Long-term forest fire assessment over Zagros Forests

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Abstract

Wildfires are known as one of the most important natural hazards, adversely impacting the ecosystems and human lives. Monitoring and management of wildfires is necessary to minimize their negative effects. Global burned area products are widely used to study wildfires, but their accuracy is not constant over different environments. In this study, the MCD64A1 burned area product was spatially validated using ground truth maps in a fire-prone Zagros Forest over 2021-2023. Our results indicated that its performance varies temporally, as the Kappa coefficient ranged from 0.04 to 0.69. Overall accuracy was higher than 0.96 percent in all years, indicating that MCD64A1 can be considered as a source for studying wildfires; however, its underestimation should be considered. In the next step, the trend of fire and its relationship with precipitation (i.e., obtained from the CHRIPS dataset) were analyzed in three forest ecosystems from 2001 to 2024. In two regions, Marivan and Kermanshah, wildfires experienced an increasing trend, in contrast to the other region, Shiraz, where they decreased over time. Analyzing the correlation between fire and precipitation revealed that spring precipitation is more connected to burned areas than annual precipitation. Comparing the results of the three regions showed that this matter is also region-related, and the results of one region cannot be referred to another. This study provided information on the performance of MCD64A1 in semiarid forests and the wildfire conditions in the Zagros Mountains to aid wildfire management.

1. Introduction

Forest fire ranks as one of the most serious natural disasters, endangering both ecosystems and human lives, with extensive consequences at local and global scales (Noroozi et al., 2023). Air pollution (Singh et al., 2025), biodiversity loss (Maillard et al., 2022), forest degradation (Bourgoin et al., 2025), and intensifying climate change (Zhao et al., 2025) are examples of its adverse effects on the environment. Therefore, wildfires should be monitored and managed to control and mitigate their harmful impacts.

For monitoring wildfires and detecting burned areas (BA), remote sensing has been proven to be an efficient tool (Fathi & Pir Bavaghar, 2025; Nolde et al., 2025). In many studies, remote sensing data, i.e., satellite imagery, have been utilized to map BA (Chuvieco et al., 2019; Digavinti & Manikiam, 2021; Jiao et al., 2022; Kang et al., 2023; Motalebizade et al., 2025; Pepe & Parente, 2018). In addition to regional studies, different algorithms have been developed to map BA globally, and the two most well-known BA products are MCD64 and FireCCI, based on MODIS imagery. Several studies have validated these BA products regionally or globally (Alves et al., 2018; Boschetti et al., 2019; Fornacca et al., 2017; Hall et al., 2021; Huang et al., 2023). Their results indicate that the performance of BA products is highly site-specific and depends on the environmental variables such as topography, vegetation cover, and climate (Chen et al., 2021). As a result, spatial validation and accuracy assessment of BA products using ground truth data are a crucial prerequisite for employing them in studying different aspects of wildfire. In this study, we aimed to assess the accuracy of the MCD64A1 product over a fire-prone Mediterranean forested area, called the Zagros Forest in the western part of Iran. This BA product was chosen over FireCCI because it has been seen to perform better in forested areas (Huang et al., 2023; Xu et al., 2025).

The occurrence of wildfires is changing due to climate change (Gallo et al., 2025) and human activities (García et al., 2022). Analyzing its trends and investigating the drivers of fire regimes have interested researchers. Bai et al. (2024) studied the relationship between climate and wildfires and found the variables most correlated with wildfire events, such as sea surface temperature, maximum temperature, and drought severity. Strydom (2025) analyzed the changes in wildfires and climate and how they are related. Heidarlou et al. (2024) explored the climate factors affecting the fire regime in the north of Zagros, Iran, and found that heatwaves are strongly correlated with fire behavior, while average precipitation had no significant effect. Nevertheless, the link between climate and wildfires is very spatially heterogeneous, and local studies are needed (Rodrigues et al., 2019). Thus, the wildfire trend and its relationship with precipitation were analyzed in three regions located in the Zagros Forest, where wildfires are very frequent due to its unique climate, dense vegetation (mostly oak trees), and mountainous terrain, with an average of 76.2 fire events per year (Karami & Tavakoli, 2025). Local people are extremely dependent on these forests, and besides the ecological importance of the region, its socio-economic values also emphasize the need for wildfire management (Sayahnia et al., 2024).

2. Methodology

2.1. Study area

The Zagros Forest can be divided into three parts: the Northern, Middle, and Southern Zagros. We selected a region in each sub-biome. The Marivan region is located from 45.7° to 46.3° northern latitude and 35.43° to 31.88° eastern longitude (3337297 ha). The second study area, named Shiraz, is located from 54.17° to 50.85° northern latitude and 28.47° to 31.35° eastern longitude (10117487.90 ha). The last one covers the area between 45.85° and 46.17° northern latitude and 34.88° to 35.06° eastern longitude, named Kermanshah (48950.98 ha) (Figure 1).

2.2. Data sources

2.2.1. **MCD64A1:** MCD64A1 is the newest MODIS BA product using MODIS Terra and Aqua daily reflectance (500 m spatial resolution) and MODIS active fire product (1 Km spatial resolution) for mapping daily fires with 500 m spatial resolution. It utilizes an updated algorithm designed to enhance the detection of small BAs and decrease omission error (Giglio et al., 2018)(https://modis-fire.umd.edu, last visited on 11/9/2025). This dataset is available from 2000 to the present (Chen et al., 2021) and can be used directly on Google Earth Engine (last access date: 11/16/2025)

2.2.2. **CHRIPS:** The Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) is a precipitation product derived from satellite data and in situ rain gauge observations, to account for the bias of satellite data and the sparsity of rain-gauge stations. Its algorithm produces a high-resolution (0.05̊) monthly precipitation dataset since 1981 and is available on Google Earth Engine (https://www.chc.ucsb.edu/data/chirps, Last visited on 11/9/2025) (Funk et al., 2015)

2.2.3. **Sentinel-2:** Ground truth maps were generated using Sentinel-2 Level 2A (S2A) Surface Reflectance products. S2A has different spatial resolutions (i.e., 10 m, 20 m, and 60 m) (https://dataspace.copernicus.eu, last visited on 11/9/2025); however, only the Red, Green, and Near Infrared bands (10 m) were utilized to create pseudo-true-color images. Sentinel-2 was chosen because it is the only freely available high-resolution dataset with high temporal resolution (Stroppiana et al., 2025).

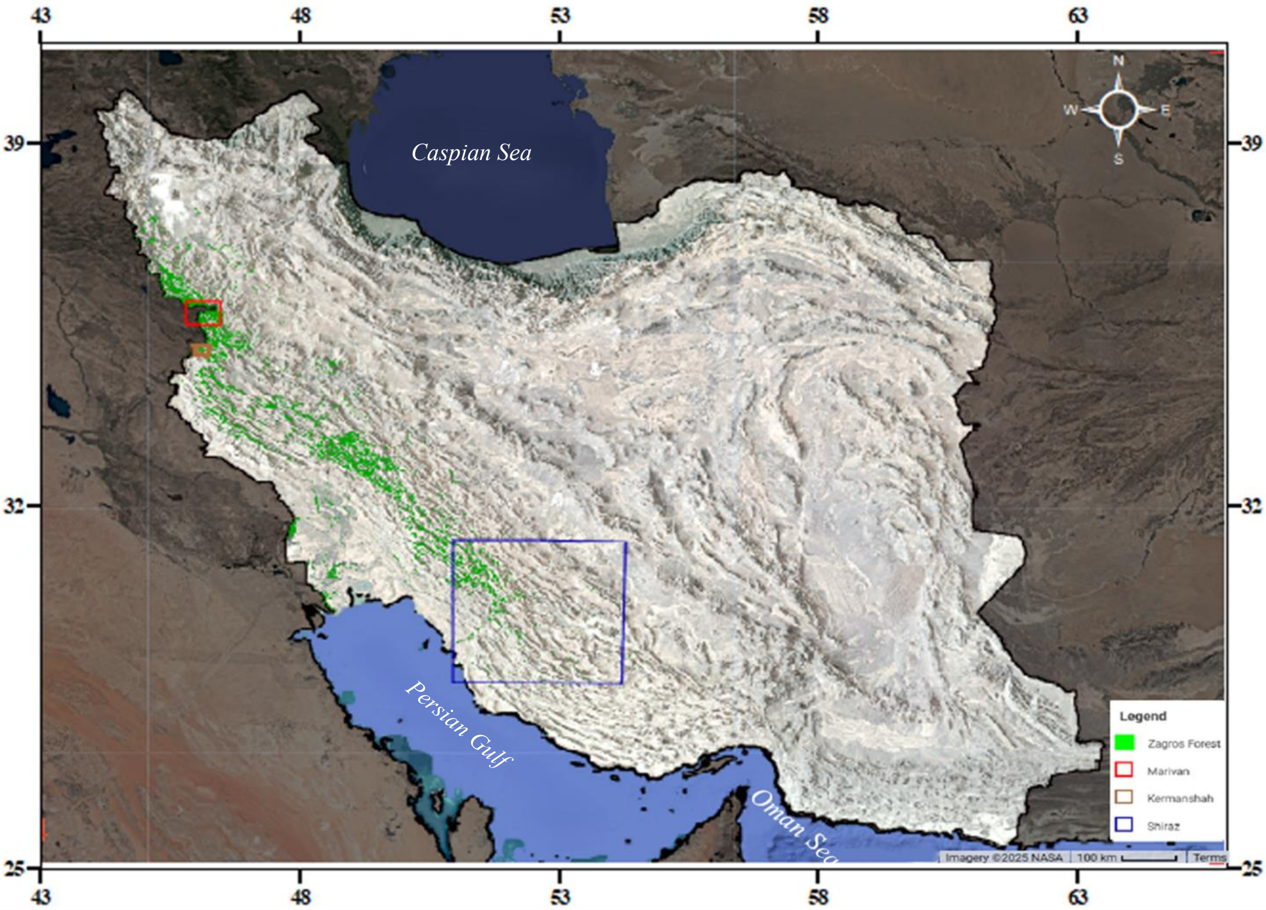

Figure 1 Study area

This contribution has been peer-reviewed. The double-blind peer-review was conducted on the basis of the full paper.
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Three dates, i.e., 1) 2021/10/05, 2) 2022/09/20, and 3) 2023/09/25, were selected over 2021-2023, ensuring that they are at the end of the growing season.

2.3. Data Processing

Processing datasets (MCD64A1 and CHRIPS) was conducted on Google Earth Engine (GEE), a cloud-based platform, allowing for rapid, free, and efficient processing of remote sensing data (Gorelick et al., 2017). The monthly MODIS BA product, MCD64A1, was summed up to generate annual BA maps. CHRIPS provides daily data, which were converted to monthly data to extract annual and spring precipitation.

2.4. Accuracy assessment

Different methods are used to prepare reference data for validation; however, a visual interpretation approach based on an image with higher spatial resolution is a widely used method (Obando-Cabrera et al., 2025; Xiao et al., 2021), especially due to the impractical process of BA field measurements at large scales (Gonzalez-Ibarzabal et al., 2024), and it is also accurate (Dias et al., 2025). The ground-truth maps were produced through visual interpretation of Sentinel 2A imagery, i.e., four spectral bands with 10m spatial resolution. Among the three regions studied, ground truth maps were created for the Marivan region from 2021 to 2023. In addition, BA maps of the Marivan region (2021-2023) were produced from the MCD64A1 BA product and resampled to 30 m (the spatial resolution of the ground truth maps), enabling direct comparison with the reference data. These BA maps are not based on the whole year, but only the months that are considered in the ground truth maps.

The accuracy of the MODIS BA products was evaluated using ground truth maps and by calculating the confusion matrix. A confusion matrix prepares a summary of the relative agreement of burned and unburned classes with the reference data (Boschetti et al., 2019). Common metrics, i.e., Overall Accuracy (OA) and Kappa Coefficient, Omission (OE), and Commission Error (CE) for burned area validation were evaluated.

2.5. BA and Precipitation trend and relationship analysis

After the accuracy assessment of MCD64A1 data, the fire and precipitation trends and their relationships were analyzed. For this purpose, four parameters, i.e., number (fire occurrence), area of BA, annual and spring precipitation, were analyzed over 24 years (2000-2024).

Analyzing the area and number of fire polygons allows us to examine the distribution and severity of fires. Typically, in coarse resolution BA products like MCD64A1, the area of fire patches is a major factor in the accuracy of the product (Majdalani et al., 2022). Thus, examining the distribution of the area and number will help us to predict the accuracy and whether the product is reliable or not. After creating annual BA maps based on MCD64A1, the area and number of fire polygons were measured.

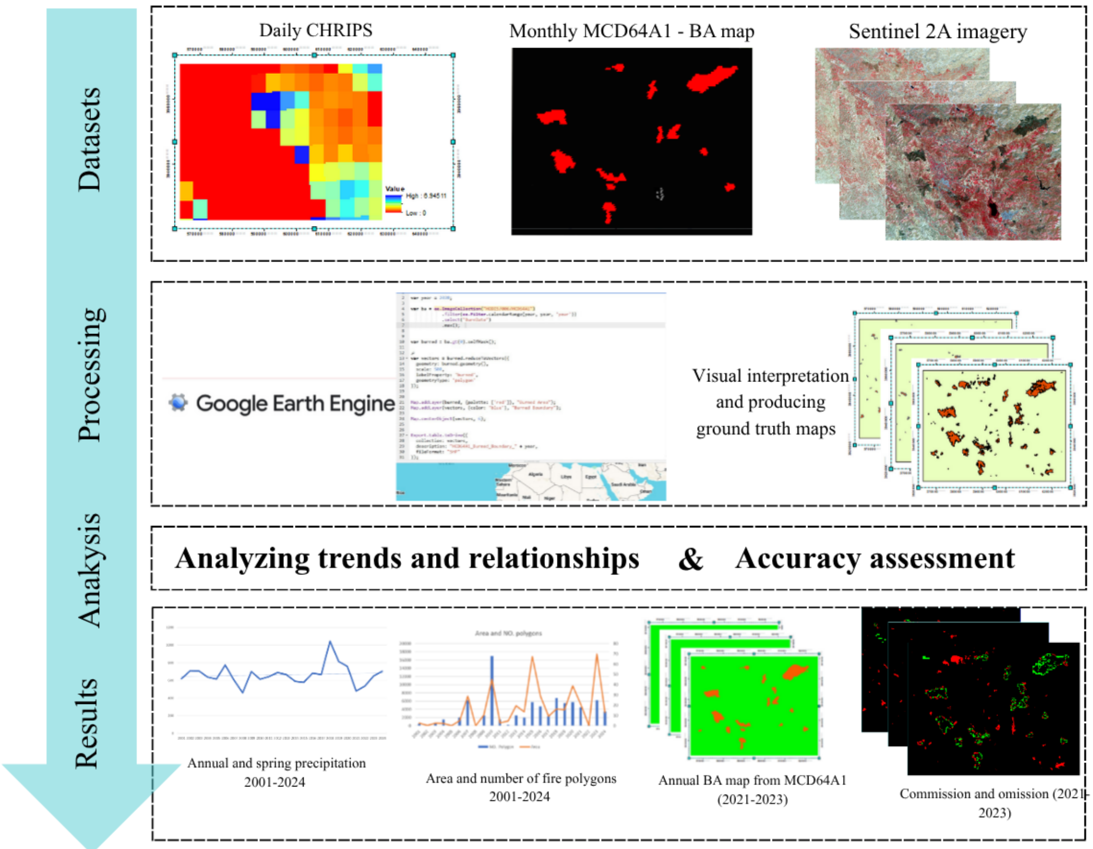

Figure 2 Flowchart of the study

The general workflow of the methodology is illustrated in Figure 2.

3. Results

3.1. Accuracy assessment

The accuracy assessment was conducted only in the Marivan region and for the years 2021-2023. The results of the accuracy assessment are indicated in Table 1. All the years experienced underestimation in MCD64A1 by higher OE than CE. The most accurate BA map belonged to 2023 with a KC of 0.69 and an OV of 96.78. While MCD64A1 almost missed all the BA in 2022, with the OE of 99.13%.

Table 1 Accuracy assessment of BA maps based on the MCD64A1 for 2021-2023 in the Marivan region

Year	KC	OA	OE	CE
2021	0.44	97.58	62.77	41.84
2022	0.01	99.61	99.13	54.69
2023	0.69	96.78	29.55	27.65

3.2. BA and Precipitation trend and relationship analysis

Trends of BA and precipitation from 2001 to 2024 were analyzed. Assessing the relationship between precipitation and BA revealed that spring precipitation is more correlated with wildfire occurrence than annual precipitation. For example, the R^2 for annual precipitation and BA was 0.0009 in Marivan, but it increased to 0.2 once considering spring precipitation (Figure 3). The correlation between spring precipitation and BA was much weaker in Shiraz and Kermanshah (R^2 = 0.007 & 0.01, respectively) (Figure 4). In each year, the area and number of fire polygons were measured for all the study regions, and the results are shown in Figure 5.

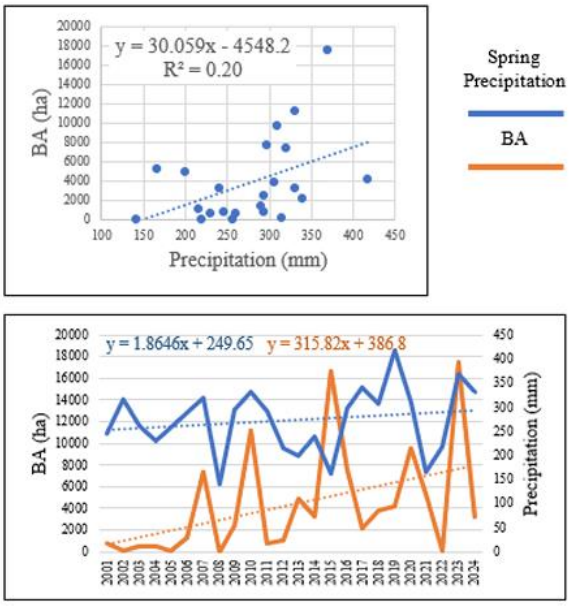

Figure 3 The relationship between BA and spring precipitation in Marivan (2001-2024)

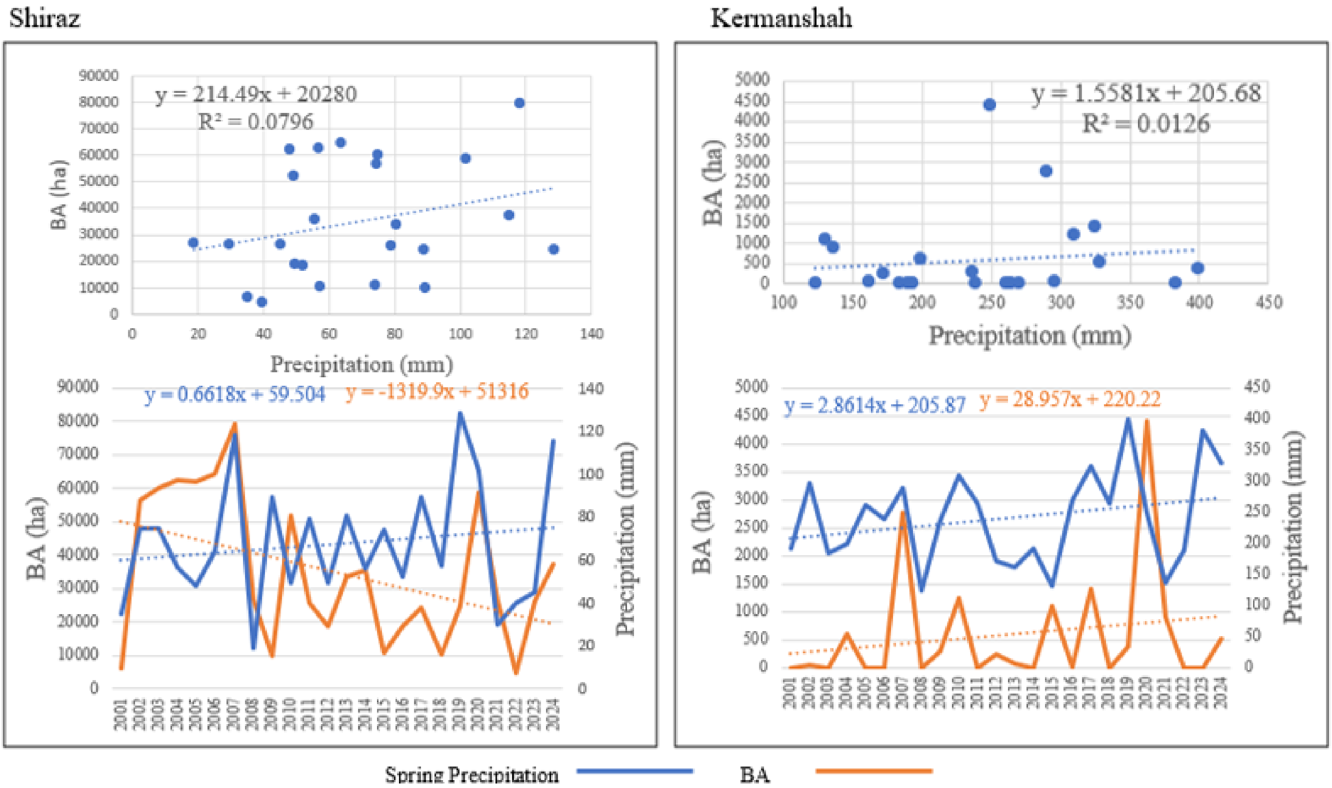

Figure 4 The relationship between BA and spring precipitation in Shiraz and Kermanshah (2001-2024)

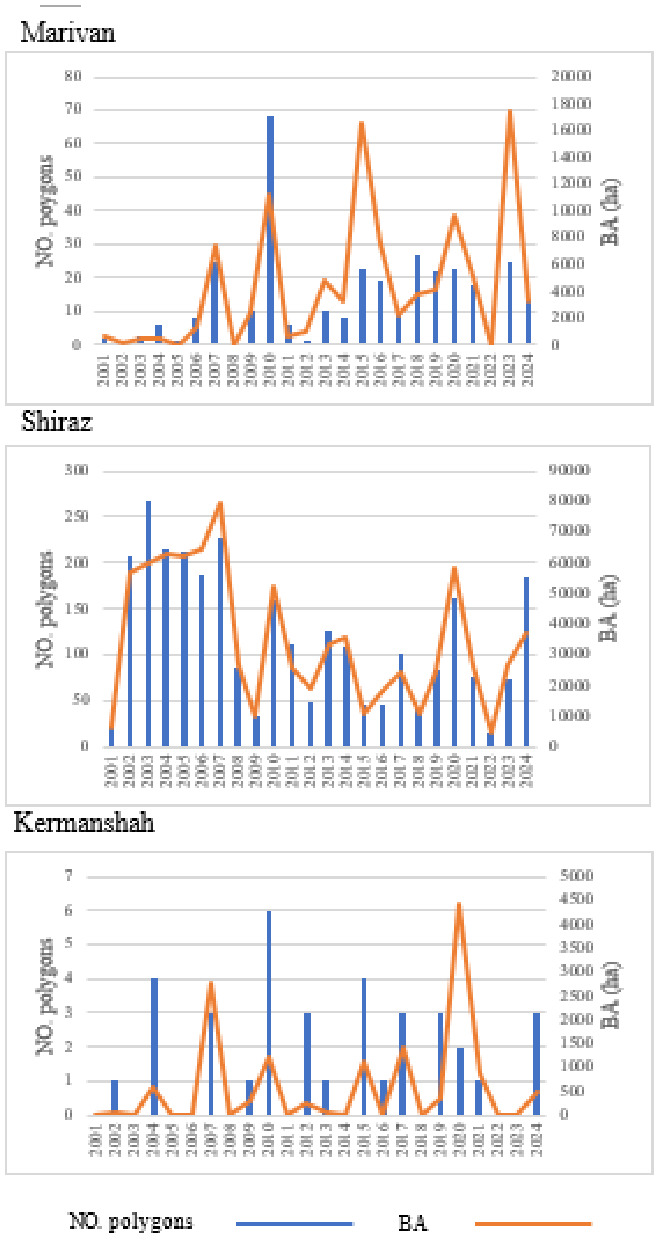

Figure 5 Area and number of observed fire polygons in Marivan, Shiraz, and Kermanshah 2001-2024

4. Discussion

Based on the results of the accuracy assessment, MCD64A1 underestimates the BA, which aligns with the results of previous studies (Boschetti et al., 2019; Xu et al., 2025). The coarse spatial resolution of this BA product prevents it from detecting small BAs. It has been reported that global BA products such as MCD64A1 usually miss the BAs smaller than about 100 ha (Katagis & Gitas, 2022; Majdalani et al., 2022). However, it estimated the BA of about 10 ha in Kermanshah in 2016, indicating that MCD64A1 can detect BAs down to 10 ha.

Assessing the accuracy of MCD64A1 in Marivan using ground truth maps for 2021 to 2023 showed that BA product accuracy is not only region-specific but can vary over time. MCD64A1 performs differently in different ecosystems (Chen et al., 2021), but even in the same environment, the accuracy of MCD64A1 changed dramatically, i.e., the Kappa coefficient ranges from 0.69 in 2023 to 0.01 in 2022. This is due to different fire patterns in these three years, as the number of fire events, distribution, and size of BAs were diverse, resulting in different outcomes of BA mapping (Katagis & Gitas, 2022). The lowest accuracy belonged to 2022, when more than half of the BA patches were smaller than 10 ha. Therefore, we concluded that MCD64A1 is not very accurate in times or across ecosystems where small fires are frequent (Chuvieco et al., 2022).

Despite variability among validation results, the MCD64A1 can be reliably used for regional burned-area analysis since its overall accuracy is generally high (i.e., more than 96%). This reflects the strong class imbalance between burned and unburned areas, where unburned pixels dominate, and omission of smaller burned patches has less effect on the overall accuracy. Despite the uncertainties and conservative estimation of BA in MCD64A1, it can provide us with good insights into the changes of wildfires; nonetheless, the omission bias should always be considered (Giglio et al., 2018).

Analyzing the correlation between spring precipitation and BA revealed that total spring precipitation plays a crucial role in wildfire occurrence rather than annual precipitation in the Zagros forest area. The same result was achieved by Whitman et al. (2022), that seasonal climate variables are more correlated than annual ones. However, this matter is region-specific, and further investigations should be done to find the stronger predictors in Shiraz and Keranshah. In addition, wildfire regimes are complex and depend on many different factors, including climatic (Whitman et al., 2022), environmental factors (Rodrigues et al., 2020), and anthropogenic activities (García et al., 2022), and only one variable cannot be considered.

The success of BA mapping strongly depends on BA polygon size, and larger BAs lead to more accurate BA products (Franquesa et al., 2022). For instance, in 2021, the smallest detected BA by MODIS was 17 ha, while there were 37 and 25 BA polygons in the GT map smaller than 17 ha and 6.5 ha (i.e., 1 MODIS pixel), respectively. Similarly, in 2023, 103 polygons in the GT map were smaller than the smallest BA polygon (i.e., with an area of 33 ha)generated from MODIS. These small BA polygons cannot be distinguished by MODIS, therefore, reducing the accuracy of the BA maps. Thus, the size of BA can be a relevant indicator of the accuracy and reliability of BA products such as MCD64A1. The number and the area of fire patches can help determine the size distribution of fire patches. Larger areas with a smaller number of fire polygons indicate that fires were more severe and occurred over larger areas. For that reason, the ratio between area and number of fire polygons reflects the reliability of the product.

5. Conclusion

In this study, the accuracy of the MCD64A1 BA product was assessed by comparing it to ground truth maps in Mraivan (2021-2023). The accuracy assessment showed that the performance of MCD64A1 varies spatially and temporally. The accuracy assessment was only done for Marivan, reducing the generalizability across the Zagros region. For further study, it will be helpful to expand the validation area across different parts of the

Zagros forests to have a more comprehensive assessment of the MCD64A1 BA product capability. Our results indicated that this product underestimates the BA and misses the small fires. Implementing advanced approaches, i.e., machine learning or fusion with higher spatial resolution imagery, i.e., Sentinel 2, may improve the BA detection. BA changes were analyzed in three regions of Marivan, Shiraz, and Kermanshah from 2001 to 2024. It was found that BA is more connected to spring precipitation than annual precipitation, but the strength of this link is region-specific as well. Understanding the fire regime and contributing factors helps to combat the adverse effects and manage this phenomenon. The agreement between fire occurrence and spring precipitation may support the Silvo-pastoralism practice to manage and handle the green biomass in these regions. Nevertheless, the complex dynamic of wildfires makes one factor inadequate to predict the event completely. Therefore, other climatic and anthropogenic factors should be taken into account. It is recommended to analyze other factors (i.e., temperature, drought, and human activities) in future studies.

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