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Burned Area Mapping Based on KazEOSat 1 Satellite Datasets †

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Abstract: Forest fires are common occurrences in Kazakhstan, particularly from June until September, and damage extensively to the country's forest resources. The mapping of burned areas is crucial for fire management to implement the proper mitigation strategies and restoration actions following the fire season. The mapping of burned areas enables a thorough evaluation of the damage caused by fires to forests. The unique characteristics of forest plants and soil are dramatically altered by the fire's destruction, leading to a dramatic shift in reflectance. The destruction caused by fires can be mitigated, and vegetation can be replanted, with the use of maps depicting the affected areas. Accurate and timely mapping of burned areas is critical for fire prevention methods such as planning, mitigation, and vegetation regeneration. The country Kazakhstan launched two satellites KazEOSat 1 and KazEOSat 2 as part of the Earth Remote Sensing Satellite System (ERSSS) for the management of natural resources and monitoring. The KazEOSat 1 is a high-resolution observation satellite, launched in Sun-synchronous orbit at an altitude of about 630 km, consisting 4 spectral bands (4m) and very high panchromatic (1m) band. In this study, KazEOsat 1 satellite datasets were used to map the burned area in various parts of Kazakhstan. Three different spectral indices viz. Global Environmental Monitoring Index (GEMI), Ashburn Vegetation Index (AVI) and Burn Area Index (BAI) are used and the findings are compared to the best burnt area discrimination index using KazEOsat 1 satellite datasets. The results show that the BAI shows the higher accuracy than other indices to map the burnt area using the KazEOsat 1 satellite datasets.

Keywords: burned area, KazEOsat 1 satellite, GEMI, AVI, BAI

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1. Introduction

Wildfires, often known as forest fires, are one of the factors contributing to the devastation of forests. Burnt area mapping is essential for taking preventive measures and determining the damage assessment for the fire management in order to suppress fire activities in the upcoming fire season [1]. A thorough evaluation of the damage to the forest throughout the fire season is provided by the satellite-derived Burnt Area Product. Reflectance is significantly altered by plant damage caused by the fire event because the composition of forest vegetation and soil qualities differ [2]. During the fire season, burned area mapping is crucial for planning mitigation measures and reestablishing vegetation regrowth efforts [3-4]. Since fire prevention efforts including planned preparation, mitigation measures, and vegetation regrowth activities need to be prepared, burned area mapping should be accurate and quick [4-5].

Kazakhstan launched two satellites, known as KazEOsat 1 and KazEOsat 2, for the management of natural resources; the former has a higher resolution (4 m) than the latter (6.5 m). In this study, high spatial resolution KazEOsat 1 satellite datasets are utilized to map the burned area in the parts of Kazakhstan. With four bands—blue, green, red, and NIR multispectral bands—and a spatial resolution of four meters, the KazEOSat 1 satellite sits in a Sun-synchronous orbit. Panchromatic data has a spatial resolution of one meter. Using KazEOsat1 records, three distinct indices—the Burn Area Index (BAI), the Ashburn Vegetation Index (AVI), and the Global Environmental Monitoring Index (GEMI)—are investigated for the mapping of burned regions.

2. Study Area

Kazakhstan is the largest nation in Central Asia, bordered by China, Russia, Kyrgyzstan, Uzbekistan, and Turkmenistan. It is the ninth largest nation globally, with forests covering 4.6% of the total geographical area. Due to the severe weather, June through September are the months when forest fires occur most frequently in Kazakhstan. Nearly 39 km2 of forests burned, resulting in a loss of 3,70,802 US dollars, according to a report from Kazakhstan's Ministry of Emergency Situations (www.aips.kz). Since the beginning of 2019, 499 forest fires have been reported in Kazakhstan's forest regions, with total damage amounting to $5,89,570 US dollars, according to the country's vice minister of ecology, geology, and natural resources (https://kursiv.kz).

3. Methods

The New AstroSat Optical Modular Instrument (NAOMI-1), a high-resolution pushbroom imager, is part of the KazEOSat 1 satellite. We downloaded the KazEOSat-1 photographs from the official website of Gharysh Kazakhstan. The image product includes a tiff image and meta data in a.DIM format. Since KazEOSat-1 has a 12-bit spectral resolution, each image on the given day has DN values ranging from 0 to 4095. These images were first mosaicked to create a seamless output image. The radiometric calibration of these datasets is done in two steps: first, the Digital Number (DN) is converted to sensor radiance, and subsequently to TOA reflectance. KazEOsat-1 is equipped with a NAOMI-1 instrument.

Equation (1) was used to convert the DN values to at-sensor radiance (L).

$$L = (DN * Gain) + Bias \quad (1)$$

Gain, also known as the gain coefficients for various bands. It was believed that bias was set to zero.

Using equation (2), we determine the spectral reflectance of each band after converting its DN values to radiance.

$$\rho = \frac{\pi * L * d^2}{Esun * \cos\theta} \quad (2)$$

where is the solar zenith angle, 'Esun' is the mean solar irradiance at the top of the atmosphere, and 'd' is the Earth-Sun distance in astronomical units (0.98496).

Equation (3) is used to calculate the solar zenith angle from the sun elevation angle recorded in the satellite metadata file provided by the satellite data.

$$Solar\ zenith\ angle = 90 - sun\ elevation\ angle \quad (3)$$

The Thuillier standard sun solar system, approved by CEOS (Committee on Earth Observation Satellites), is the source of "Esun" values. Thus, using the aforementioned formulas, DN values are converted into TOA reflectance for every spectral band.

Three spectral indices—the Ashburn Vegetation Index (AVI), the Burn Area Index (BAI), and the Global Environmental Monitoring Index (GEMI)—were selected for this study to generate the burned area because the KazEOsat 1 satellite image comprises four spectral bands. The Ashburn Vegetation Index (AVI), which is derived from the following equation (4) [6], is a straightforward index that is helpful for measuring green vegetation in photos.

$$\mathrm{AVI} = 2 * (\mathrm{NIR} - \mathrm{Red}) \quad (4)$$

The spectral distance of each pixel to a reference spectral point, where active burned areas have converged using red and NIR reflectance bands, is used to calculate the Burn Area Index (BAI), which shows the charcoal signal in the red to near infrared region of post-fire images [7].

The following formula (5) is used to calculate BAI [8].

$$BAI = \frac{1}{[(0.1 - Red)^2 + (0.06 - NIR)^2]} \quad (5)$$

A hybrid vegetation index called the Global Environmental Monitoring Index (GEMI) was developed to extract burned areas using red and NIR bands. It is nonlinear in design to minimize atmospheric effects, and its calculation is based on equation (6) [9].

$$GEMI = \eta * [1 - (0.25 * \eta)] - \frac{(Red - 0.125)}{(1 - Red)} \quad (6)$$

Here

$$\eta = \frac{2 * (NIR^2 - Red^2) + 1.5 * NIR + 0.5 * Red}{(NIR + Red + 0.5)} \quad (7)$$

As a result, the four KazEOsat 1 reflectance data collected on September 25, 2018, and October 5, 2018, following the forest fire occurrence, are used to compute the spectral indices AVI, BAI, and GEMI.

3. Results and Discussion

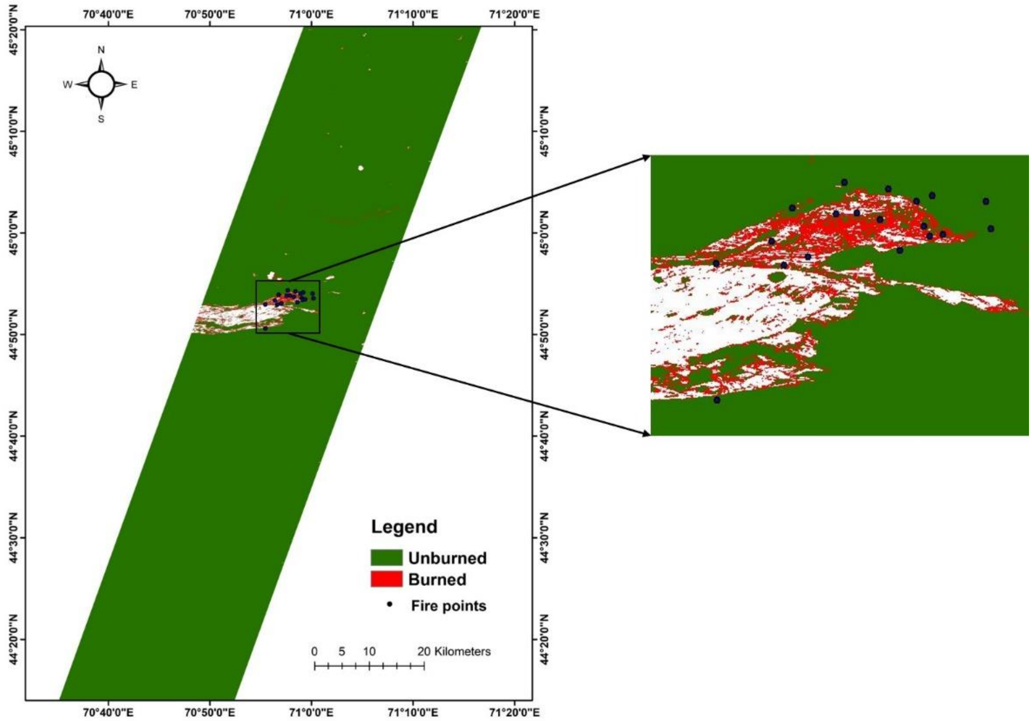
The Moderate Resolution Imaging Spectroradiometer (MODIS) TERRA and AQUA active fire product (MCD14) were utilized to validate the burned area map, which were obtained from the "Fire Information for Resource Management System (FIRMS)" website [10]. The accuracy of the number of fire events that fell in burned and unburned areas was determined by calculating the percentage of forest fires that fell in burned areas relative to the overall number of fires that occurred, as shown in Table 1.

Table 1. Accuracy of burned area indices AVI, BAI and GEMI.

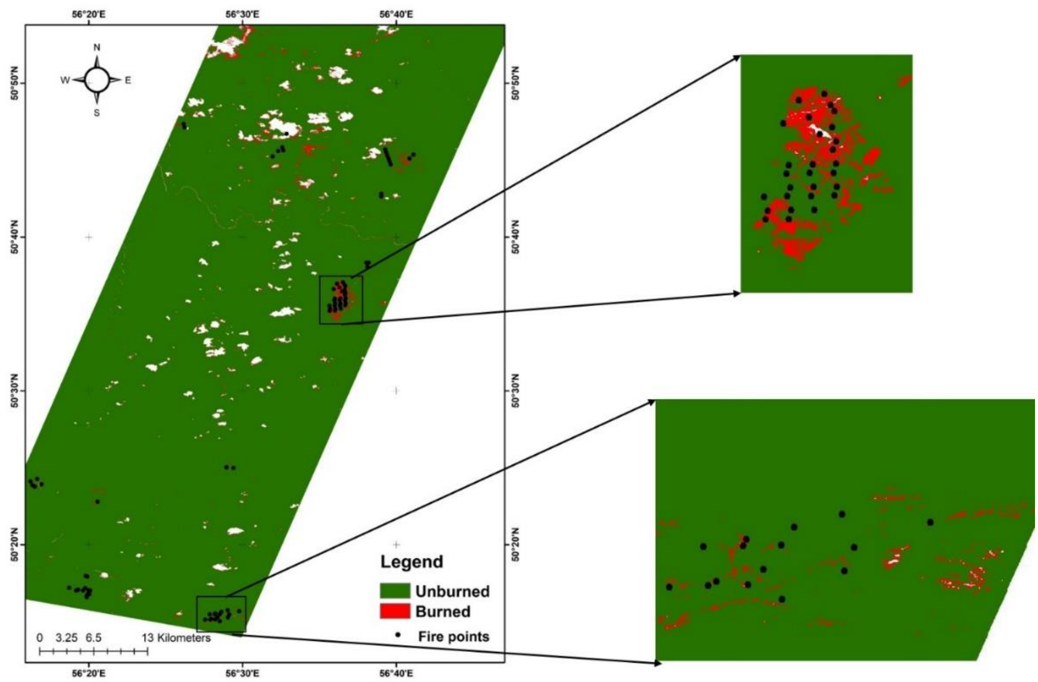
Date	Spectral Indices	No. fire incidents		Accuracy (%)
		Burned area	Un-burned area	
September 25, 2018	AVI	18	9	66.66
	BAI	22	5	81.48
	GEMI	20	7	74.07
October 13, 2018	AVI	59	23	71.95
	BAI	71	11	86.58
	GEMI	63	19	76.83

Table 1 revealed that the BAI had the highest accuracy (81.48%; 86.58%), followed by the GEMI (74.07%; 76.83%) and the AVI (66.66%; 71.95%) with the lowest accuracy.

The images of the burned area map based on the BAI are displayed in Figures 1(a) and (b), overlaid with corresponding active fires that occurred on September 25, 2018, and October 13, 2018, respectively.



(**a**)



(**b**)

Figure 1. The burned area maps based on the BAI, (**a**) September 25, 2018 (**b**) October 13, 2018 overlaid with the corresponding day active fire points for the respective day.

The results shows that the BAI exhibits the greatest degree of accuracy when it comes to identifying the burned area from the KazEOsat-1 satellite datasets.

3. Conclusion

Because KazEOsat 1 satellite datasets have a greater spatial resolution (4 m), they are used in this study to map the burned area in Kazakhstan's various regions. This work analyzed four spectral bands—NIR, blue, red, and green—of KazEOsat 1 satellite datasets to map the burned area using three spectral indices: AVI, BAI, and GEMI. Prior to calculating the aforementioned spectral indices, TOA reflectance is computed from the DN values for each band. accuracy was determined based on the quantity of forest fire occurrences that occurred in both burned and unburned areas. The results indicate that, of the two, BAI has the highest accuracy and AVI has the lowest accuracy. As a result, while utilizing the datasets from the KazEOsat 1 satellite, the BAI has the best capacity to highlight the burned area. Given that KazEOsat has a three-day revisit interval, this study will be helpful in mapping Kazakhstan's burned area and fire progression.

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Conflicts of Interest: The authors declare no conflict of interest.

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