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Method for Burned Forest Biomass Estimation at Subcompartment Level Using GF-1 images and GIS Datasets

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Abstract

To estimate the burned biomass and get the burned fuel types information by forest fire for the need of Chinese forestry management, basing on the fuel load from digital reference data, the combustion factor gotten from fieldwork, and the results of burned scar mapping by using the No.1 High-Resolution satellite (GF-1) of Chinese, the burned biomass estimation method at the subcompartment level has been developed using satellite images and Geography datasets. The method has been validated by the selected forest fire, which had taken place in Huangcaobai of Anning City, Yunnan province in year 2012.The total burned biomass is about 1.18 × 10^8 kg by using the panchromatic and multispectral scanners (PMS) image of GF-1; however, it is about 1.11 × 10^8 kg by using the Wide Coverage Image (WFV) of GF-1. The difference between them is 7.10 × 10^6 kg. This study also supplies a method for the single forest fire case when the fire radiative power (FRP) or fire radiative energy (FRE) of detected active fire points by using sparse low spatial resolution satellite images doesn't satisfied the condition of Power Law distribution or Gaissian function.

Keywords: Burned forest biomass; GF-1; Forest fire; Remote sensing technique

Introduction

Vegetation biomass burning has been identified as a significant source of aerosols, carbon fluxes, and trace gases, which pollute the atmosphere and contribute to radiative forcing responsible for global climate change [1,2]. The trace gas from vegetation biomass burning has been paid more attention from the scientific community over the past several decades as an important contributor to total climatic radiative forcing [3]. Spatial and temporal explicit mapping of the amount of burned biomass by fire is needed to estimate atmospheric emissions of greenhouse gases and aerosols that have a significant climate forcing effect. The methods for burned biomass estimation have been recently developed according to the assumption that the fire radiative power (FRP) or fire radiative energy (FRE) satisfies the Power Law distribution function or Gassian function [4-9]. In fact, the active fire points are so spare by using the low spatial resolution polar orbit satellite images [10-13]. The spare FRP or FRE of a single forest fire case usually doesn't satisfy the Power Law distribution function or Gassian function. In this case, it isn't suitable to estimate the burned forest biomass by using the methodology based on the model of Power Law or Gassian. In China, the basic forestry management is at subcompartment level. The information of the burned fuel type, burned biomass, and damaged is need for the forest manager at the subcompartment level after the forest fire. To get the method for burned biomass estimation at subcompartment level, the Chinese satellite images and geography datasets have been selected as the data for the study.

Study area and Materials

Study area

The burned biomass of the same forest fire, which had taken place in Huangcaobai of Anning City, Yunnan province in March 19, 2012, has been selected as the experimental area for the method implement. The location of this study is shown in Figure 1.

The forest fire had lasted about 5 days. The local forest includes Dipan pine (*Pinus yunnanensis* var. pygmaea), Yunnan pine (*Pinus yunnanensis*), and Fir (*Keteleeria fortunei* (Murr.) Carr).

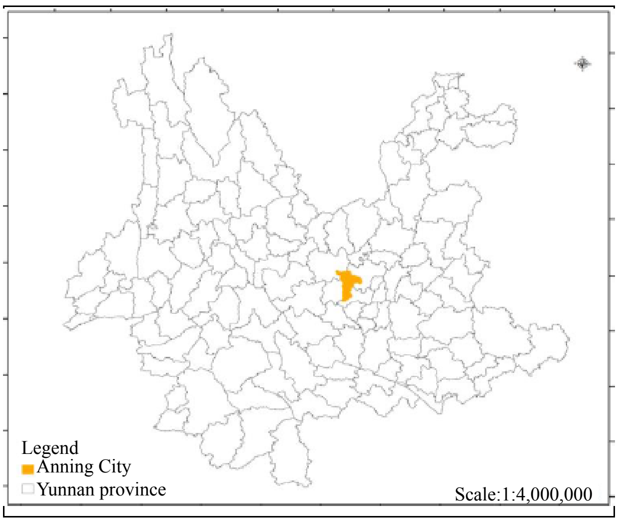

Figure 1: Experimental area.

Materials

The No.1 high-resolution satellite (GF-1) is the first series of Chinese high-resolution satellites, which had been successfully launched on April 23, 2013. Its' panchromatic and multispectral scanners (PMS) camera can get the 8 m multispectral image with blue, green, red and

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near-infrared band and 2 m panchromatic images. It also equipped with the Wide Coverage Image (WFV), which spatial resolution is 16 m. The main parameters of the GF-1 PMS and GF-1 WFV have been listed in Table 1.

To compare the difference by using different spatial resolution satellite images, the GF-1 PMS and GF-1 WFV images which cover the forest fire have been selected to the burned area mapping. The GF-1 WFV image of September 29, 2013 and the GF-1 PMS image of February 14, 2014 has been selected as the satellite image to get the burned area edge respectively because the burned area doesn't be covered by cloud. At the same times, to get the burned fuel type and biomass, the digital maps of fuel type and fuel load at subcompartment level have been collected from local institution.

Methods

After the reprocessing to the selected GF-1 WFV and GF-1 PMS data, the burned area has been respectively extracted using GF-1 WFV and GF-1 PMS data. The reprocessing includes radiometric calibration, orthorectification, atmospheric correction and resolution merger. Orthorectification using Rational Polynomial Coefficient (RPC) and Digital Elevation Model (DEM); Atmospheric correction using Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH) software; and resolution merger using Gram-Schmidt Pan Sharpening method for the Panchromatic and Multi-spectral Scaner of GF-1 PMS sensor in ENVI 5.1 software. The burned biomass can be calculated when the burned area, the fuel load and the combustion factor of every subcompartment have been known. The burned area can be gotten by using the selected GF-1 images. The digital fuel type and fuel load at subcompartment level have been collected from local institution. The flowchart of this study is shown in Figure 2.

Burned area extraction

The burned scar edge has been respectively extracted by using the GF-1 PMS image and GF-1 WFV in this study. The selected method for the burned scar edge extraction has been developed by Xiaofeng Zu, et al. [14]. Then, the burned area at subcompartment level can be gotten through the spatial analysis with the burned edge coming from satellite and the edge of subcompartment in ArcGIS 9.3 software.

Combustion factor estimation

The combustion factor of every subcompartment has been measured through filed work in this study. Their range has been assigned from 0 to 1.0, with an interval 0.1 according to the burned area and the severity of the subcompartment. The value is 0 for unburned subcompartment and 1.0 for complete burned.

Model

The model for burned biomass estimation at subcompartment level has been developed as Equation 1 based on the model of Seiler's [15].

Parameters	PMS cameras		WFV cameras
Wavelength	Panchromatic	0.45-0.90 μm	/
	Multi-spectral Scaner	0.45-0.52 μm (Band 1)	0.45-0.52 μm (Band 1)
		0.52-0.59 μm (Band 2)	0.52-0.59 μm (Band 2)
		0.63-0.69 μm (Band 3)	0.63-0.69 μm (Band 3)
		0.77-0.89 μm (Band 4)	0.77-0.89 μm (Band 4)
Spatial resolution	Panchromatic	2 m	/
	Multi-spectral Scaner	8 m	16 m
Frame width	60 km (combing 2 cameras)		800 km (combing 4 cameras)
Recycle (Shifting)	4 days		/
Recycle(No shifting)	41 days		4 days

Table 1: The parameters of GF-1 satellite image.

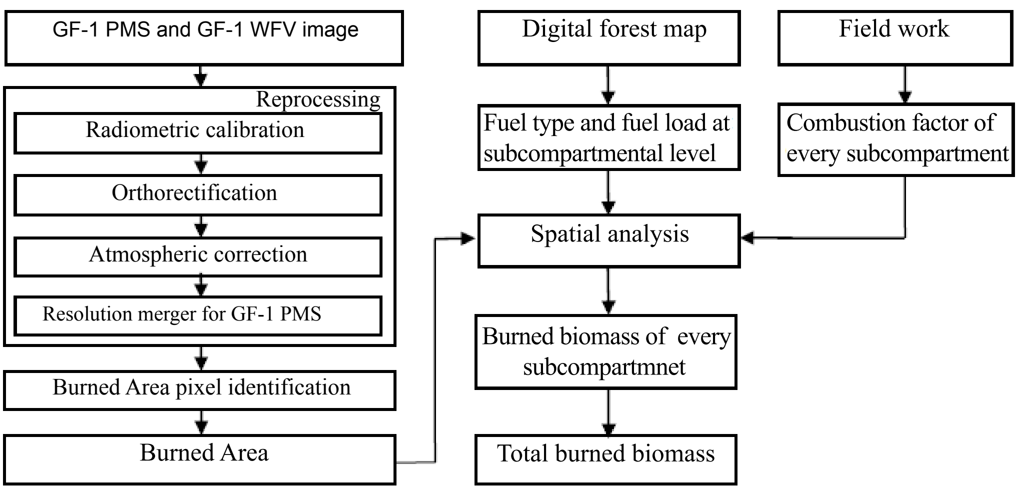

Figure 2: Flowchart illustrates the methodology of the study.

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$$M_i = A_i \times B_i \times F_i \quad (1)$$

Where: M_i is the burned biomass (kg) of the subcompartment i; A_i is the burned area (m^2) of subcompartment i; B_i is the fuel load (kg/m^2) of subcompartment i; and F_i is combustion factor (fraction of available burned fuel) of subcompartment i.

Then, the total burned biomass can be calculated using Equation 2.

$$M = \sum_{i=1}^{n} M_i \quad (2)$$

Where: M is the total burned biomass (kg); n is the number of sub-compartment.

Results

The results of burned area mapping by using the GF-1 PMS and GF-1 WFV have been showed in Figure 3. The results of estimated burned biomass according to the model and using the same classification value have been showed in Figure 4. It clearly shows the distribution of burned biomass from Figure 4, which can help the forest managers know the information of damaged forest and arrange the management in future.

Discussion

The effection of burned area mapping

The results of burned area mapping had been compared by using the GF-1 PMS image and GF-1 WFV image. To get the different between the burned area and the active fire points, the active fire points, which had been gotten from the Terra/Aqua MODIS active fire production (MOD14A1/ MYD14A1) during the forest fire, have been analyzed with the burned area mapping in ArcGIS 9.3 software. The results showed in Figure 5. As we can see from the Figure 5, the extracted burned scar edge was clearly different by using the GF-1 PMS and the GF-1 WFV image. The spatial resolution of GF-1 PMS is 2/8 meter at nadir; However, it is 16 meter for the GF-1 WFV image. The validation showed that the accuracy of extracted burned scar edge by using the GF-1 PMS image is higher than that of GF-1 WFV image. There is a large burned area that didn't covered by the active fire points from Figure 5.

At the same times, we also analysed the frequence of FRP of the active fire points. There were only 24 active fire points by using Terra/ Aqua MODIS during the five days. The results showed in Figure 6. It shows that the distribution of FRP of the selected forest fire doesn't satisfy the condition of Power Law distribution or Gassian. So, the burned biomass estimated methodology based on the distribution of Power Law or Gassian function couldn't be properly applied in the forest fire case.

Burned biomass analysis

The main burned fuel type and the difference of burned biomass had also been analysed. The relative error about the estimated burned biomass between by using the GF-1 PMS image and GF-1 WFV image has been also calculated using Equation 3. Because there are't the truth value of the burned biomass, the estimated burned biomass by using GF-1 PMS image has been selected as the based burned biomass. The R hasn't been calculated when the estimated value is 0 by using GF-1 PMS image or GF-1 WFV image. The results showed in Table 2.

$$R = \tfrac{D}{A} \times 100\% \quad (3)$$

Where: R is the relative error; A is the estimated burned biomass by using GF-1 PMS image; D is the difference of burned biomass according to the fuel type of subcompartment by using the GF-1 PMS image and GF-1 WFV image.

It shows that the main burned biomass is Dipan Pine from Table 2. Both of them are more than 9.00×10^6 kg. There are large difference between using GF-1 PMS and GF-1 WFV images from Table 2. The total difference between the value using the GF-1 PMS image and GF-1 WFV iamge is 7.10×10^6 kg. In this study, the fuel load coming from the reference data and the combustion factor gotten by filed work at subcompartment level; the burned scar edge has been extracted by using GF-1 PMS and GF-1 WFV images respectively. So, the difference comes from the different result of burned scar mapping.

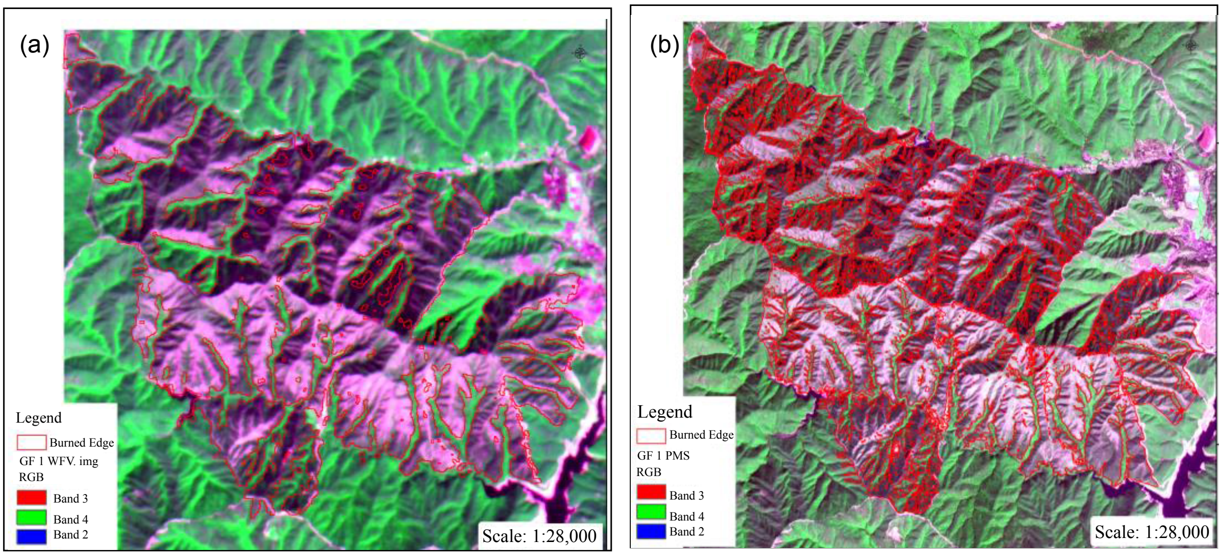

Figure 3: The results of burned area mapping (a) Using GF-1 WFV image; (b) Using GF-1 PMS image.

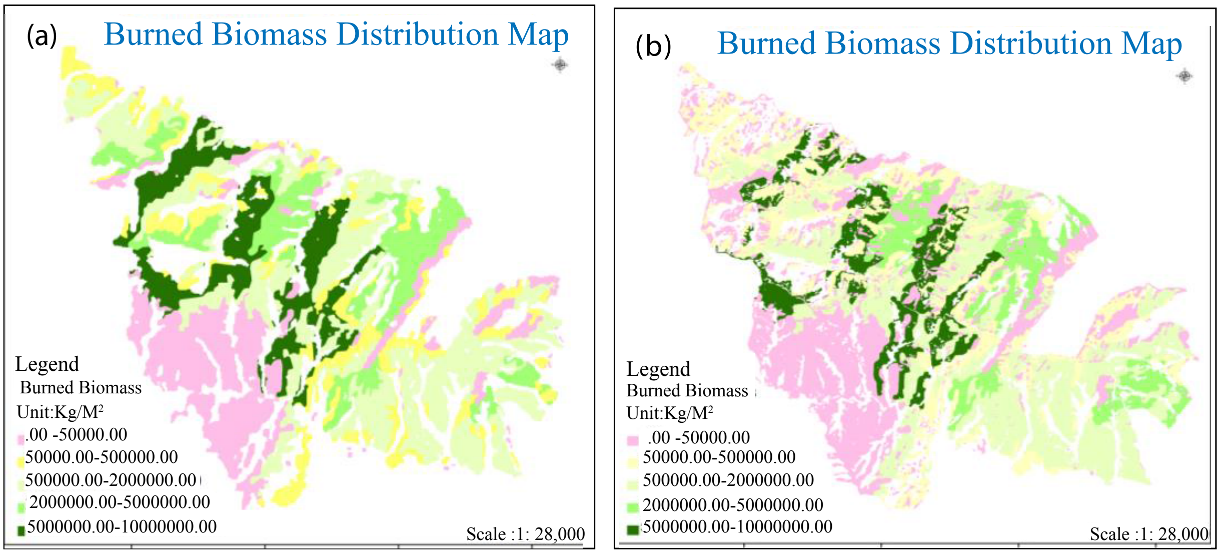

Figure 4: Burned biomass distribution map (a) using GF-1 PMS image; (b) using GF-1 WFV image.

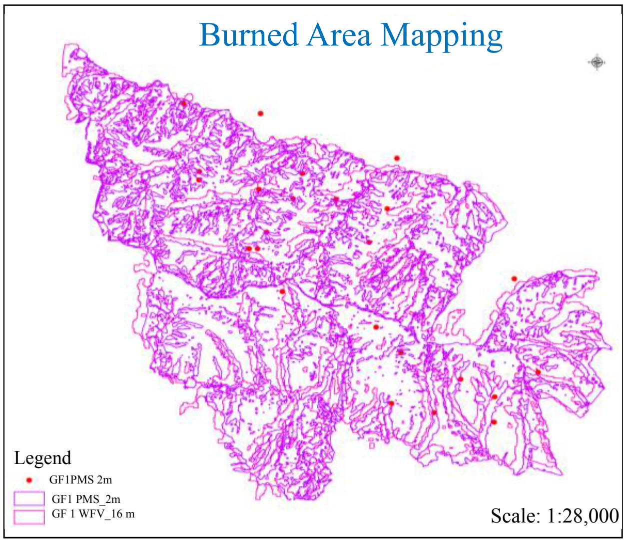

Figure 5: The result for comparing the burned area and active fire points.

Fuel Type	GF-1 PMS (kg)	GF-1 WFV(kg)	Difference (kg)	R (%)
Yunnan Pine	0.00	11008.00	11008.00	nodata
Dipan Pine	94608843.17	90541690.42	-4067152.75	-4.30
Economic Forest	553096.81	2655.35	-550441.46	-99.52
Shrub	18939224.23	15843165.94	-3096058.29	-16.35
Grass	1742097.00	1664911.52	-77185.48	-4.43
Others	2513504.42	3189824.14	676319.72	26.91
Total	118356765.63	111253255.37	-7103510.26	-6.00

Table 2: The results of burned biomass estimation according to fuel types.

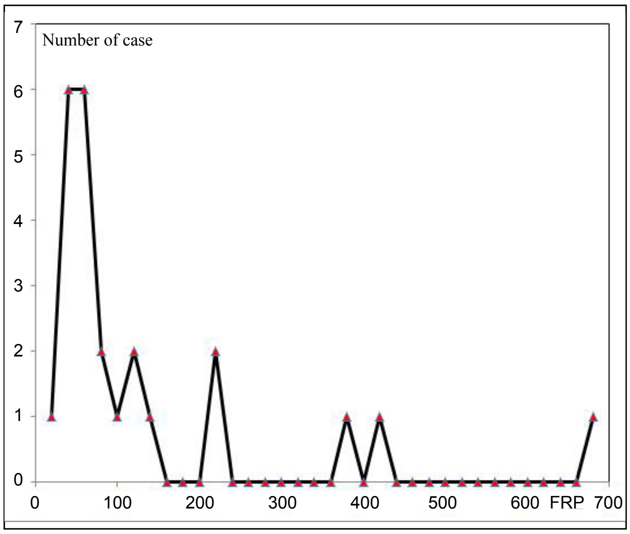

Figure 6: The frequency of FRP of active fire points using Terra/Aqua MODIS image.

It shows that the highest on R is Economic Forest from Table 2, with -99.52%. The second is others, with 17.46%. In addition, the lowest on R is Dipan Pine, with 4.58%. The R of the total difference is -6.00%. At the same times, the burned biomass has been also analyzed according to the subcompartment. Part of the results showed in Table 3 (because there are 249 subcompartment for the forest fire).

The estimated burned biomass according to the subcompartment is obvious difference between by using the GF-1 PMS and GF-1 WFV image from Table 3. The highest on R is the No. 4482 subcompartment, with 370.50%. The lowest on R is the No. 4854, with the 0.09%.

Conclusions

The burned forest biomass has been estimated by using the burned area, the fuel load and the combustion factor based on the subcompartment level. It shows that the method can supply the forestry manager the information of burned fuel type, burned biomass and burned area of every subcompartment by the forest fire for forestry

Subcompartment Number	GF-1 PMS (kg)	GF-1 WFV (kg)	Difference (kg)	R (%)
4156	251157.76	256055.03	4897.27	1.95
4300	0.00	4041.92	4041.92	/
4307	107000.44	140208.23	33207.79	31.04
4313	305305.61	310595.12	5289.51	1.73
4350	123164.61	120621.01	-2543.60	-2.07
4353	55500.69	165249.76	109749.07	197.74
4356	144927.56	323715.94	178788.38	123.36
4360	859584.17	915335.96	55751.80	6.49
4377	49496.14	34499.33	-14996.80	-30.30
4382	45586.46	102786.60	57200.14	125.48
…	…	…	…	…
4482	5184.05	24391.01	19206.95	370.50
…	…	…	…	…
4854	652313.39	652889.81	576.42	0.09
…	…	…	…	…
Total	118356765.63	111253255.37	-7103510.26	-6.00

Table 3: Part of burned biomass estimation results according to subcompartment.

management. At the sometimes, it supplies a method for the single forest fire case when the FRP or FRE of active fire points, getting from the sparse low spatial resolution satellite images, doesn't satisfied the condition of Power Law distribution model or Gassian function.

However, there are some disadvantages of the methodology because the uncertainty about the burned scars edge. The accuracy of burned area mapping is a key factor to the burned biomass estimation. It is the better way to select the high spatial resolution satellite images to map the burned area than using the low spatial resolution satellite images.

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Author Contributions

Xianlin Qin conceived and designed the experiments, field work, developed the burned biomass estimation method, and wrote the paper. Xiaofeng Zu mapped the burned area using GF-1 images. Lingyu Ying analyzed the FRP distribution. Guifen Sun has taken part in the validation for the burned biomass.

Conflicts of Interest

All of us declared no conflict of interest in our study and in this paper.

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