Forest Fire Risk Assessment and Proposal for Fire Stations in different Geographical Regions of Central Nepal

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Abstract

Forest fire is considered as the most persistent terrestrial disturbance affecting ecosystems, natural resources and threats to human life. Nepal predominantly faces forest fires during dry seasons (November-June) with increasing trend in the recent years that need proper management interventions. In line to this, our paper aims at assessing fire risk zones in four districts of central Nepal representing different geographical characteristics, through hotspot analysis and further proposing potential fire stations. Data acquired from Visible Infrared Imaging Radiometer Suite (VIIRS) was projected through the Projected Coordinate System and integrated into ICOUNT for hotspot analysis using Neighbor Count Tool and Getis-Ord Gi* tool, Inverse Distance Weighted (IDW) technique and neighborhood function for proposing fire stations from ArcGIS. It was observed that hotspots and cold spots are demonstrated by points with the values 6.969622 > z > 0.926061 (red) and -1.705619 < z < -0.926060 (blue). Likewise, in terms of physiography, Chure zone has the highest concentration of hotspots followed by Terai whereas cold spots are mostly concentrated in the Hilly region. In order to mitigate the problem of forest fire, establishment of fire stations for the areas with road access is pertinent, while in areas with poor, or without road access, formation of Forest Fire Management Committee (FFMC) is recommended. These management interventions can serve as a milestone for prevention and control of forest fire in the days to come, for Nepal.

Keywords: Fire station, forest fire, Getis-Ord Gi, hotspot analysis, risk

INTRODUCTION

Forest fire is defined as any form of wildfire or prescribed fire burning in forested areas, grassland, or alpine/tundra vegetation (Merrill and Alexander 1987). Forest fire is a universal phenomenon which contributes to disturbances and devastation in some cases, to natural ecosystems throughout the world. Although the role of fire in organising physical and biological attributes of vegetation is well defined, its adverse impacts in the ecosystem are well known (Satendra and Kaushik 2014). With changing climate and lack of management of natural habitats, incidences of forest fire have been increasing across different regions.

Forest fires occur normally during the dry summers in temperate and northern boreal forests. North America and Eurasia annually suffer an average of 5-20 million hectares of forest burn (Satendra and Kaushik 2014). The severity of forest fire is well accounted through the recent bushfire in Australia which largely contributed to the extinction of a number of animal species along with a widespread damage to the forest ecosystem (Badal and Mandal 2021). Similarly, about 39,194 incidents were detected in the Amazon region during the period of January-August 2019 that resulted in disruption of biodiversity and natural ecosystem (Radu 2020). Likewise, 15000 cases of forest fires were reported in China during the last 50 years with the 1987 fire being the most devastating which resulted in the death of 200 people and burned around 1.3 million hectares of forest area. Fire in Koung

Kangwon region of Korea was equally devastating where it engulfed and damaged 3700 hectares of forest area (Satendra and Kaushik 2014). In India alone, over 30,000 forest fires were recorded in 2019 (Xanthopoulos and Nikolov 2019). Nepal is not an exception to the problem where forest fire, especially during the dry season, results in damage to forest area and biodiversity, every year.

The increasing trend and intensity of forest fire in the recent years, calls for a proper comprehension of the risks from forest fire and its management. Forest fire risk management starts from its assessment (Guettouche and Derias 2013). The risk assessment involves identification of risks and adoption of preventive measures to reduce the frequency and magnitude of those risks. The three key requisites to manage forest fires include hotspots identification, risk probability evaluation and measures to reduce risks (He *et al.* 2010). These requirements practically line up with strategies put forward by other researchers in assessing forest fire risk through the use of Geographical Information System (GIS) (Gai *et al.* 2011; Sivrikaya *et al.* 2014). The determination of spatial location of fire stations precisely is pivotal in detection and control of forest fires. The early detection of forest fire will disseminate better information like spatial locations, accessibility and actual size (Johnson and Miyanishi 2001). This reinforces that fire stations are an effective appliance to detect and monitor forest fires (Oğurlu 1990).

Numerous studies have been carried out relating to forest fire risk assessment using GIS which has been an important tool (Chuvieco and Salas 1996; Sivrikaya *et al.* 2011; Sivrikaya *et al.* 2014). However, almost none of the studies have assessed the significance of forest fire stations in the probable fire prone areas in Nepal. In this regard, the study aims to identify the forest fire hotspots viz. Getis-Ord Gi* along with recommending suitable locations for fire stations taking into consideration the road network and existing forest fire distribution record/ forest fire hotspots in Nepal.

MATERIALS AND METHODS

Study Area

The four districts of Nepal (Makwanpur, Chitwan, Bara and Parsa) representing Chure, Terai, and Mid-Hills were designated as the study area (figure 1). Three out of 18 districts which have been listed as very high and high fire risk zones by Matin *et al.* (2017) falls in the study area (Chitwan, Makwanpur and Parsa) having the highest number of fire days. Nestled in the Central region of Nepal, the study area extends from $27^{o}0'$ to $27^{o}35'$ N latitude to $84^{0}00'$ to $84^{0}52'$ E longitude. The region of interest is located in the southwestern part of Bagmati province (Makwanpur and Chitwan district) and Madhesh Province (Bara and Parsa district) of Nepal. Administratively, the study area includes two metropolitan cities, three sub-metropolitan cities, 14 urban municipalities and 28 rural municipalities. According to the census of 2011, the overall population of the region is 22,89,186 with a land cover area of 7,207 sq km^2 (CBS 2012).

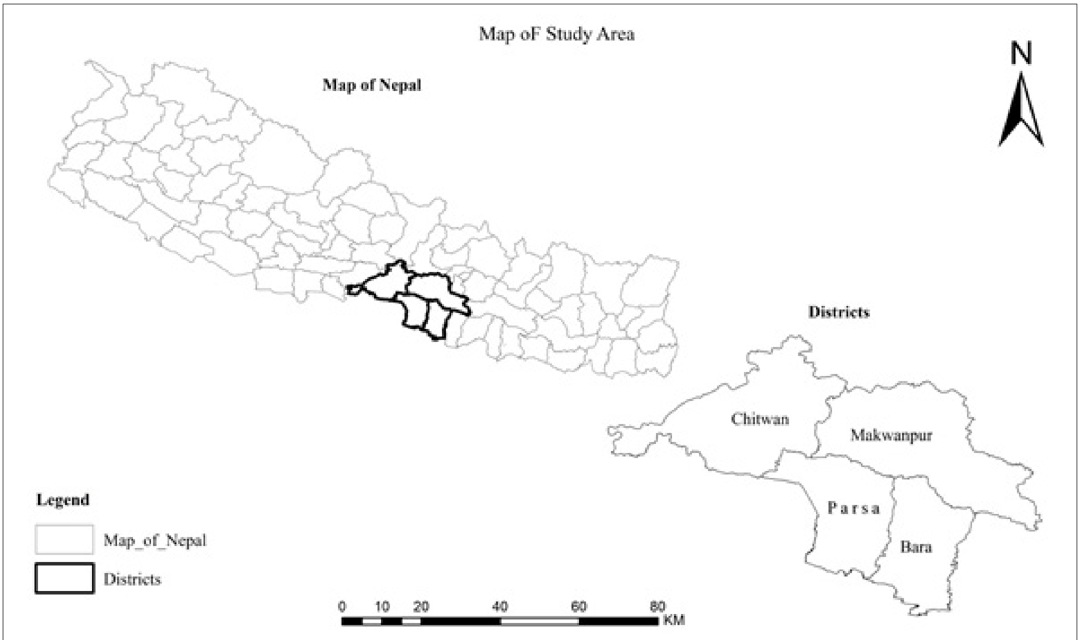

Figure 1: Location Map of the Study Area

The overall forest area coverage in the study area includes 15,186 hectares in Makwanpur, 66903 hectares in Chitwan, 17224 hectares in Parsa and 46,132 hectares in Bara district (DFRS 2018). It encompasses lower tropical to temperate region with major vegetation types of lower tropical Sal (*Shorea robusta*) and mixed broad-leaved forest, hill Sal forest, *Schima-castanopsis* forest, Chir pine (*Pinus roxburghii*) forest, having the climatic condition of semi-arid and humid condition (Lillesø *et al.* 2005).

Data Acquisition and Processing

Visible Infrared Imaging Radiometer Suite (VIIRS) was used for acquiring the fire occurrence during five years' time period across the country. The Visible Infrared Imaging Radiometer Suite comprises of the Suomi NPP (National Polar-orbiting Partnership) satellite that has been in application since 2012. It has a resolution of 375 meters per pixel that enables it to detect fires which Moderate Resolution Imaging Spectroradiometer (MODIS) overlook. It is considered to be more effective for monitoring fire activity as compared to MODIS (UN-spider 2015). This further enables us to model and predict forest fire behavior more accurately. Additionally, it provides much accurate information for identifying the spot from where fires originate (Coen and Schroeder 2015). Likewise, GPS coordinates within the *csv file* data of fire incidents were adapted through the Projected Coordinate System (WGS_1984_UTM_Zone_45N; False Easting-500000.0; Scale Factor-0.9996) using ArcGIS.

An integration tool was used to maintain the integrity of features that fall within a short distance of one another and considered as identical or coincident (ArcMap 2016). The reason was to correct the slightly inaccurate GPS coordinates for each fire incident. Ultimately, they got snapped together and were considered to have the same location. Similarly, collect events was used to create weights from each fire events as weighted points are required for the hotspot analysis rather than individual incidents (figure 2). Field named ICOUNT was subsequently added which holds the sum of all fire events occurred at each unique location (Said *et al.* 2017).

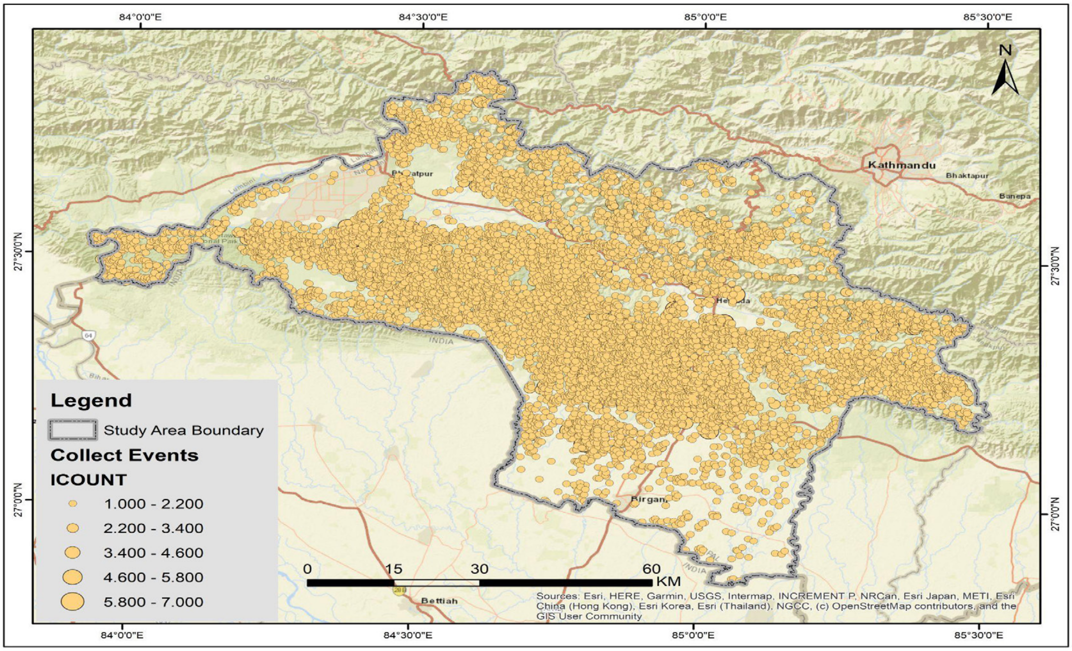

Figure 2: Output of Collect Events Tool

Data Analysis

Following the acquisition and processing of the data, certain parameters were considered prior to the hotspot analysis. The following parameters were considered:

Calculation of Distance Band: Distance band was calculated using the Neighbor Count Tool in ArcGIS. This provides the minimum, average and maximum distance where each fire occurrence point has at least one neighbor. Based on this, the beginning distance between the fire occurrence points and distance increment was determined. The minimum and maximum distances between the fire occurrence points in study area were found to be 3391meters and 6007 meters respectively i.e., there is at least one neighbor point at an interval of 3391meters. Thus, 3391meters was used as the beginning distance. The average distance increment on using the tool was found to be 290 meters. This was used in the study for observing the peak distance at which there are maximum fire events with at least one neighbor point as shown in figure 3.

Incremental Spatial Autocorrelation: Incremental Spatial Autocorrelation tool was run to measure the degree of clustering of data with increasing distance. Figure 3 shows the output of this tool which creates the graph of incremental distance and corresponding z factor. Z factor output represents the statistical significance of clustering for a specified distance. The peak corresponds to the distance at which there is a high clustering. Thus, obtained clustering distance was used in hotspot analysis using Getis-Ord Gi* analysis techniques.

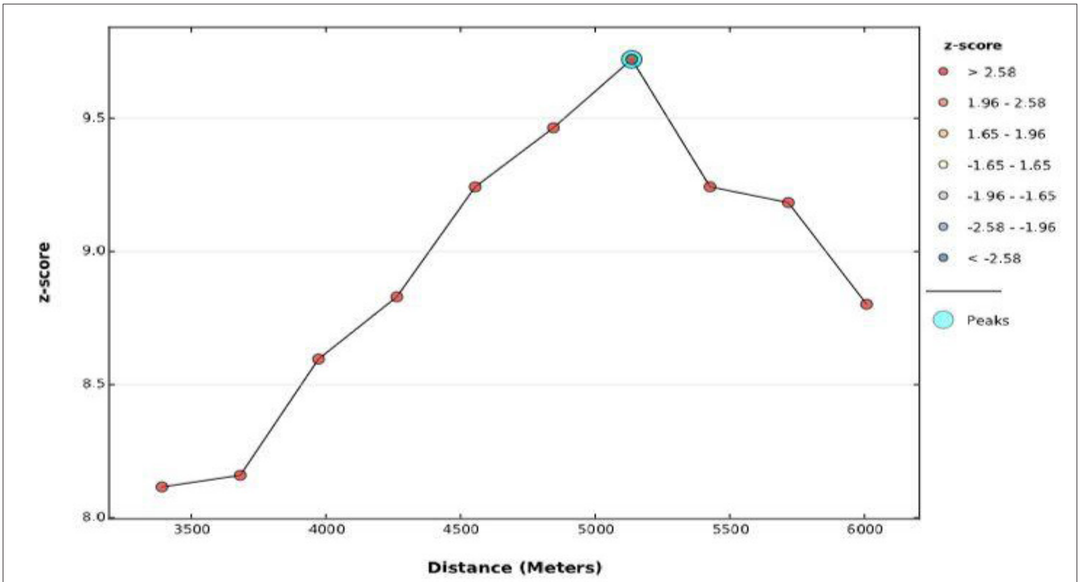

Figure 3: Spatial Auto-correlation by Distance

Hotspot Analysis

For the hotspot identification in the study area, Getis-Ord Gi* hotspot analysis method was employed using the ArcGIS Software. It's a spatial autocorrelation method for the recognition and understanding of hot and cold spots (Wubuli *et al.* 2015). This technique was used by Said *et al.* (2017) for the fire risk assessment using hotspot analysis. Thus, similar approach was used for the purpose of the study which identifies the hotspot using the Gi* statistics.

$$G_i^* = \frac{\sum_{j=1}^{n} w_{ij} x_j}{\sum_{j=1}^{n} x_j}$$

Where, Gi* is the spatial autocorrelation statistics of an event i over n events, The term xj defines the magnitude of variable x at events j over all n, and the term w_{ij} defines the weight value between the event i and j that represent their spatial interrelationship.

This tool calculates the z score and p value for each feature and indicates the statistical significance of the calculated z score which determines the clustering pattern of the hotspot and cold spot of the study area (Said *et al.* 2017).

Following the analyses of forest fire hotspots, speed criteria provided by Nepal Road Standard, 2013 (GoN 2013) along with forest fire flashover time period of 4 and 10 minutes from ESRI (2007) was considered for identifying the potential fire station locations. In particular, for proposing fire stations, road types of the study area with their corresponding maximum and minimum vehicle speed were considered from Nepal Road Standard, 2013 whereas the standard time period of fire flashover was adopted from ESRI (2007). All of this data was taken as input in neighborhood function tools of ArcGIS in order to produce distance coverage (in the form of polygon) by fire stations of the study area. Nepal Road Standard, 2013 has proposed different speed limits to vehicles on the basis of road classes and terrain. According to this, there are four categories of road both administratively (national highway, feeder road/ local road, district road and urban road) and functionally (Class I, Class II, Class III and Class IV). The national highway roads can be understood as class II roads and local roads as class IV roads. Table 1 shows road categories with design speed for different terrain.

Table 1: Road Categories with Design Speed for Different Terrain

	Road categories	
	II (> =2 lanes)	IV (<2 lanes)
Design speed (Km/hour) based on terrain	Plain-100	Plain-60
	Rolling-80	Rolling-40
	Mountainous-60	Mountainous-30
	Steep-40	Steep-20

Source: Nepal Road Standard 2013

In terms of the scope of this paper, area comprising of plain, rolling and mountainous terrain only were considered. In addition, vehicle speed limits of mountainous terrain is considered as the minimum speed and speed of plain terrain as maximum speed for both the road classes i.e., 60 to 100 km/hour speed range for class II road and 30-60km/hour speed range for class IV road. These speed ranges were applicable to overall road conditions in the study area from highway to local roads.

RESULTS

Forest Fire Occurrence

The fire occurrence data of five years (2017-2021) extracted from VIIRS shows fluctuation in the trend with intense forest fire occurrence observed in the recent years. Although forest fire incidents recorded in 2021 were for a three months period (January to March), it recorded the highest number of fire incidents in comparison to previous years. The fire vulnerability class also depicted Bara district as a high-risk zone while Chitwan, Makwanpur and Parsa districts fall within a very high-risk zone, according to incidence data, with a percentage of 63, 62 and 52 respectively in comparison to total area of district (Matin *et al.* 2017). The forest fire events in the study area for the last five years, before the application of Getis-Ord Gi* tool has been illustrated in figure 4.

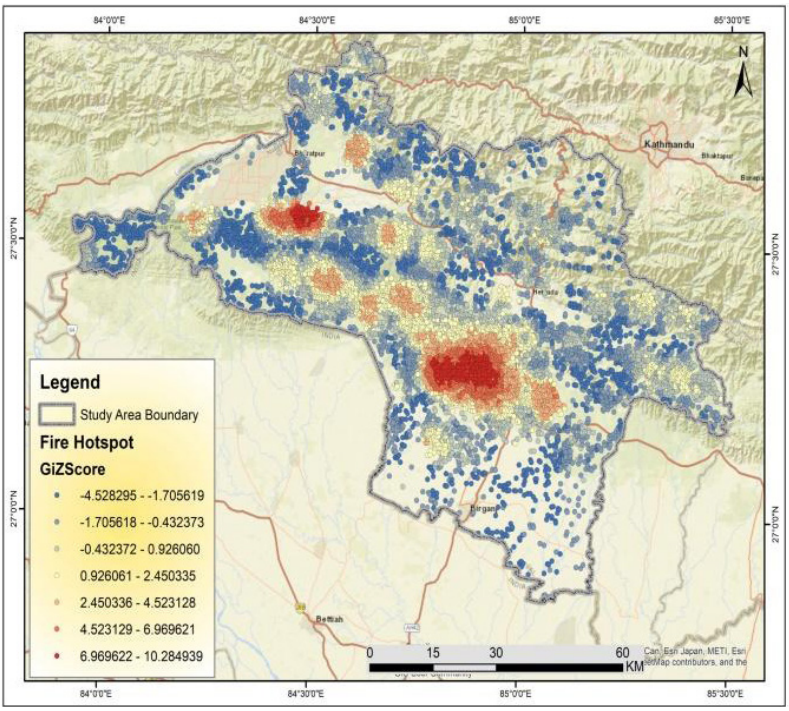

Figure 4: Forest Fire Statistics in Study Area

Forest Fire Hotspots

The output in terms of GiZscore map representing hot and cold spots after the use of the tool is shown in figure 6. Point features were generated by the tool to specify hot and cold spots. Output was derived in the form of GiZScore which generated z-score values indicating each feature for statistical significance of feature clusters, along with hot and cold spots. Using Getis-Ord Gi* tool, the hotspots and cold spots are indicated by points with values 6.969622 > z > 0.926061 (red) and -1.705619 < z < -0.926060 (blue). Smooth continuous surface of forest fire hotspots was obtained as an end result of Inverse Distance Weighted (IDW) technique. This was further classified into 5 different classes of hotspots ranging from very low (denoted as blue) to very high (denoted as red) as shown in figure 7.

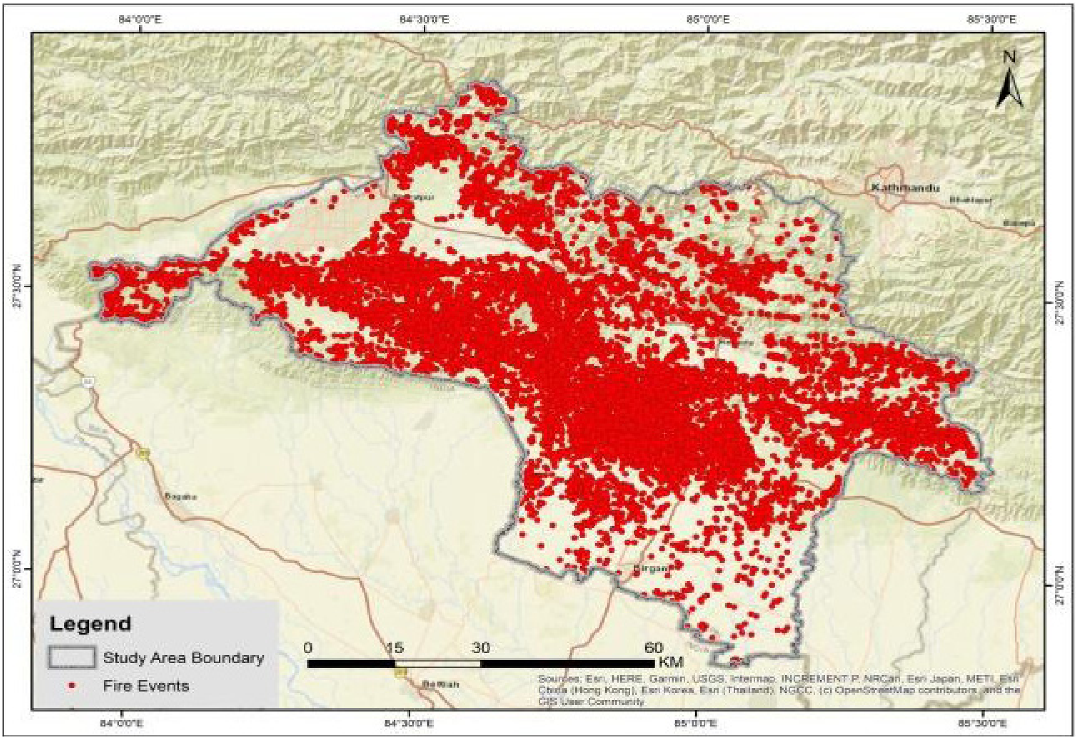

Figure 5: Coverage of Forest Fire Events in Study Area

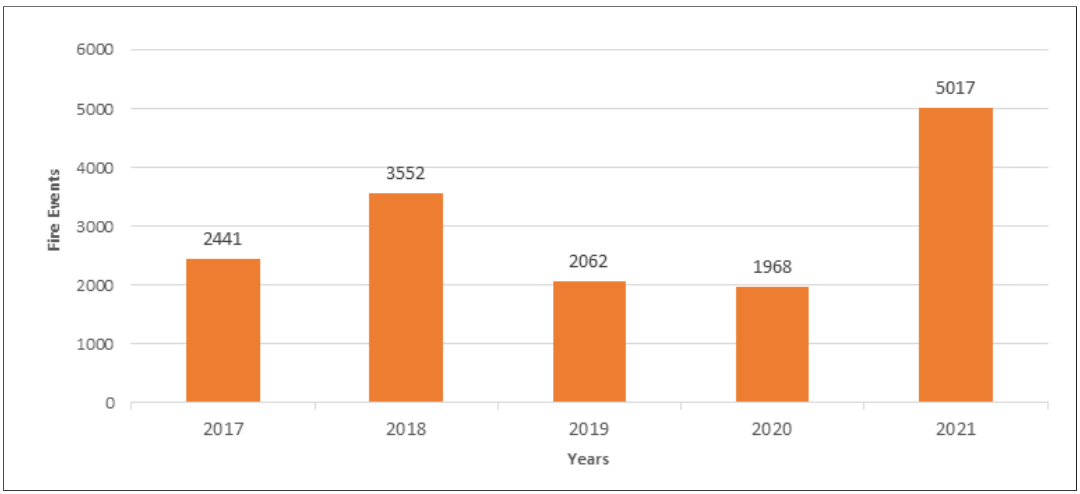

Figure 6: GIZScore Maps of Geti-Ord Gi* Hotspot Analysis

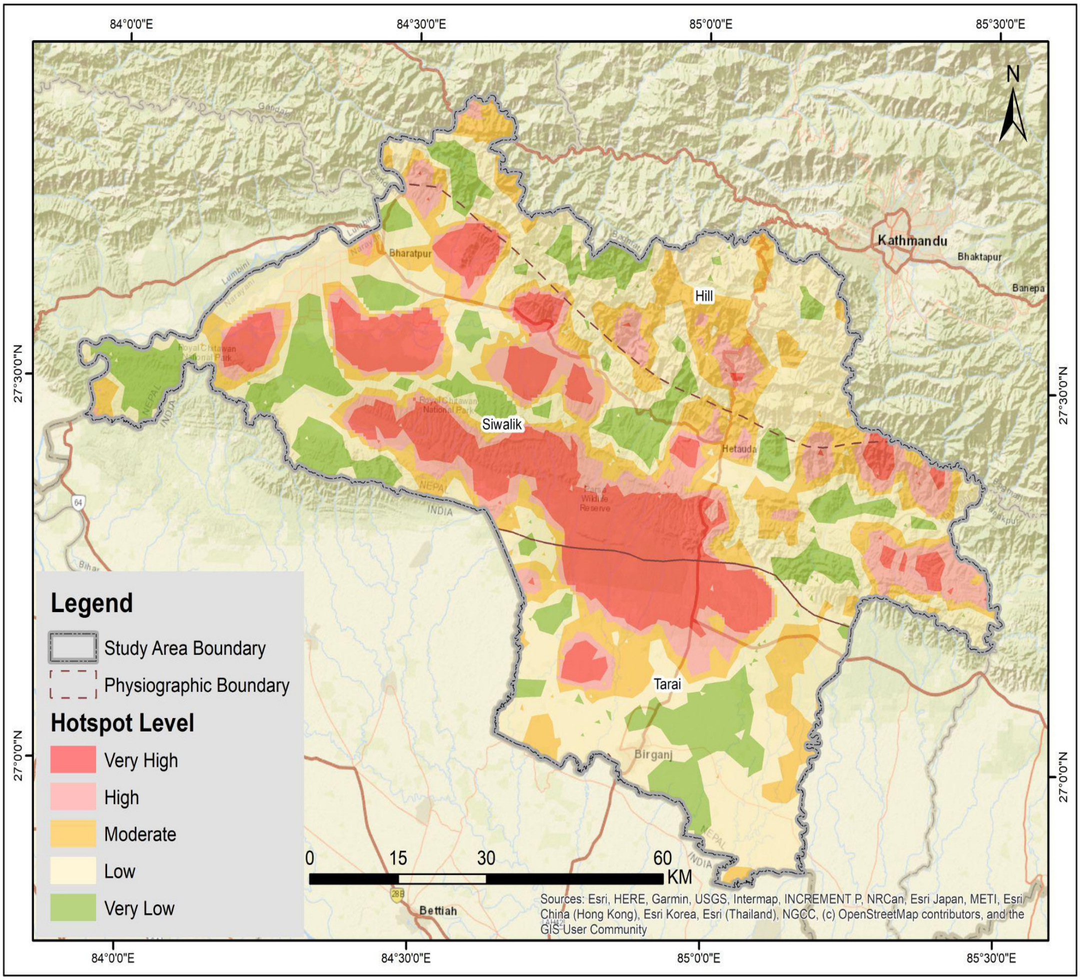

Figure 7: IDW of GIZScore Map with Physiographic Differentiation

Table 2: District-wise Forest Fire Hotspots Level

Hotspot level	District wise area (Sq.km.)				Total
	Bara	Chitwan	Makwanpur	Parsa	
Very High	161.678	402.197	144.219	563.633	**1271.728**
High	84.169	206.791	418.566	166.715	**876.241**
Moderate	218.672	378.722	616.535	253.822	**1467.751**
Low	566.263	727.318	956.469	359.172	**2609.223**
Very Low	240.202	517.150	302.298	63.791	**1123.442**
Total	**1270.984**	**2232.178**	**2438.087**	**1407.133**	**7348.382**

Table 2 shows different hotspot levels of each district for the five years period (2017-2021) and are expressed in terms of area (square kilometer). In terms of the risks based on area, Parsa National Park has the highest area with a very high-risk level of forest followed by Chitwan while most of the high hotspot level is found in Makwanpur. Likewise, in physiographic terms, Siwalik zone has the highest concentration of hotspots followed by Terai whereas cold spots are mostly concentrated in the Hilly region. Overall, 1271.728 sq.km of area is under very high fire risk zone, 876.242 sq.km of area in high zone and most of the area i.e., 7348.382 sq.km is under very low risk category.

Management Intervention: Fire Station

In regard to mitigating forest fire, management interventions are mandatory, especially for a naturally rich and geographically diverse country like Nepal. One of the possible interventions is the establishment of fire stations in areas with road access (figure 8).

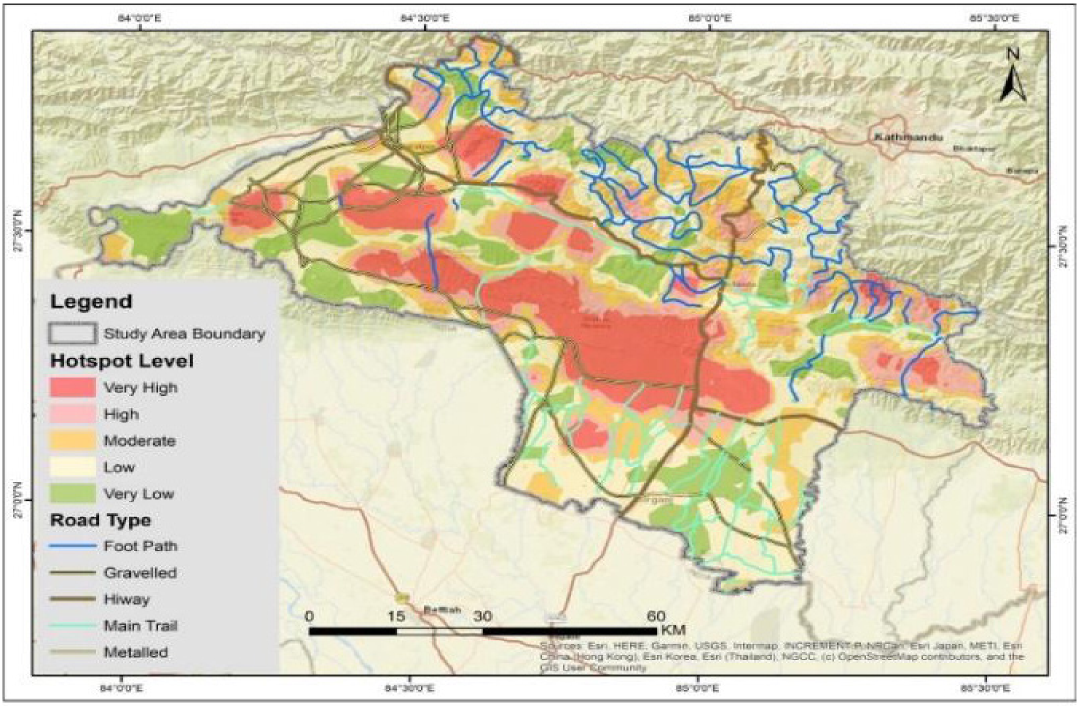

Figure 8: Map Showing Hotspots with Road Access

Despite several fire management interventions, no concrete plans or decisions have been made regarding the establishment of fire stations in the context of Nepal. Thus, using neighborhood function in ArcGIS, this paper locates the probable fire stations in the area with road access. Neighborhood function takes time and speed as an input and generates the extent of fire station distance coverage in the form of a polygon.

In terms of the speed limits, Nepal Road Standard, 2013 was considered. According to the standards, the maximum and minimum design speed limit for Terai region is 100km/hr and 60 km/hr respectively, while the maximum and minimum speed limit for Chure and/or hill is 60km/hr and 30km/hr respectively. This is however determined by the design features and road conditions. Likewise, for time input in neighborhood function tool, flashover time period by ESRI (2007) was considered. The fire flashovers particularly occur between the periods of 4 to 10 minutes after free burning starts. Beyond 10 minutes, post flashover occurs more intensely with higher temperature making fire management a huge challenge. So, 4 minutes (shortest) and 10 minutes (longest) drive time taking into consideration the speeds limits mentioned in the Road Standard 2013, was considered to analyse and compare the extent of fire station coverage using the neighborhood function in ArcGIS software.

The produced layer of coverage area maps was overlaid and evaluated with the identified hotspots map as shown in figure 9(a) and 9(b). Figure 9(a) shows the coverage area of each station by considering maximum speed limit of each physiographic zone (100km/hr for Terai and 60km/hr for Chure/Hills) in the given drive time i.e., 4 and 10 minutes. Meanwhile, figure 9(b) depicts area coverage by those stations by considering the minimum speed limit (Terai-60km/hr and Hilly/Chure-30km/hr) in the same drive time. The maps showed that proposed fire stations based on road access are not sufficient to cover very high (red portion of map) and high (pink portion of map) categories of forest fires, which in fact is in crucial need of management. In particular, Siwalik region, which has the largest fire hotspots, has been assigned with the lowest coverage of proposed fire stations, mainly due to road access.

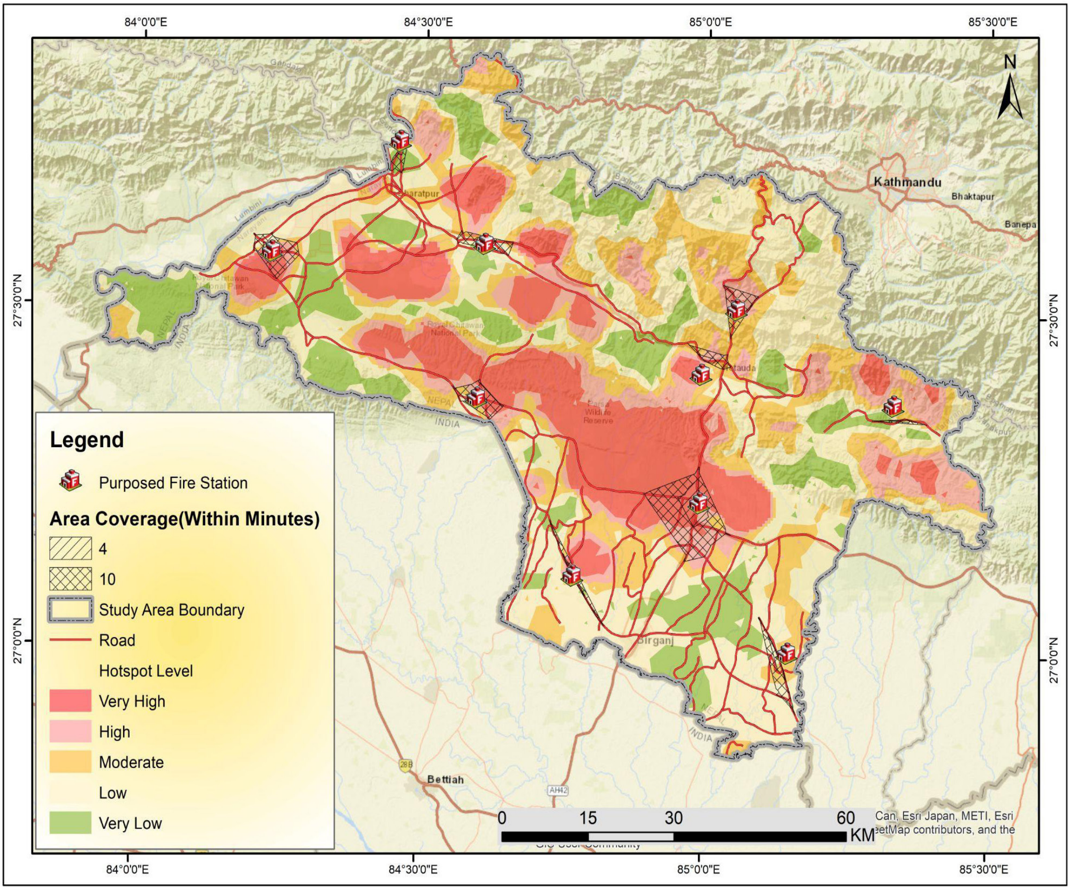

Figure 9(a): Fire Station Area Coverage with Maximum Speed in Terai (100km/hr) and Chure/Hill (60km/hr)

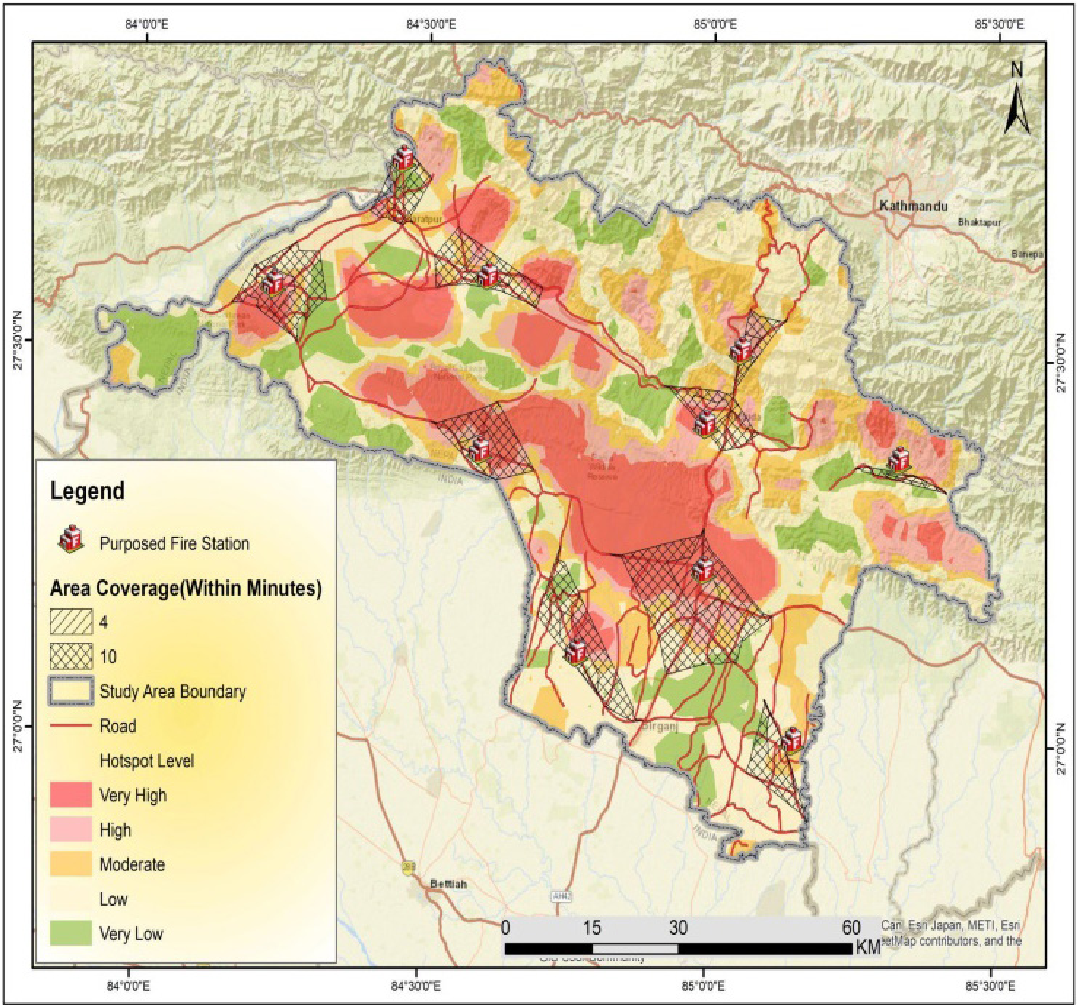

Figure 9(b): Fire Station Area Coverage with Minimum Speed in Terai (60km/hr) and Chure/Hill (30km/hr)

DISCUSSION

Annually, about 400,000 hectares of land is damaged by forest fire in Nepal (Bajracharya 2002). According to the study by Kunwar and Khaling 2006, 58 per cent of the total forest fire accounts to deliberate burning by grazers, poachers and non-timber forest products collectors, 22 per cent to negligence, and 20 per cent to accidental burning, and this varies across the physiographic zones. Our study found that Siwalik zone has the highest concentration of hotspots followed by Terai whereas cold spots are mostly concentrated in the Hilly region. In contrast to our finding, Bhujel *et al.* (2017) mentioned that Terai region accounts to the highest wildfire density with 0.05 incidence and 2.3 hectares per km^2 during 2000-2015, which climbed up to 0.16 wildfire incidence and 6.4 hectares per km^2 in 2016. Siwalik region ranks second in recording high wildfire density which was followed by mid hills of Nepal. This, could be due to the fact that this study only covers four districts of central Nepal unlike in Bhujel *et al.* (2017).

For the purpose of this study, Getis Ord Gi* tool of ArcGIS software was used for the fire hotspot analysis using five years (2017-2021) fire occurrence data acquired from VIIRS. Kumari and Pandey (2020) and Zahran *et al.* (2020) have also used the same tool for hotspot mapping where the authors have used 17 years of fire events data from MODIS and 10 years data from the country's Fire and Rescue Department respectively. On the other hand, Matin *et al.* 2017 have taken natural parameters (vegetation, humidity, elevation, slope and aspect) and anthropogenic parameters (proximity to settlements and roads) for forest fire risk zone mapping. Similarly, Pandey and Ghosh (2018) considered biophysical parameters for fire risk zoning using Analytical Hierarchy Process (AHP). The authors used a parametric approach for fire risk zoning whereas this study has adopted the Inverse Distance Weighted technique of ArcGIS (non-parametric approach) for fire risk zoning.

In addition, Kumari and Pandey (2020) which have used the similar techniques have differentiated fire risk map into five categories which supports the logic for having five hotspot categories (Very low, Low, Moderate, High and Very high). The red zone requires greatest concern from relevant authorities for forest fire management whereas the blue zone requires minimal interventions and management approaches. Thus, different levels of attention are required by areas that are characterized as high, moderate and low.

Fire data from VIIRS depicted an increasing fire events in the recent years. Similar incremental trend was observed by Said *et al.* (2017). Through these fire events over years, Getis Ord Gi* tool provides output in terms of GIZscore which helps in classification of hotspot and cold spot (Kumari and Pandey 2020). Moreover, the value of highest GIZscore found by Said *et al.* (2017) and Rossi and Becker (2019) were 1.576269 and 2.58 respectively. Comparatively, the value found by this study was 6.969622 which is much higher to the rest of the previous studies. This higher value signifies more intense clustering of hotspots (Santiago and Kheladze 2011) which in turn denotes that the study area is more prone to fire risks and needs immediate management measures.

As a fire management intervention, Said *et al.* (2017) also have used the same tool for fire station coverage in Brunei Muara district of Brunei Darussalam, as in this study where additional data on population and existing fire stations was used. Podolskaia *et al.* (2019) have also considered similar approach but the difference lies in the fact that they already have fire stations in Irkutsk region of Russia which they want to expand whereas it's a completely novel step for Nepal. Thus, it creates an opportunity for further study in this fire station field.

This study proposed 10 potential fire stations in the study area on the basis of road network/ access and standard time period of fire flashover. Those fire stations couldn't cover forest fire risk zones entirely. Meanwhile, Said *et al.* (2017) and Podolskaia *et al.* (2019) have proposed additional forest fire stations to existing one in order to provide broader coverage to the fire risk zone. This was possible because of developed road facilities in those study areas whereas the scenario is not the same in case of this study, as the road access is mandatory for any fire stations to function properly, however, this is lagging behind in case of Nepal. In India, the Forest Fire Prevention Committee (FFPC) is functioning as an effective forest fire management strategy in different states with no road access (Satendra and Kaushik 2014).

In case of Nepal, the Ministry of Forests and Environment along with underlying departments are the major responsible government bodies for forest fire management. However, no formal institutional setup has been formulated till date (Sharma and Regmi 2018). Thus, this study can serve as an important basis for advancing existing forest fire management strategy with proposed probable fire stations in hotspot areas with road access.

CONCLUSIONS

Nepal is highly prone to forest fire with increasing trend in recent years resulting in huge damage and degradation of forest area. This paper adopts Getis Ord Gi*, a hotspot analysis tool of ArcGIS software using five years of fire events data from VIIRS for the identification of the forest fire hotspot in the study area. A forest fire risk map was prepared which showed that the forest fire hotspot is highly concentrated in the Churia region followed by Terai and Mid-hills. Management interventions are crucial in order to tackle this challenge. However, there is paucity in such approaches in Nepal. Thus, the study proposed 10 Fire stations, using neighborhood function tool in ArcGIS, in the areas with road access and would like to recommend the Forest Fire Management/prevention Committee for inaccessible areas as an appropriate fire management intervention for Nepal. This paper argues that fire stations should be recommended for all over Nepal by considering fire events of a longer time period.

REFERENCES

ArcMap. 2016. *Integrate. Environmental System Research Institute (ESRI).* (https://desktop.arcgis.com/en/arcmap/10.3/tools/data-management-toolbox/integrate.htm accessed on 21 June 2021)

Badal, D. and Mandal, R. A. 2021. Spatial Assessment of Forest Fire Distribution, Occurrence and Dynamics in Province-2, Nepal. *Biomedical Journal of Scientific & Technical Research*, **35**(2): 27441-27459.

Bajracharya, K. M. 2002. Forest Fire Situation in Nepal. *International Forest Fire News*, **26**: 84-86.

Bhujel, K. B., Maskey-Byanju, R. and Gautam, A. P. 2017. Wildfire Dynamics in Nepal from 2000-2016. *Nepal Journal of Environmental Science,* **5**: 1–8. https://doi.org/10.3126/njes.v5i0.22709

CBS. 2012. National Population and Housing Census 2011, National Report. Central Bureau of Statistics, Government of Nepal, Kathmandu, Nepal.

Coen, J. L. and Schroeder, W. 2015. The High Park Fire: Coupled Weather-wildland Fire Model Simulation of a Windstorm-driven Wildfire in Colorado's Front Range. *Journal of Geophysical Research,* **120**(1): 131–146. https://doi.org/10.1002/2014JD021993

Chuvieco, E. and Salas, J. 1996. Mapping the Spatial Distribution of Forest Fire Danger using GIS. *International Journal of Geographical Information Science*, **10**(3): 333-345.

DFRS. 2018. *Forest Cover Maps of Local Levels (753) of Nepal*. Department of Forest Research and Survey, Government of Nepal, Kathmandu, Nepal.

ESRI. 2007. GIS for Fire Station Locations and Response Protocol. ESRI, 380 New York Street, Redlands, CA 92373-8100 USA.

Gai, C., Weng, W. and Yuan, H. 2011. GIS-based Forest Fire Risk Assessment and Mapping. Paper presented in *Fourth International Joint Conference on Computational Sciences and Optimization*, 1240-1244.

GoN. 2013. Nepal Road Standard. Ministry of Physical Infrastructure and Transport Department of Roads Planning and Design Branch Road and Traffic Unit Babarmahal. Government of Nepal, Kathmandu, Nepal.

Guettouche, M. S. and Derias, A. 2013. Modelling of Environment Vulnerability to Forest Fires and Assessment by GIS Application on the Forests of Djelfa (Algeria). Journal of *Geographic Information System*, **5**(1). 10.4236/jgis.2013.51003

He, Y., Lin, Y. and Wu, M. 2010. The Effect on Organizational Performance by Human Resource Management Practices: Empirical Research on Chinese Manufacturing Industry. Paper presented in International Conference on Management and Service Science. 1-6.

Johnson, E. A. and Miyanishi, K. (Eds.). 2001. *Forest Fires: Behaviour and Ecological Effects.* Academic Press, London, UK.

Kumari, B. and Pandey, A. C. 2020. MODIS-based Forest Fire Hotspot Analysis and its Relationship with Climatic Variables. *Spatial Information Research*, **28**(1): 87-99.

Kunwar, R. M., and Khaling, S. 2006. Forest Fire in the Terai, Nepal: Causes and Community Management Interventions. *International Forest Fire News*, **34**: 46-54.

Lillesø, J.-P. B., Shrestha, T. B., Nayaju, R. P. and Shrestha, R. 2005. *The Map of Potential Vegetation of Nepal*, 86. Center for Skov, Landskab og Planlægning/Københavns Universitet. Development and Environment No. 2/2005.

Matin, M. A., Chitale, V. S., Murthy, M. S. R., Uddin, K., Bajracharya, B. and Pradhan, S. 2017. Understanding Forest Fire Patterns and Risk in Nepal using Remote Sensing, Geographic Information System and Historical Fire Data. *International Journal of Wildland Fire*, **26**(4): 276. https://doi.org/10.1071/WF16056

Merrill, D. F. and Alexander, M. E. 1987. Glossary of Forest Fire Management Terms. Canadian Committee on Forest Fire Management, National Research Council of Canada: Ottawa, ON, Canada.

Oğurlu, İ. 1990. Determination of Optimum Fire Observation Point using Set Covering Model. *Turk. J. Agric. For*, **14**.

Pandey, K. and Ghosh, S. K. 2018. Modelling of Parameters for Forest Fire Risk Zone Mapping. *ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* XLII, **5**: 299-304.

Podolskaia, E., Ershov, D. and Kovganko, K. 2019. GIS-analysis of Ground Transport Accessibility of Fire Stations at Regional Scale. *International Cartographic Association*, **1**: 301.

Radu, R. 2020. *Understanding Climate Change in Nursing Practice: An Educational Tool for Nurses*, PhD dissertation, University of British Columbia, Vancouver, Canada.

Rossi, F. and Becker, G. 2019. Creating Forest Management Units with Hotspot Analysis (Getis-Ord Gi*) over a Forest affected by Mixed-Severity Fires. *Australian Forestry*, **82**(4): 166-175. https://doi.org/10.1080/00049158.2019.1678714

Said, S. N. B. M., Zahran, E.-S. M. M. and Shams, S. 2017. Forest Fire Risk Assessment using Hotspot Analysis in GIS. *The Open Civil Engineering Journal*, **11**(1): 786–801. https://doi.org/10.2174/1874149501711010786

Santiago, I. T. and Kheladze, N. 2011. GIS Wildland Fire Hazard Modeling in Georgia. Matra Project Report, Caucasus Environmental NGO Network.

Satendra, and Kaushik, A. D. 2014. *Forest Fire Disaster Management* (Edition: First). National Institute of Disaster Management, Ministry of Home Affairs, Govt. of India.

Sharma, S. P. and Regmi, S. 2018. Forest Fires in Nepal: Current Situation, Challenges and Future Directions. *Hamro Ban* (Fiscal Year 2074/75), Department of Forest and Soil Conservation.

Sivrikaya, F., Akay, A. E., Oğuz, H. and Yenilmez, N. 2011. Mapping Forest Fire Danger Zones using GIS: A Case Study from Kahramanmaraş. In the 6th *International Symposium on Ecology and Environmental Problems*, 17-20.

Sivrikaya, F., Sağlam, B., Akay, A. E. and Bozali, N. 2014. Evaluation of Forest Fire Risk with GIS. *Polish Journal of Environmental Studies*, **23**(1).

UN-Spider. 2015. Detecting Forest Fires with Satellites MODIS and VIIRS. United Nations Office for Outer Space Affairs. (https://www.un-spider.org/news-and-events/news/detecting-forest-fires-satellites-modis-and-viirs accessed on 2 July 2021)

Wubuli, A., Xue, F., Jiang, D., Yao, X., Upur, H. and Wushouer, Q. 2015. Socio-demographic Predictors and Distribution of Pulmonary Tuberculosis (TB) in Xinjiang, China: a spatial analysis. *PloS one*, **10**(12): e0144010.

Xanthopoulos, G. and Nikolov, N. 2019. Wildfires and Fire Management in the Eastern Mediterranean, Southeastern Europe, and Middle-east Regions. *Fire Management Today*, **77**(1): 29-38.

Zahran, E.-S. M. M., Shams, S. and Said, S. N. B. M. 2020. Validation of Forest Fire Hotspot Analysis in GIS using Forest Fire Contributory Factors. *Systematic Reviews in Pharmacy*, **11**(12): 249-255. http://dx.doi.org/10.31838/srp.2020.12.40