THE APPLICATIONS OF REMOTE SENSING AND GIS IN MODELING FOREST FIRE HAZARD IN MONGOLIA

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ABSTRACT:

Fire is one of the disasters causing threats to the forests and the ecosystem through out the world. Fires have adverse effects on soil, forests and humans. During the process of burning, the soil nutrients are reduced and the soil is left bare making it more susceptible to both soil and water erosion. The forest cover is drastically reduced through the death of fire intolerant tree species. Furthermore, animal populations dwindle due to their death and others migrate due to loss of their habitats. Fire also leads to an increase in green house gas emissions. Air pollution due to smoke causes prolonged effects on human health such as respiratory and cardiovascular problems. Mongolia has a serious increase in forest fires. According to fire statistics, most of fires burned within the central and eastern parts of the forested areas. The mentioned areas are susceptible to fire because of the high flammability of the pine and larch stands. Mongolia has two fire season peaks. One peak is from March to mid June which accounts for 80% of all fires, while the other peak is from September to October which accounts for 5% of all fires. On average about 50-60 fires occur annually and the largest occurrence of the fires are human caused. According to statistics, it was revealed that since 1981 to date, fires have occurred and hundreds of thousands of hectares of forests have been destroyed. Therefore, it is vital to have correct and timely knowledge of the total area burned and the type of forest burned. It is impossible to effectively manage fires without a clear and correct understanding of the distribution and dynamics of forest fires. Remote Sensing and GIS can play an important role in detecting burnt forest and developing a spatial model to predict potential forest for fire. This study demonstrates the effective use of geo-information as a main source of information on fire. The study aims at developing a fire risk model for Mongolian forests. The ultimate goal is to manage and prevent fire from happening in Mongolian forests. The study is conducted in Batsumber District in Tov Province of Mongolia. Low spatial resolution MODIS 250 and 1000 meters and high spatial resolution ASTER 15 meter images are used in this study. The research is focused on mapping the land cover types in the study area, detecting and mapping burnt areas as well as developing a fire hazard model to identify fire prone areas using parameters such as forest cover types, topography, road network, habitation, rivers and weather parameters. Forest stand parameters such as, forest type, tree species and forest density are also be used in developing the model.

1. INTRODUCTION

Forest fires in Mongolia, particularly Batsumber, occur frequently. In spite of the repeated occurrence of the fire, detailed dependable up to date information about the precise spatial distribution and extent of forest fires is insufficient (FAO, 2006; George *et al.*, 2006; Justice *et al.*, 2002) . This is attributed to the fact that fire detection is partly depended on the use of course resolution data. How ever the detection of fire is heavily relied on traditional methods such as ground surveys. Ground surveys do not offer reliable information about the location of fire scars, size and intensity due to the small areas that can observed influenced by unfavourable. This scenario results in a lot of underestimations of the fire extent emanating from lack of monitoring and recording of fire occurrence in inaccessible areas and high costs of the ground surveys. This state of affairs has led to a non harmonization in the burnt area statistics. Furthermore, there is no cartographic representation of the burned areas (Chuvieco, 1999). Without reliable information about the extent of fires, fire management is totally difficult to handle (Chuvieco, 1996).

Due to the negative impacts caused by fire, there is a need to manage the fires effectively so that the negative effects are reduced. A critical issue that affects effective fire management is lack of reliable records about fire incidence and its spatial distribution (Chuvieco, 1999). Without a clear and correct understanding of the distribution and dynamics of forest fires, it is impossible to effectively manage them (Goldammer & de Ronde, 2004). No phenomenon has ever been controlled before it was completely understood. This concept is applicable to the prevention and control of fires. Therefore, land managers require up to date information and maps about fire activity so that they are in a better position to manage the fires efficiently. Policy makers and resource managers need to be provided with reliable, accurate and detailed information about the burned areas so that fires are managed efficiently.

There is a direct link between the availability of information about burned areas and sound decision making for effective fire management because information is a foundation for a well structured decision for effective fire management (Chuvieco, 1999).Acquisition of the lacking information about the fire statistics need to be gathered and processed on a regular basis and in an efficient and swift manner. Owing to the nature of fire and its extensive geographic extent, satellite remote sensing provides the only practical means of monitoring and acquiring information about the spatial distribution of fire scars and fire activity.

Given enormous geographic extent over which to gather information, remote sensing and GIS offer an appropriate way of acquiring information on a regular and permanent basis even in areas where accessibility is limited (Chuvieco, 1999). Remote sensing permit the capture of types of data that humans cannot sense such as near infrared and thermal part of the electro magnetic spectrum, which provide additional information. Furthermore, remote sensing provide regular observations allowing for regular updates of the fire situation (Goldammer & de Ronde, 2004). Additionally, remote sensing has the advantage of presenting different spectral reflectance characteristics between the fire scars and healthy vegetation especially in the infra-red part of the electro magnetic spectrum (Goldammer & de Ronde, 2004). Through the application of GIS and remote sensing, the objective of effective fire management can be achieved. Remote sensing in monitoring fire activity in Mongolia, specifically Batsumber, has been applied although mainly for detecting active fires where AVHRR/ NOAA sensor is used. The spatial extent of burning can not be approximated consistently from active fires because the satellite may not pass at the time burning is taking place and the clouds may prevent active fire detection (Justice *et al.*, 2002). Additionally accurate detection is hindered when there is smoke and when the fire is too tiny or has low heat intensity (George *et al.*, 2006). Additionally, Fire detection is relied on field observations which may result to the non detection of fires in areas which are inaccessible.

The objectives of this research work were: to assess and compare the ability of Landsat TM data and MODIS NDVI data in detecting and mapping fire scars, to monitor and assess the trend in fire incidence with time using Landsat TM images, to analyse the fire regime for the study area and to assess the extent to which biophysical factors influence the likely occurrence of fire. Consequently, a fire hazard model can be developed for Mongolia.

2. STUDY AREA

The study was conducted in Batsumber found in Tov province of Mongolia. It is about 62km from the capital city of Ulaanbaatar. It is located between latitude 48°11'N to 48°39'N and longitude 106° 47'E to 107° 19'E. It is 36 km x 52 km in size. The area was selected because it is susceptible to fires and most of the parts within the study area are accessible making the collection of field data possible. Additionally, remote sensing approaches have not been applied in mapping the fire scars within this area. The area has an average elevation of 1,100 meters above sea level covered with hills and mountains. The eastern part of the area which is close to the mountains has an elevation ranging from 1,500 to 2,100 meters above sea level and the maximum elevation is 2,400 meters above sea level. The study area has an extreme continental type of climate with long winters and short summers. The temperatures vary through out the year. The hottest is the summer season which is from June to August with a temperature range of +29.5°C to +43°C. The coldest is the winter season from December to February with temperatures varying from -35.6°C to -46.7°C. The area receives an average precipitation of 93.5 to 273.5 millimetres per year and it increases in summer from June to August. The soil temperature varies according to the season. The highest soil temperature is in the summer season from June to August with an average soil temperature range of 10 to 20 degrees Celsius. The lowest soil temperatures are in the months of December and January with a soil temperature range of -18 to -20. The speed of the wind is highest in the months of April to July. The area has various soil types which are differentiated according to colour and elevation. The brown and dark brown soils are found on an elevation of 1,400 meters above sea level, black soils are found on an elevation ranging from 1500 to 1700 meters above sea level while grey soils are found on an elevation of 1800 to 2000 meters above sea level. There is one big river namely Kharaa which has several tributaries.

The area has different land cover types which include the forests, Shrub lands, burnt areas, pastureland and bare soil. It has heterogeneous mixtures of forest tree species and in some areas, homogeneous tree species are found. The different tree species found are: *Larix sibirica, Betula phatiphylia, Pinus sibirica, Pinus Sylvestris Picea obovata, Populus tremulia*, and *Populus labrifulia. Larix sibirica* is the most dominant tree species. Tree species are distributed according to elevation. *Pinus silvestris* and *Larix sibirica* are found on an elevation of 700 to 1200m above sea level, *Larix sibirica* is found on an elevation of 1,500 to 1,800, *Pinus sibirica* and *Larix sibirica* are found on an elevation of 1,800 to 2,000 meters above sea level. Apart from trees, shrubs are also found in the area covering 4,976 hectares of land. The shrubs found are; *Rhododendron dahuricum*, *Carex lanceolota*, *Pteridium anguilium*, *Rosa acicularis* and *Ledum palustre*. The table below shows the tree species distribution by area in hectares and in percentage form.

The study area is susceptible to fire. It experienced fires in the year 1990, 1996, 2003, 2005, 2006, and 2007. The areas mostly affected by fire were Bayangoliin, Sharjulga, Shatan, Shurguut. Figure 1 shows how much area in hectares was consumed by fire for the years 2005, 2006 and 2007.

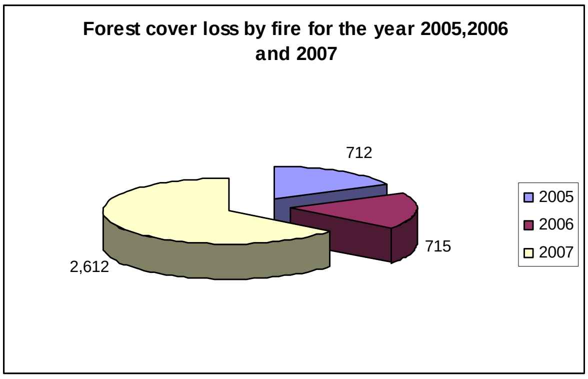

Figure 1: Forest cover loss by fire in hectares

3. MATERIALS AND METHOD

Several data sets were essential for this research. These included the topographic map covering the study area at a scale of 1: 50,000. It was acquired from the survey department of Mongolia, the Digital Elevation Model, the roads shape file, the river shape file which were obtained from Information Computer Centre (ICC) particularly from the Remote Sensing and GIS Department. The habitations were digitised from the topographic map using GIS. The MODIS images were acquired from Http //edcimswww.cr.usgs.gov/ pub/imswelcome while Landsat TM images were purchased. Micro Soft excel, Micro soft word, ERDAS 9.1, Arc GIS, 9.2 and ILWIS 3.3 were used in the analysis.

During field work, several equipments were used to collect the required data. A densiometer was used to measure canopy density, a compass for measuring aspect, a measuring tape was used to measure crown diameter, Global Positioning System (GPS) receiver was used to locate the sample plots and clinometers were used for measuring slope. Figure 2 shows the method followed in this research.

4. RESULTS AND DISCUSSIONS

A comparison of the spatial distribution of fire scars mapped from Landsat TM and the MODIS NDVI was beneficial in assessing the accuracy of the fire scars mapped from the MODIS NDVI image. Fire scars were successfully mapped from Landsat TM and MODIS NDVI image, however, from visual inspection, the output fire scar maps appeared different. The different out put maps showed a distinct variation related to the spatial resolution of the two input images. Owing to the high resolution of the Landsat TM image, it was possible to detect small sized fire scars with much detail contrary to the low resolution MODIS NDVI image which could not detect the fire scars with much detail. Although Landsat TM gave much detail in fire scar mapping as compared to MODIS NDVI, some agricultural land overlapped with the fire scars because they had the same reflectance as the fire scars. Even if there were some overlap in the classification of the fire scars and agricultural land, the results from the classification are accurate in that the validation of the map was done using ground truth data which is a true reflection of the ground situation.

It was observed that the trend in the size of fire scars increased with time. In the year 1989, there were no fire scars in the study area, in the year 2000, 11,688 hectares of fire scars were mapped while in the year 2007 a total of 15, 363 hectares of fire scars were mapped. There is an increasing trend in fire scar size from 1989 to 2007. These results are in agreement with what Pereira *et al.*, (2005) found in the Iberian forests of Portugal. He attributed the increase in the burnt areas to the extreme dry spells that influenced fire behaviour as well as the complex land use practices that resulted into several ignitions. The increase in fire scar size in Mongolia was as a result of the increased temperature and wind speed. In this study, an increasing tendency in fire scar size is most likely due to social economic change that led to increased human activities in the forest (FAO, 2006). Between 1990 to 2002, the living standard for most of the people in Mongolia dropped as a result, the majority of these people ventured into forest resource exploitation for survival. They used the forest for berry collection, fuel wood collection, hunting and illegal logging activities. The forest activities were further boosted by a high demand for mining poles, transmission poles, rail sleepers as well as the deer horns on the Chinese and south-eastern Asian markets. These forest activities are related to an increase in fire incidence in that as loggers are carrying out logging activities, they use mechanised equipment (chainsaws) which in the process produce sparks and start fires. Furthermore, during transportation of the forest products, sparks from the exhaust pipes of vehicles could cause fire. Additionally the loggers, the hunters and the berry collectors are a major source of fire when they throw the burning ends of cigarettes and when they leave the camp fires carelessly in the forest after use.

Climatic change is another possible factor responsible for the increasing size of fire scars. The frequency and occurrence of fire depends greatly on climate through weather conditions which allow fire to build up. A change of climate has an effect on the behaviour and ignition of fire (Chuvieco, 1999). In the year 1996 and 1998, the area experienced large fires from the month of February to early June of the same years which were mainly attributed to severe dry conditions (FAO, 2006). When the weather is dry it has an effect on relative humidity and temperature which directly affect the moisture content of the fuels. High relative humidity increase the moisture content of the fuels and low relative humidity reduces the moisture content of the fuels, on the other hand, high temperatures reduce the moisture content of the fuels while low temperature increase the moisture content of the fuels (Goldammer & de Ronde, 2004). Since ignition of a fire depends on fuel flammability, the 1996 and 1998 dry weather contributed to the incidence of fire by increasing the temperature and reducing the relative humidity in the air which further contributed positively to the flammability of the fuels by reducing their moisture content. Flammability of the fuels increases with reduced moisture content. Though the environment is suitable for a fire to start, it cannot start without the flammable material. High fuel moisture contents in the fuels reduce the possibility of the fire even in the presence of an ignition source. The climatic change which resulted in dry spells during 1996 and 1998 played a major role in the reduction of the moisture content of the fuels thereby increasing their flammability and consequently increase the possibility of fire incidence.

The fires were said to be prevalent in the summer season when both air and soil temperatures were high. This is from April to June. The influence of temperature on fire behaviour is to reduce the moisture content of the fuels. When temperatures are low, the moisture content of the fuels is high making the ignition difficult while when temperatures are high, the moisture content of the fuels is reduced resulting into easy ignition of the fire (Goldammer & de Ronde, 2004). The distribution of the average monthly air and soil temperatures in Mongolia are higher in the months of April to June. This is the reason why fires are prevalent around this time because of the increased air and soil temperatures. Wind is influential in the way the fire behaves. Wind influences fire behaviour by providing a lot of oxygen to the fire which later affect the drying rate of the fuels in front of a fire (Goldammer & de Ronde, 2004). An increase in the wind leads to an increase in the spread of a fire front. The stronger the wind, the faster will be the spread of a head fire whilst a decrease in the wind results into a reduced spread of fire. An increased wind speed in the summer season (April to June) confirms that fires are frequent during this time due to the effect of wind that makes the fire spread faster.

The research revealed that most of the fire scars were close to rivers and roads. This implies that forests close to the roads and rivers are susceptible to fires due to human activities that contribute to starting the fires either accidentally or intentionally. Movements on the road by humans, animals and vehicles create high chances of human caused fires.

The findings of the research showed that most of the fire locations were distributed further away from the habitation. The results of this study are odd especially that in this study area, the fires are caused by humans. It was expected that the highest distribution of the fire scars should have been at distances closest to habitation. The findings of this research reveal that other factors apart from distance from habitation (availability of the ignition source) influence the occurrence of fire such as availability and flammability of the fuels. It was observed during field work that habitations are very far away from forests. This could be the reason why fire scars are far away from habitation because illegal loggers being the cause of fires carry out their activities in forests which are far away from habitation. The other factor why fire scars are far away from habitation could be related to legal implication. People know that start fires is illegal and to avoid charges they would rather start fire away from settlement because they know that no one will easily see them.

The distribution of fire incidences was more in the elevation classes of 1,573 to 1,773 and 1773 to 2,023. There were small sizes of fires scars observed in the lowest elevation because higher elevations usually have higher incidences of fire than lower ones. On the other hand, highest elevations did not have fire incidences as a result of the general trend that temperature reduces while humidity increases with increased elevation. This implies that the moisture content of fuels on the highest elevation is high reducing the flammability of the fuels eventually reducing the chances of fire incidences. This distribution of fire scars within the middle elevation classes is attributed to species distribution as was observed during field work. Most of the trees were within the elevation classes of 1,500 to 2000. There were fewer trees observed in the low and very high elevations. On the highest elevations, vegetation was non existent because they were covered by rocks which can not support the growth of most tree species. The middle elevation classes are accessible as compared to high elevations which may lead to starting of fires due to human activities.

Slope plays a significant role in the spread of fire in that fire spreads rapidly up slope than down slop. The rapid spread of fire upslope is made possible with the wind which supplies more oxygen to the fire front and affects the rate at which fuels dry ahead of a fire front (Goldammer & de Ronde, 2004). An increase in the speed of wind results in an increased rate of fuel drying and consequently increasing the spread of fire. The results showed that most of the fire scars were distributed on steeper slopes than on the gentle slopes. This is because the spread of fire is more on steeper slopes than on flat slopes. Since the study area is mountainous, the steep slopes that have dominated it increase the spread of fires thereby increasing the areas consumed by fire.

Though aspect does not have an effect on ignition of the fire, it has an influence on the rate at which fuels dry consequently affecting fire behaviour (Goldammer & de Ronde, 2004). The research revealed that most fire occurrences were highly distributed on the North-western and Northern aspects. Aspect plays a role in species distribution because certain vegetation types are found on certain aspects (Chuvieco, 1999). Though it was mentioned that frequent fires are expected on the aspect which is exposed to the sun for long hours, in the study area, trees are mostly found on the Northern and North-Western aspects which are less exposed to the sun. This is because the Northern and North- Western aspect have a lot of moisture to support vegetation growth (Goldammer & de Ronde, 2004). This could be the reason why fire scars` are more prevalent in the Northern and North- Western aspect because the Southern which is more exposed to the sun is too dry and consequently barely have any vegetation to burn.

Vegetation and the forest type to be specific is influential in the ignition and spread of fire because some forest types are highly flammable as compared to others hence increasing the chances of fire occurrence. The ignition of a fire depends on fuel flammability. Though the environment is suitable for a fire to start, it cannot start without the flammable material. The results showed that most of the fires occurred in the coniferous forests than in the broad leaved forest which could have been due to the higher flammability of coniferous forests than the broad leaved forest.

Although there was a positive relationship between fire occurrence and distance from roads, rivers and elevation, the relationship shown by distance from habitation and fire occurrence is negative which justifies the reason for rejecting the null hypothesis stating that fire scars are expected in areas which are highly accessible. Therefore the alternative hypothesis is accepted because habitations' being a factor considered to contribute to high incidences of fire has shown opposite results.

5. CONCLUSIONS

The research showed that Landsat TM is more accurate in fire scar mapping than MODIS NDVI. This was proved by the overall accuracies obtained when the two sensors were used in the mapping of fire scars. An overall accuracy of 80% was obtained when mapping using Landsat TM while only 66% overall accuracy was achieved when mapping using MODIS NDVI.

The trend in fire incidence is in an increasing manner. The results showed that in the year 1989, there were no fire scars in the study area. In the year 2000, a total of 11,688 hectares of land was burned by fire. The year 2007 had a total of 15,363 hectares of land burned. These values show that indeed there is an increase in the incidence of fire. While the fire incidences showed an increasing trend, the forest cover was decreasing, however, the area of forest cover decrease was not linear to the area lost by fires. This implies that other factors such as illegal logging and insect infestation were responsible for the other losses.

It was found out that fires are more prevalent in the months of April, May and June. This is the time when both soil temperature and air temperature are high. The wind speed during these months also increase leading to high chances of fire occurrence. High temperatures reduce the moisture content of the fuels while increased winds speeds supply more oxygen to the fire front that reduces the moisture content of the fuels.

The different biophysical factors considered influenced fires differently. It was found out that most of the fire scars were located in distances close to the rivers and roads while the opposite happened with distance from habitation where an increase in the size of fire scars was observed further away from the settlement areas. Fire scars were higher in the middle elevation classes than the lower and higher elevations. Fire scars in relation to slope were observed in the middle slope classes than in the lower and higher classes. Aspect had an influence in fire occurrence in that most of the fires were in the north and north-western aspects as compared to other aspects. It was also discovered that with regard to forest types, more fires scars were observed in the coniferous forest than the broad leaved forests.

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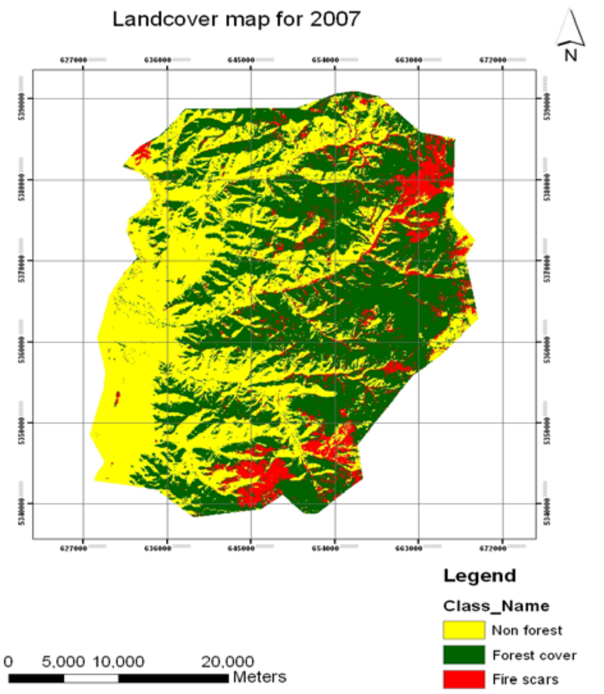

Figure 3 Distribution of forest cover and fire scars for the year 2007

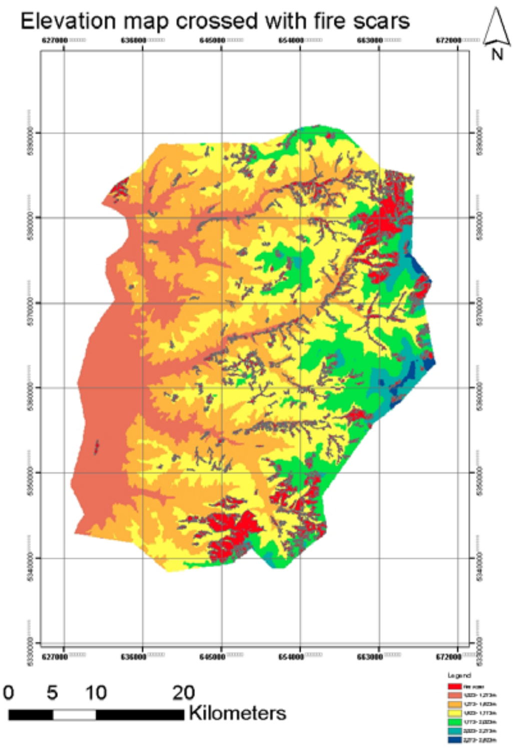

Figure 4. Spatial distribution of fire scars in relation to elevation.

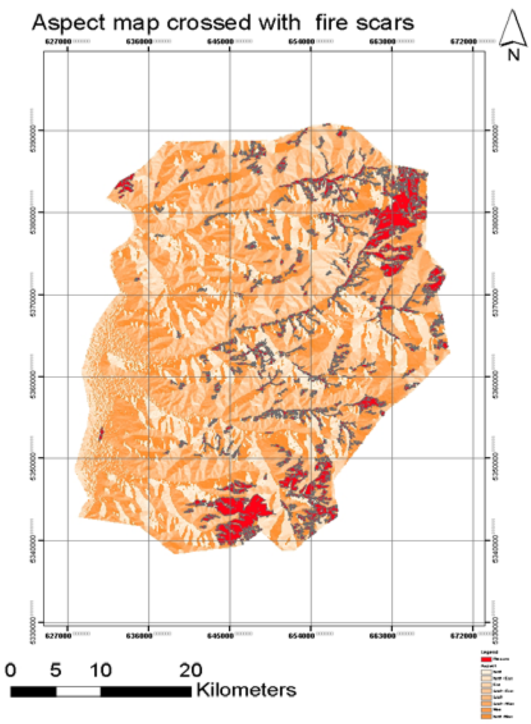

Figure 5. Spatial distribution of fire scar locations in relation to aspect.

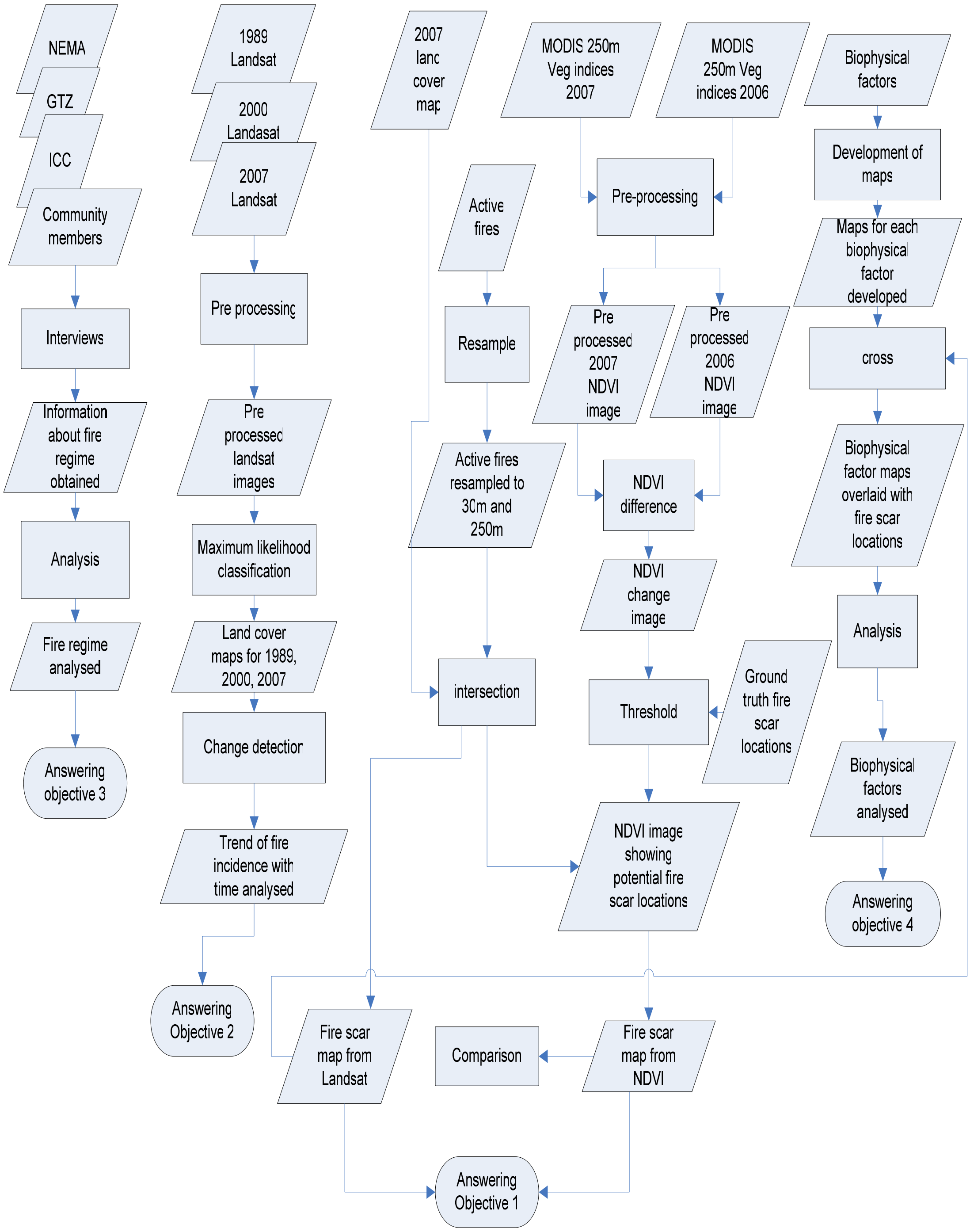

Figure 5. Research method and analysis