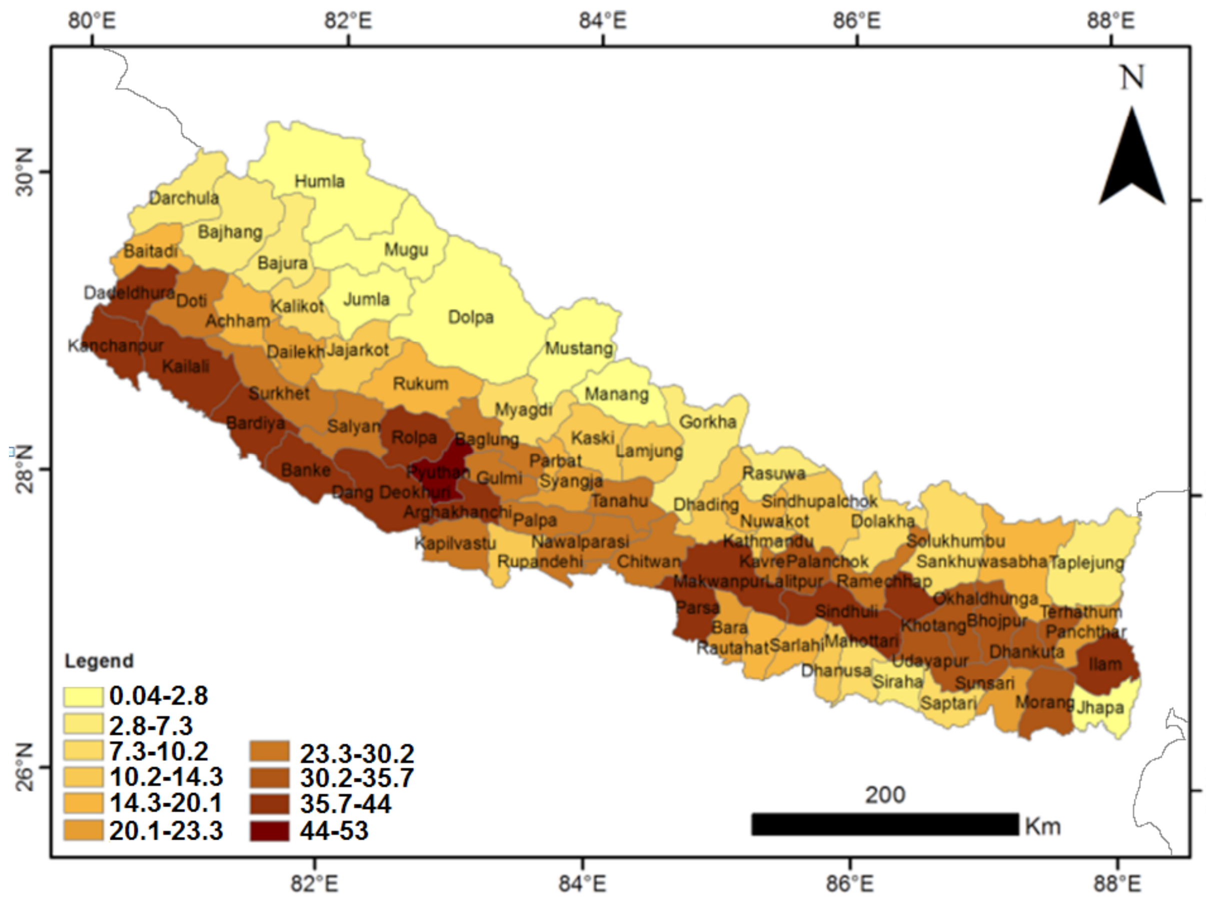

Fig. 11 - District Wise Forest Fire Hazard Map of Nepal.

The district wise forest fire hazard mapping as shown in Fig. 11 was prepared for all the 75 districts of Nepal. The districts with darker colour shades are more vulnerable to forest fire compared to the districts with faint colour shades. The map was prepared based upon the percentage of high forest fire hazard prone forest areas with respect to the total forest area lying inside each of the 75 districts.

The Figure 10 shows the areas potential for forest fire, most of the areas with large concentration of fire hazard are towards the Terai region with tropical climate, heavy forest area, near the roads, south facing slopes and flat lands. The analysis of the forest fire hazard map shows the distribution of percentage wise forest fire hazard level as shown in Table 7.

Table 7: Forest fire hazard level percentages.

Hazard Level	Percentage (%)
Very High	16.2
High	22.3
Medium	45.3
Low	16.2

The data clearly illustrates that more than 83% of the total area of Nepal lies in the region of very high to medium forest fire hazard potential.

5.2 Validation of the Forest Fire Hazard Map

The validation of the forest fire hazard map derived in the above section was done according to the fire data available from the two sources for Nepal as mentioned in the following.

5.2.1 Validation against data from NASA

NASA has started keeping record of forest fire all around the world form November 2000 to date using the sensors named Moderate Resolution Imaging spectra- radiometer (MODIS). MODIS is flying on board in two satellites named Aqua and Terra which are polar orbiting satellites. The forest fire data from MODIS for Nepal is also available from November 2011 until nowadays.

The basic principle of recording forest fire by this satellite is by detecting the brightness temperature of the area under the field of view of satellite using the temperature sensors. The sensor will detect the area with forest fire if it finds the uncommon temperature under certain points. The forest fire data is then stored in the memory of the satellite and then send back to the earth stations, from when we can get the forest fire data. The MODIS forest fire data are real time data, so we can obtain the information of forest fire at particular location around the world instantly.

A total number of 22177 forest fire data points which are above the confidence level of 50% from the date November 2000 to December 2013 have been collected from NASA (Figure 12) by formal request to NASA and is used for the validation of the forest fire hazard map produced in this study.

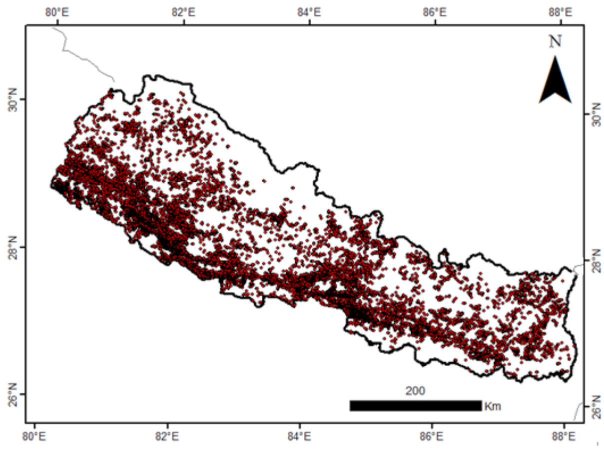

Fig. 12 - Active Forest Fire Map from NASA.

While comparing the Active forest fire data from NASA Figure 12, with the fire hazard map (Figure 13) derived from the study the fire hazard seems to be concentrated towards the Terai, Siwalik and Middle Mountain regions where there are heavy forest density and hot weather. The locations near to the road networks seem to be in high risk zones as compared to the places farther from the roads.

The GIS analysis between the active fire hazard points from NASA for Nepal with the forest fire hazard map developed shows the very good coincidence as shown in Table 8.

Table 8: Spatial Comparison between Forest Fire Hazard Map with NASA data

Hazard Category	No. of Forest Fire Points	%	Cumulative %
Very High	7998	36	36
High	6612	30	66
Medium	5401	24	90
Low	2166	10	100

Among the total number of active fire hazard points, about 90% of the total data lies inside the Very High, High and Medium forest fire risk zones as derived from this study. So this can be concluded that the derived forest fire hazard map satisfies the historical forest fire data, and the model can be used for forest fire hazard mapping for Nepal especially for broad scale and decision making method. This might be very useful for disaster risk management and forest fire fighting planning process.

5.2.2 Validation against Data from DesInventar

DesInventar is an online Disaster information platform, and it is developed as a Disaster Information Management System, which is a sustainable arrangement within an institution for the systematic collection, documentation and analysis of data about losses caused by disasters associated to natural hazards around the world.

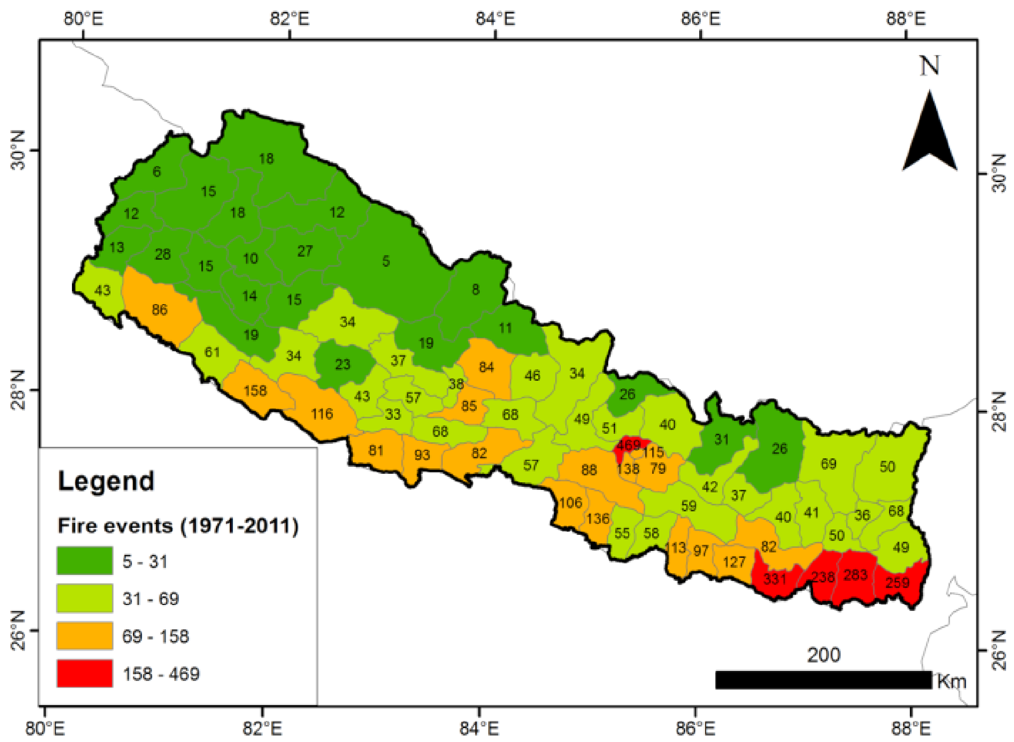

Fig.13 - Fire Hazard frequency map of Nepal.

DesInventar has started to keep the record of different hazard incidents in Nepal since 1971. The fire data from the DesInventar when comparing the forest fire hazard susceptibility map obtained from the study, clearly illustrates that the districts of Terai region, Bhawar region, Siwalik region are with large frequency of fire hazard and this scenario is also same for very high to high risk zone in the derived forest fire hazard susceptibility map in this study (Figure 13).

There seems to be exception in the Kathmandu valley, as it has large number of fire data, this might be because it is a capital city and the fire incidents are more often and easily recordable to media but they are not forest fire. Hence this can be concluded that the fire data from the DesInventar also satisfies the forest fire hazard map derived from this study.

6. CONCLUSION

The method adopted in this study takes into consideration various factors which influence the forest

fire such as land use/land cover type, proximity to roads, aspect, slope and elevation, with appropriate

weightage to these factors according to their contribution to fire thus this method is much reliable for generating fire hazard zone map. The fire hazard Equation 1 calculated represents the hazardous forest area of Nepal. This equation clearly shows that the combination all these five variables can classify the forest fire hazards for whole Nepal, but the weights must be analyzed in each situation, and the model must be adapted to local conditions. The output district wise forest hazard map of Nepal shows that the districts of Terai region, Bhawar region and Siwalik region are comparatively more vulnerable to forest fire than other districts of Nepal.

Forest fire is considered one of the very destructive hazards as it destroys the natural resources within a very small span of time. It becomes very important to take some prevention and control measures and to implement efficiently. For efficient and effective forest fire management, we require adequate logistic infrastructure, funding for prevention and suppressing of forest fire. For any prevention and control management, we need through and detailed knowledge on the areas which are prone to the forest fire. For this we have to analyze different parameters, which are responsible for forest fire. The fire hazard map derived from this study shows good coincidence with the historical data from NASA and DesInventar. Thus the use of GIS and the AHP can proved to be a very effective and easy tool to detect the forest fire hazard areas.

7. REFERENCES

BAJRACHARYA, K. M. Forest fire situation in Nepal. **International Forest Fire News**, n. 26, p. 84-86, 2002.

BROWN, A. A.; DAVIS, K. **Forest Fire Control and Use**. New York, NY: McGraw-Hill Book company, 1973. 686 p.

CHUVIECO, E.; CONGALTON, R. G. Application of remote sensing and geographic information systems to forest fire hazard mapping.**Remote Sensing of Environment**, v. 29, n. 2, p. 147-159, 1989

GALTIÉ, A. C. Is El Niño now a man-made phenomenom?.**The Ecologist**, v. 29, n. 2, p. 64-67, 1999.

GHOBADI, G. J.; GHOLIZADEH, B.; DASHLIBURUN, O. M. Forest fire risk zone mapping from Geographic Information System in morthern forests of Iran (case study, Golestan province). **International Journal of Agriculture and Crop Sciences**, v. 4, n. 12, p. 818-824, 2012.

GOLDAMMER, J.G. Wildfires and forest development in tropical and subtropical Asia: outlook for the year 2000. In: PROC. SYMP. WILDLAND FIRE, 1987, South Lake Tahoe, **Proceedings…** Cal., 164-176. USDA For. Ser. Gen. Techn. Rep. PSW-101, 258 p.

GOLDAMMER, J.G. Early warning systems for the prediction of and appropriate response to wildfires and related environmental hazards. In: **Health Guidelines for Vegetation Fire Events**. Background Papers, p. 9-70. Institute of Environmental Epidemiology, Ministry of the Environment, Singapore: Namic Printers, 1997. 498 p.

VADREVU, K. S.; EATURU, A.; BADARINATH, K. V. S. Fire risk evaluation using multicriteria analysis - a case study, **Environment Monitoring and Assessment**, v. 166, p. 223–239, 2010.

SHARMA, L.K.; KANGA, K.; MAHENDRA, S.N.; SINHA, S.; PANDEY, P. C. Fuzzy AHP for forest fire risk modeling. **Disaster Prevention and Management: an International Journal**, v. 21, n.2, p. 160 – 171, 2012.

JUNG, J.; KIM, C.; JAYAKUMAR, S.; KIM, S.; HAN, S.; KIM, D. H.;, HEO, J. Forest fire risk mapping of Kolli Hills, India, considering subjectivity and inconsistency issues. **Natural Hazards**, v. 65, n. 3, p. 2129–2146, 2012.

JAISWAL, R. K.; MUKHERJEE, S.; RAJU, K. D.; SAXENA, R. Forest fire risk zone mapping from satellite imagery and GIS. **International Journal of Applied Earth Observation and Geoinformation**, v. 4, n. 1, p. 1-10, 2002.

JO, M.; BO LEE, M.; YOUNG LEE, S.; JO, Y.; RYUL BAEK. S. The development of forest fire forecasting system using internet GIS and satellite remote sensing. In: ASIAN CONFERENCE ON REMOTE SENSING, 2000, **Proceedings...** 2002. Available in: <http://geospatialworld.net/Paper/Application/ArticleView.aspx?aid=1063>. Access in: 13 oct. 2015.

JULIÃO, R. P.; NERY, F.; RIBEIRO, J. L.; CASTELO BRANCO, M.; ZÊZERE, J. L. **Guia metodológico para a produção de cartografia municipal e para a criação desistemas de informação geográfica (SIG) de base municipal**, Autoridade Nacional de Protecçåo Civil: Portugal, 2009.

LEAL, P. H.; ARBELO, M.; CALVO, A. G. Fire risk assessment using satellite data. **Advances in Space Research**, v. 37, n. 4, p. 741-746, 2006.

RAWAT, G. **Fire risk assessment for forest fire control management in Chilla forest range of Rajaji national park, Uttaranchal, India**. 2003. Thesis (Master in Science in Geoinformatics) - International Institute for Geoinformation Science and Earth Observation, The Netherlands, 2003. 66 p.

SAATY, T. L. How to make a decision: the analytic hierarchy process. **European Journal of Operational Research**, v. 48, n. 1, p. 9-26, 1990.

SAXENA, A.; SRIVASTAVA, P. Integrating biophysical characters microclimate and human factors in forest fire risk modeling. In: International Wildland Fire Conference, 4., 2007, Sevilla, Spain. **Proceedings...** Sevilla: Wildfire, 2007. p. 13-17.

SETIAWAN, I.; MAHMUD, A.; MANSOR, S.; SHARIFF, A. M.; NURUDDIN, A. GIS-grid-based and multi-criteria analysis for identifying and mapping peat swamp forest fire hazard in Pahang, Malaysia. **Disaster Prevention and Management**, v. 13, n. 5, p. 379-386, 2004.

YIN, H. W.; KONG, F. H.; LI, X. Z. RS and GIS based forest fire risk zone mapping in Da Hinggan Mountains. C**hinese geographical science**, v. 14, n. 3, p. 251-257, 2004.