



# Burned Area Mapping Based on KazEOSat 1 Satellite Datasets <sup>†</sup>

K. V. Suresh Babu <sup>1,\*</sup> , Swati Singh <sup>2</sup>, Kabdulova Gulzhiyan <sup>1</sup>, Gulnara Kabzhanova <sup>1</sup> and GR Baktybekov <sup>1</sup>

<sup>1</sup> The Joint-Stock Company, Astana 7172, Kazakhstan; kabdulova.kazakh@gmail.com (K.G.); gulnarakabzhanova@gmail.com (G.K.); baktybekov.kazakh@gmail.com (G.B.)

<sup>2</sup> College of Forestry, Wildlife and Environment, Auburn University, Auburn, AL 36849, USA; swati.sikarwar12@gmail.com

\* Correspondence: sureshbabu.iith@gmail.com

<sup>†</sup> Presented at the 5th International Electronic Conference on Remote Sensing, 7–21 November 2023; Available online: <https://ecrs2023.sciforum.net/>.

**Abstract:** Forest fires are common occurrences in Kazakhstan, particularly from June until September, and damage the country's forest resources extensively. 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. The 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 a Sun-synchronous orbit at an altitude of about 630 km, consisting of four spectral bands (4 m) and a very high panchromatic (1 m) band. In this study, KazEOSat 1 satellite datasets were used to map the burned areas in various parts of Kazakhstan. Three different spectral indices, viz., the 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 the KazEOSat 1 satellite datasets. The results show that the BAI shows a higher accuracy than the other indices at mapping the burnt area using the KazEOSat 1 satellite datasets.



**Citation:** Suresh Babu, K.V.; Singh, S.; Gulzhiyan, K.; Kabzhanova, G.; Baktybekov, G. Burned Area Mapping Based on KazEOSat 1 Satellite Datasets. *Environ. Sci. Proc.* **2024**, *29*, 82. <https://doi.org/10.3390/ECRS2023-16841>

Academic Editor: Riccardo Buccolieri

Published: 25 January 2024



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**Keywords:** burned area; KazEOSat 1 satellite; GEMI; AVI; BAI

## 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 damage assessments for 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 the plant damage caused by a 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 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 have 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 its total geographical area. Due to the severe weather, June through September are the months when forest fires occur most frequently in Kazakhstan. Nearly 39 km<sup>2</sup> of forests burn, resulting in a loss of USD 370,802, according to a report from Kazakhstan’s Ministry of Emergency Situations ([www.aips.kz](http://www.aips.kz)). Since the beginning of 2019, 499 forest fires have been reported in Kazakhstan’s forest regions, with the total damage amounting to USD 5,89,570, according to the country’s vice minister of ecology, geology, and natural resources (<https://kursiv.kz>) (accessed on 20 June 2018).

## 3. Methods

The New AstroSat Optical Modular Instrument (NAOMI-1), a high-resolution pushbroom imager, is part of the KazEOSat 1 satellite. We downloaded KazEOSat-1 photographs from the official website of Gharysh Kazakhstan. The image product includes a tiff image and metadata in a .DIM format. Since KazEOSat-1 has a 12-bit spectral resolution, each image on a 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 achieved 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).

$$L = (DN * Gain) + Bias \tag{1}$$

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

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

$$\rho = \frac{\pi * L * d^2}{E_{sun} * \cos \theta} \tag{2}$$

where  $\theta$  is the solar zenith angle, ‘ $E_{sun}$ ’ 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 with the satellite data.

$$Solar\ zenith\ angle = 90 - sun\ elevation\ angle \tag{3}$$

The Thuillier standard sun solar system, approved by the CEOS (Committee on Earth Observation Satellites), is the source of “ $E_{sun}$ ” 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 the green vegetation in photos.

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

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].

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

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].

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

Here,

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

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

#### 4. 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 was 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.

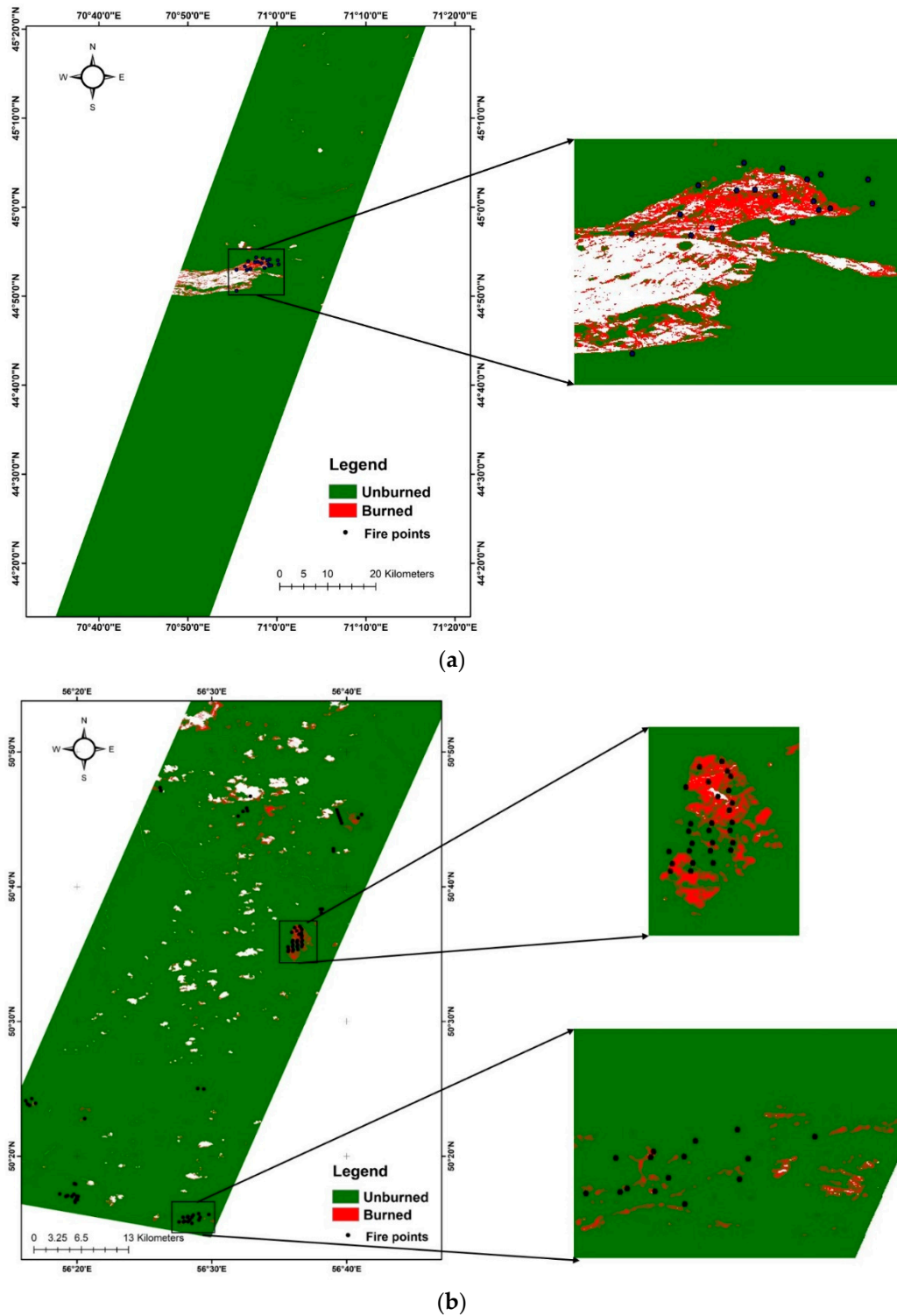
**Table 1.** Accuracy of burned area indices AVI, BAI, and GEMI.

Date	Spectral Indices	No. Fire Incidents		Accuracy (%)
		Burned Area	Unburned Area	
25 September 2018	AVI	18	9	66.66
	BAI	22	5	81.48
	GEMI	20	7	74.07
13 October 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 then the AVI (66.66%; 71.95%), with the lowest accuracy.

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

The results show that the BAI exhibits the greatest degree of accuracy when it comes to identifying burned areas from KazEOSat-1 satellite datasets.



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

### 5. Conclusions

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 the 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 was 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 three, 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 areas and fire progression.

**Author Contributions:** K.V.S.B. and K.G. designed the study. K.V.S.B. and S.S. wrote the paper and analyzed the data. S.S., G.K. and G.B. contributed to the critical analysis of the paper. All authors contributed to proof-reading and commenting on the manuscript. All authors have read and agreed to the published version of the manuscript.

**Funding:** The findings reported in this article were obtained as part of the Republican budget program 008 No. BR0533648/EFP "Development of scientific methods for evaluating soil fertility of North Kazakhstan on the basis of the Earth remote sensing data from KazEOSat—1,2 satellites and geoinformation technologies", Subprogram 1 "Optimization of technical parameters and a methodological approach to the use of remote sensing data of domestic satellite KazEOSat—1,2".

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The satellite datasets can be downloaded from the Gharysh Kazakhstan official website (<http://www.gharysh.kz>).

**Conflicts of Interest:** The authors declare that this study received funding from the Joint Stock Company. The funder was not involved in the study design, collection, analysis, interpretation of data, the writing of this article or the decision to submit it for publication.

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