FIRE OCCURRENCE AND BURNING BIOMASS STATISTICS IN MONGOLIA

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ABSTRACT

In this paper discussed remote sensing and GIS analysis results of burned areas, calculation of burned biomass over Mongolian pasture lands and integration of results of comparison with some fire emission components.
In 1996, the National Remote Sensing Center (NRSC) has begun fire monitoring in Mongolia using NOAA-AVHRR data. It expanded its detection technology with the MODIS data in 2008, giving it a spatial resolution of 250 m, and developed a related methodology and technology for detection and monitoring of active fires and mapping of the burned areas over Mongolia.

Forest and steppe fires most frequently occur in Mongolia among Asian countries, due to its lower humidity and strong winds the driest seasons. According to scholarly surveys, 55.6% of the country's total area is located in a zone exposed to forest and grassland fires and a considerable fraction (98.5%) of the country's territories covered with forests are in a zone assessed as of highest fire risk.
The fire statistics were analyzed in five-year periods, and due to extremely high number of fire occurrences and extent of burning, the period of 1996-2000 ranked highest in all fire parameters (number of fires, burned area, damage etc.).

Additionally, a geodatabase of existing pasture biomass map with scale of 1:1 million established and used for integrated analysis with remotely sensed products in order to generate new outcomes as burned biomass in pastoral areas of Mongolia. The burned biomass calculation was done for pasture land. However, forest fires accounted for 22% of total fires, and are therefore further needed to consider burned forest biomass.
The results of Global Fire Emission Database were used for Mongolia and considered only carbon, carbon dioxide and methane in order to compare with burned biomass and these 3 types of pollutants were well correlated with burned biomass.

1. INTRODUCTION

The economic and social specific features of Mongolian nature and geography account for this country's considerable vulnerability to natural disasters. Mongolia has a typical continental climate, with hot summers (temperature up to 41^0C) and cold winters (temperatures to -53^0C). Rainfall is relatively low, varying from 50 mm in the southern desert region, to 450 mm in mountain areas, with 80% ~ 96% falling in the warm period from May to September. In the spring season (March-May), due to severe dry climate the wind is strong enough which can cause the quick spread of started fire on both forest and open steppe zones.

Forest and steppe fires most frequently occur in Mongolia among Asian countries, due to its lower humidity and strong winds the driest seasons (Figure 1). According to scholarly surveys, 55.6% of the country's total area is located in a zone exposed to forest and grassland fires and a considerable fraction (98.5%) of the country's territories covered with forests are in a zone assessed as of highest fire risk. About 95 percent of steppe and forest fires in Mongolia are caused by human activities.

Remote sensing and Geographic Information System (GIS) techniques help for detection of active fires, burned area estimation and geo-statistical analysis.

Pasture types and their biomass amounts were mapped in early 2000s. In the present study, we have analyzed the burned areas by integrating using the map we obtained, and tried to estimate burned biomass.

2. DATA SETS AND METHODOLOGY

Our forest and steppe fire detection methodology using NOAA – Advanced Very High Resolution Radiometer (AVHRR) data was developed in 1996 at the National Remote Sensing Center (NRSC) and the methodologies were upgraded and applied for MODerate resolution Imaging Spectrometer (MODIS) data by timing.

Each TERRA and AQUA satellites with MODIS sensor are covering Mongolian territory 2 times a day. The MODIS sensor has 36 channels with 250m, 500m and 1 km spatial resolution and generates some standard products such as, cloud mask, Normalized Difference Vegetation Index (NDVI), snow and fire hot spot. The fire products are generated based on the temperature anomaly values.

The statistical data on number of fire occurrence and burned area from 1963 to 2010 were analyzed for estimation fire risk zones and fire occurrence trends and analyzed over five years periods.

A digital pasture map was used for burned biomass calculation from 1996 to 2010.

2.1. Active fire detection

Active fires are determined on the basis of thermal band information and ground reflectance values of both satellites' data. In the NOAA-AVHRR imagery the fire spots are mostly identified by different band combinations and also temperature values.

The fire product from MODIS data consists of two different parts; one is the hot spots geographic location file and the other is red dots extracted from raw imagery at 1km spatial resolution. At the NRSC we are still working on the checking or validation procedure of the hot spots and on fire map generation at 250m resolution.

2.2. Burned area calculation

After spring and autumn forest and steppe fire stop completely, we produce a map of the burned area for the whole territory of Mongolia. Our main method for mapping the burned area has been an unsupervised classification method with simple digitizing techniques for calculating the burned area, using image processing and GIS software.
In real time, we generating value added fire maps with rough estimation of active fire area, such as the width and length of the burning area in terms of kilometers. The MODIS data based calculation of the burned area is estimated to be 16 times better than that using National Oceanic and Atmospheric Administration (NOAA) satellite data.

2.3. Burned biomass estimation

The pasture (hay) map of Mongolia was developed in the early 2000s and it indicates biomass amount of each pasture type. We extracted yearly burned biomass amount from this map for the period of 1996 to 2010.

3. RESULTS

3.1. Fire detection

Since the establishment of a NOAA satellite receiving station at the NRSC of Mongolia in 1987, the staff of the Center has developed and tested technologies for monitoring natural disasters, such as forest and steppe fires, droughts, floods, meteorological phenomena etc.

The recent fire danger situation in forest and steppe zones has challenged the staff of the NRSC to test and improve their operational technology so as to process and transfer fire location and other data quickly to disaster-related and administrative organizations. In the last three years, 788 fires have been detected primarily by satellite data, thus saving millions of dollars. The accuracy of detected hot spots as fires is estimated to be 78.9% of the total number of cases between 1996 and 2009.

3.2. Burned area maps

Since 1986 we have mapped burned area twice a year, for spring and autumn. From that, we have mapped total burned area map for whole country (Erdenesaikhan and Erdenetuya 1999). After 2007, 250m MODIS data used, improving the accuracy of the burned area map. Figure 2 shows the size of burned forest and steppe areas and Figure 3 shows the burned area map for 1997, overlapped with pasture map of Mongolia which was used in estimation the burned biomass.

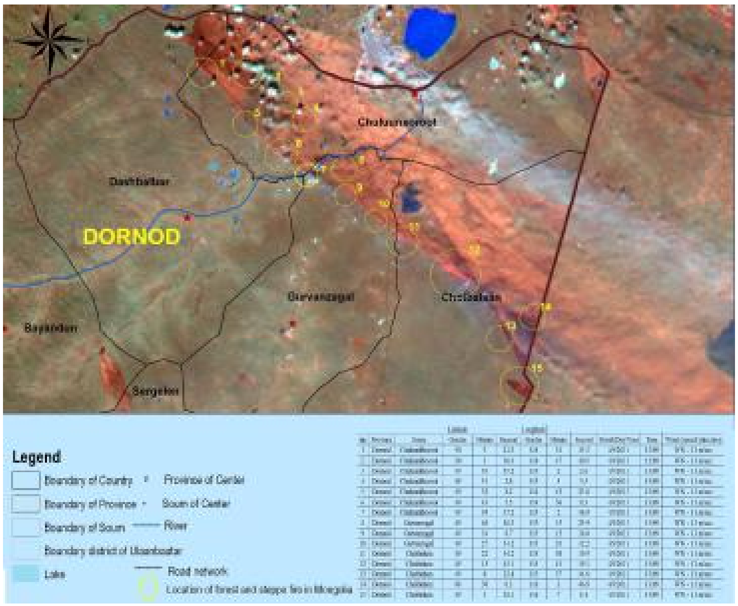

Figure 1. A forest and steppe fire on a detection map.
9 April 2011, TERRA and Aqua MODIS data, provided by NRSC of Mongolia

3.3. Fire occurrences statistics

The probability of occurrences of fire in the country's forests and steppe areas substantially increases in dry periods of spring and autumn. Over 60% of the forest fires are recorded to take place during a period from April to May and 65.5% breaking out in the afternoon, between 12.00 and 16.00 hours.

Although in most cases fire occurrences were triggered by man's actions (93.6%), there are also natural factors leading to fire occurrences. In other words, at times when the weather is dry, there is plenty of inflammable material in the forest and wind speeds are higher, all these factors provide favorable preconditions for fire occurrences. The probability of forest fire occurrences decreases to very insignificant when the amount of precipitation is over 2.0 mm. Fires raging in arid pastures are often associated with strong winds. On April 11, 1996, a violent wind rampaged through the territories of eastern *aimags* (provinces), a fierce steppe fire covering 711,000 hectares of Dornod Aimag's seven *soums* (sub provinces) killed 33,700 head of cattle, destroyed over 160 pens, 90 gers, causing damages estimated at MN 10.6 million (Mongolian tugrugs, April

2006 value: ca. $US 10000), and killing or injuring fourteen people. According to the recent statistics, 50-60 forest fires and 80-100 grassland fires are recorded in Mongolia every year (Wingard *et. al.* 1998 and updated).

The number of fire occurrence and the area affected by fires were analyzed by fife-year periods and are shown in Table 1. Winters and springs from 1996 to 1998 were extremely dry, with snow lacking in most areas. From late February to early June of these years, Mongolia suffered from large-scale forest and steppe fires that devastated large parts of the country. During these fire episodes 29 people died, 82 people were injured and 11,700 livestock were killed. Also, 218 family houses, 1,066 communication facilities, 750 fences and 26.3 million hectares of pasture and forest were burned (Goldammer, 2009). The total costs of property losses amounted to MN 820.2 million. Ecological and economical damages were estimated at MN 1,850.5 million (December 1999 value: ca. $US 1.8 million).

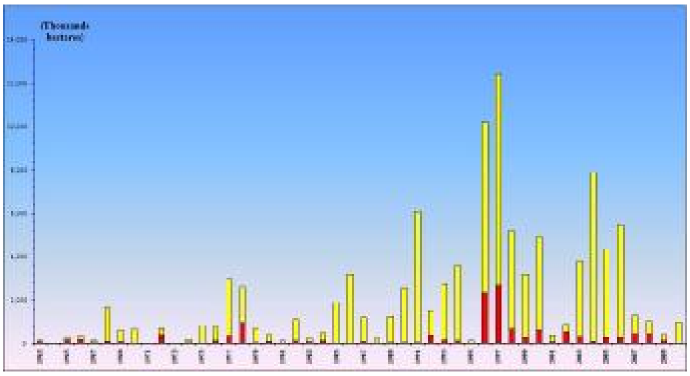

Figure 2. The burned forest and steppe area, 1963 – 2010

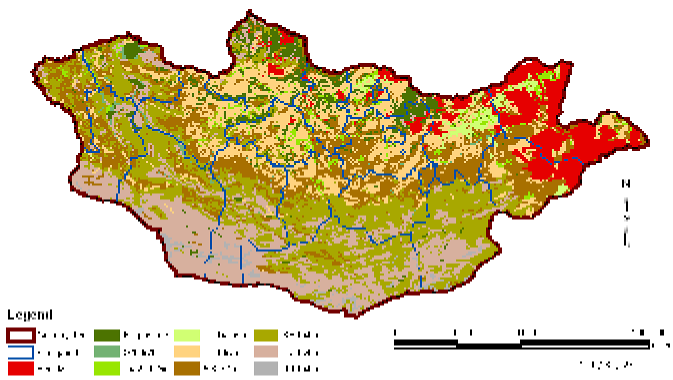

Figure 3. Burned area map of Mongolia generated from NOAA data, 1997

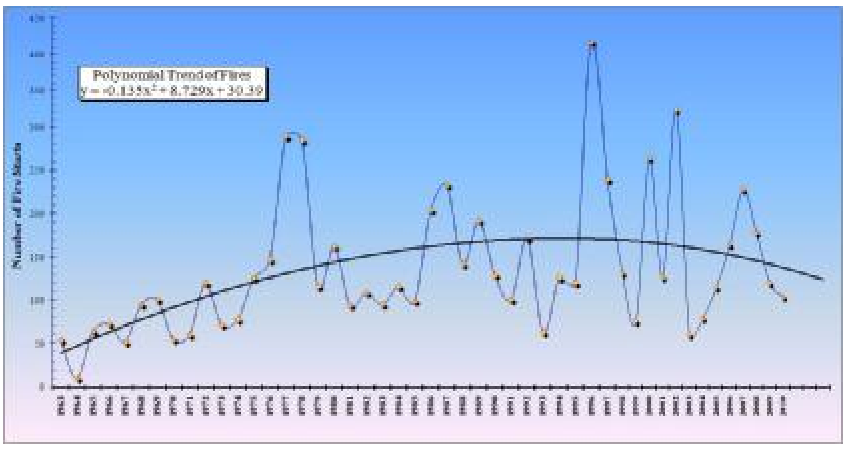

Figure 4. Number of fires occurred from 1963 to 2010

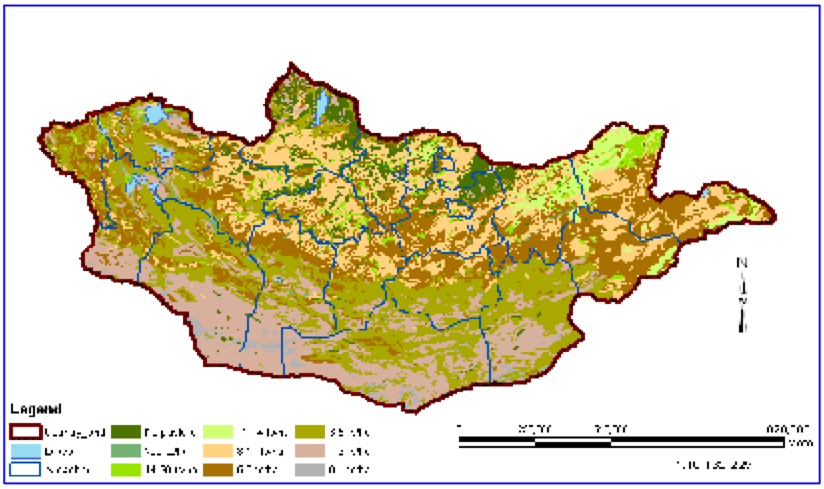

Figure 5. Pasture biomass map of Mongolia

Table 1. Number of fires and amount of area destroyed by fire (thousand hectares)

Years	Number of Fires	Total Burned Area (Thousand Hectares)	Average Hectares Burned per Fire Event
1966 – 1970	376	3520.3	9.4
1971 – 1975	456	1856.6	4.1
1976 – 1980	999	7529.0	7.5
1981 – 1985	513	3925.2	7.7
1986 – 1990	900	8516.0	9.5
1991 – 1995	581	14144.6	24.3
1996 – 2000	1128	35979.4	31.9
2001 – 2005	704	17205.6	24.4
2006 – 2010	710	8388.6	11.8

Due to extremely high number of fire occurrences and extent the period of 1996-2000 counted highest in all fire parameters. As for the amount of area affected by fires starting from 1980, some 25% of the country's forest resources or 2.4 million hectares of land were destroyed and their damages amounted to MN 32.6 billion in 1996.

3.4. Burned biomass calculation

Mongolia is a highland country located deep within the interior of Eurasia and has a marked continental climate with poor soil fertility, scanty surface water resources and harsh natural conditions.

Grassland comprises over 80% of its territory. It is assumed that most of today's steppe vegetation is on formerly forested sites that were degraded by fire. Wildfires constitute a major factor determining the spatial and temporal dynamics of forest ecosystems.

The burned biomass of each burned pasture type was extracted through GIS integrated analysis of pasture biomass map and a burned area map.

According to the results of the Global Fire Emission Database (GFED website) from 1997 to 2009, fire emission values of carbon, carbon dioxide and methane for all of Mongolia are seen to be fairly close to average of Central Asian countries and constitute less than 10 percent of total emissions, except 1997 (Figure 7).

Table 2. The burned biomass estimation

Years	Total burned area, ha	Total burned biomass, ts/ha	Burned biomass per ha area
1996	11,146,582.84	91,900,499.49	8.24
1997	12,840,587.58	106,228,449.24	8.27
1998	3,750,466.88	32,018,024.26	8.54
1999	3,199,709.26	24,857,472.19	7.77
2000	7,847,866.65	72,197,949.68	9.20
2001	855,241.39	9,112,004.08	10.65
2002	603,218.23	3,486,229.58	5.78
2003	3,083,190.77	27,910,489.36	9.05
2004	922,214.32	7,830,604.48	8.49
2005	725,093.30	6,756,216.46	9.32
2006	1,752,419.42	16,330,429.18	9.32
2007	3,026,175.43	24,742,481.26	8.18
2008	1,560,526.49	12,532,639.53	8.03
2009	1,004,219.31	5,475,135.04	5.45
2010	1,005,322.70	9,189,426.40	9.14

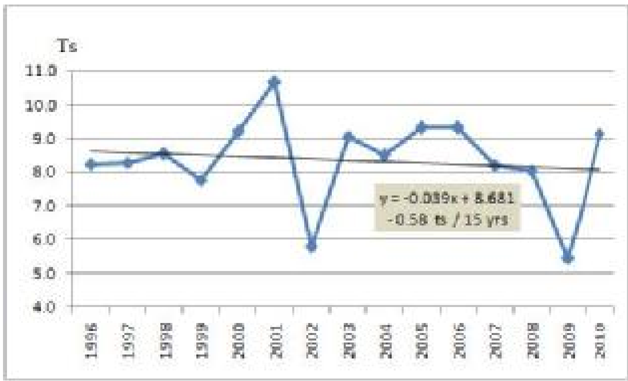

Figure 6. Burned biomass per hectare area

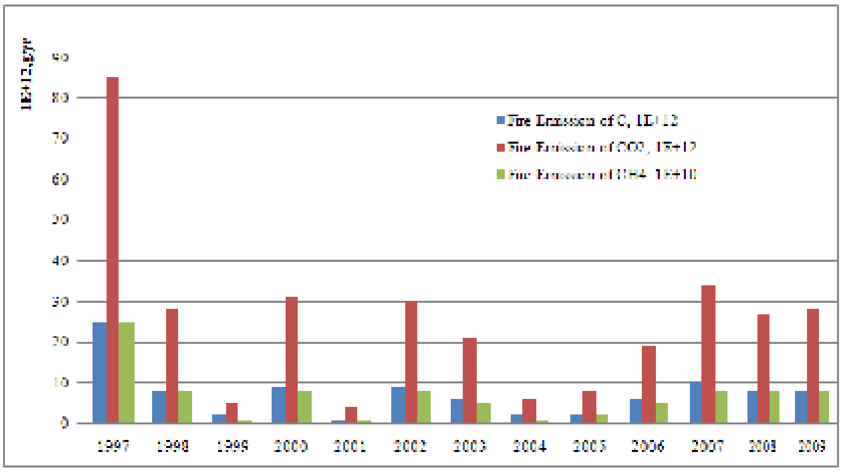

Figure 7. Fire emissions of C, CO2 and CH4 over Mongolia (from Global Fire Emission Database)

These data were obtained from ORNL DAAC by using the citation of Randerson *et. al* (2010). The GFED model developers have issued a notification requiring these values to be used carefully so in this paper we have just included statistical comparison and correlation of these components with burned biomass during this period. The above air pollutants were well correlated with burned biomass calculated using remote sensing and GIS techniques and in Figure 8 showed only correlation graphic with CO2 and burned biomass.

CONCLUSIONS

Our research showed that real time MODIS data is much accurate in fire-scar mapping than NOAA data. This was proven by the overall accuracies obtained when the two sensors were used in the mapping of fire scars.

The fire statistics were analyzed in five-year periods, and due to extremely high number of fire occurrences and extent of burning, the period of 1996-2000 ranked highest in all fire parameters (number of fires, burned area, damage etc.).

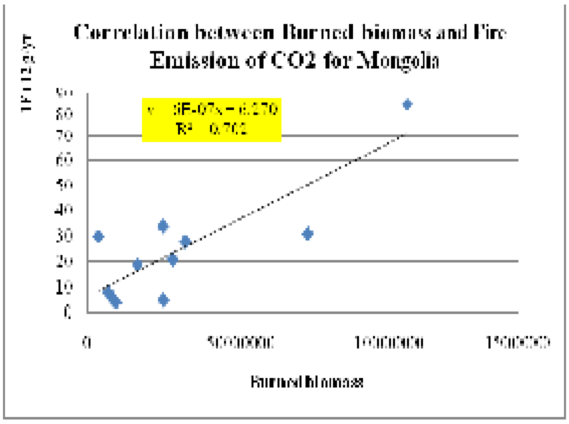

Figure 8. Correlation between fire emission component CO2 and burned biomass

The burned biomass calculation was done for pasture land. However, forest fires accounted for 22% of total fires, and are therefore further needed to consider burned forest biomass.

The results of Global Fire Emission Database were used for Mongolia and considered only carbon, carbon dioxide and methane in order to compare with burned biomass and these 3 types of pollutants were well correlated with burned biomass. This study should be continued with other gases.

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