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RESEARCH ARTICLE

Mapping of invasive plant species in Jalthal forest of Nepal using high resolution remote sensing data

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ABSTRACT

Invasive alien plant species (IAPS) can have consequential impact on the plant biodiversity, growth of native plant species and functional integrity of ecosystem. For example, in the Jalthal forest with an area of about 6000 ha in Eastern Nepal, *Mikania micrantha* and other invasive plants dominate the forest affecting the growth of native plant species, habitat of wild animals, and plant biodiversity. However, their identification and distribution over the forest is unclear to the management authorities. To address this problem and control, we mapped the distribution of invasive plant species to identify its location over the forest area. Using a high-resolution satellite imagery of ZIYUAN-3A (ZY3A), multispectral 5.8 m and panchromatic 2.1 m. A supervised image classification was performed using ground truth data and NDVI values. Accuracy assessment was performed to find the effectiveness by using high resolution satellite image. An overall accuracy of 82% with 0.74 kappa value was obtained. Results shows that about 1900 ha of the Jalthal forest is covered by the invasive plant species. The mapping of invasive alien plant species gives the current invasion level of the study area which will help in its management as well as in predicting the future distribution of the invasive plants.

Keywords: Invasion, Invasive alien plant species, Jalthal, Mapping, NDVI, ZY3A, Remote sensing

INTRODUCTION

Monitoring the structural and compositional dynamics of an ecosystem is essential to know the status of different biological components. The information obtained from the assessment is important to update the conservation strategies, operational plans and can be used for the effective management of ecosystem (Siwakoti *et al*. 2016). Therefore, reporting the invasion of alien invasive plant species (IAPS) is crucial to implant different control mechanisms and management prescriptions. Identification and prevention of invasion is one of the major challenges for the effective management of IAPS (Bradley and Marvin 2011). The invasive species such as *Mikania micrantha* and *Lantana camara* have the high capability to invade the high conservation and ecosystem value forest rapidly (Siwakoti *et al.* 2016). Invasive alien species are a major threat to native ecosystem, biodiversity and has the potentiality to alters the ecosystem process (Mukul *et al*. 2020, Raizada *et al*. 2008, Shabani *et al*. 2020). They are native to one region or area that are outside their normal distribution and are introduced either inadvertently or purposefully colonizing the new home or threatening the biological diversity (CBD 2010).

Forest fire, deforestation, increased temperature favors the distribution of invasive plants (Tiwari *et al.* 2005). It has been reported that one sixth of the land area and 17% of the earth's biodiversity hotspot are vulnerable to the invasion (Early *et al*. 2016). The morphological, physiological and ecological attributes of the exotic plants make invasive species superior than other plant species in terms of adaptability to the new environment (Li *et al*. 2022). They have the advantage on photosynthetic rate, life-history attributes, genetics and display higher spatial growth capacity as well as productivity than indigenous plants (Qi *et al*. 2014). The major impact of IAPS can be seen on the biodiversity, economy and in the livelihood of the poor people. For instance, the impact from invasive plant- *Lantana camara* in the eastern Africa have created a negative consequence on the crop yield production, and in the forage of the livestock. It has also decreased the abundance of natural resources and medicinal plants of the area (Shackleton *et al*. 2017). Similarly, the forest product offered by the invasive plants are of secondary choice as compared to the primary forests product that supports rural livelihood (Rai *et al*. 2012). The other impacts of IAPS include the reduction in the reproductive capacity of local species, it changes the hydrological structure, affect the plant photosynthesis capacity and reduces the overall ecosystem functionality (Nilsson and Grelsson 1995).

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Numerous studies from the past, monitoring the occurrence of invasive plant species were mostly based from the herbarium records, information from research scientists, and professionals within the institutions, academics and museums (Haber 1997). The environmental data collected were often limited, restricted among subset of biological species, and needed reformatting for future use. They were scattered among the institutions in incompatible formats (Davis *et al.* 1990, Stoms and Estes 1993). Moreover, the inventory technique used in past to know the distribution of invasive plant lacks sufficient data which constraints the researchers to focus on specific taxonomic groups only (Stoms and Estes 1993). With time, the methods of documenting and reporting the IAPS has slightly changed and the methods of mapping the invasive plants are now more advanced. Now most of the studies utilize remote sensing and GIS techniques to demonstrate the change in ecosystem components, level of invasion and threat, which is more effective to address the instant control mechanisms.

With the advancement in both sensors and platforms, a noticeable progress has been made in mapping the invasive plants with increased accuracy. NDVI values, spatial resolution, hyperspectral imagery plays a significant role in precise detection of invasive plants (Dhakal 2021, Skowronek *et al.* 2017, Vidhya *et al.* 2017). For example, the use of Hyperion hyperspectral imagery and the hyperspectral images acquired from unmanned aerial vehicle (UAV) platform has successfully helped in the detection of the invasive plants such as, - *Phragmites australis*, and *Asclepias syriaca* in the study done in the coastal wetlands of the United States and Hungary, respectively. The hyperspectral imagery property has helped in the identification of IAPS with overall good accuracy.

Likewise, the NDVI improves the mapping accuracy and helps to accurately identify the distribution pattern of invasive plants (Bradley and Mustard 2006, Vidhya *et al.* 2017). A very high resolution (VHR) image is preferred for the detection of vegetation and non-native plant species (Bradley 2014, Feng *et al.* 2015). The detail and precise information in the VHR data helps to separate the signatures of different land cover types (Dhakal 2021) and is widely accepted for the recognition of invasive plants (Alvarez-Taboada *et al.* 2017, Carrión-Klier *et al.* 2022). Moreover, the numerous spectral bands of very high spatial resolution of hyper-spectral sensors can even pass through the Near-Infrared (NIR) and Short Wavelength Infrared (SWIR), allowing to differentiates the plant pigments and chemistry in both infra-red and visible bands, making it suitable for the mapping of invasive plants (Bradley 2014).

The invasion of *Mikania* and other non-native species have significantly affected the National Parks and Protected Areas (PA) of Nepal. The three of the world worst invasive plant, *Lantana camara*, *Mikania micrantha* and *Chromolena odorata* have already invaded the Chitwan National Park (CNP) and Parsa National Park (PNP) of Nepal with the potential threat to the habitat of endangered plants and animals. Almost 44% of *Rhinoceros* habitat is affected by the spread of non-native plants in the CNP and the spread is further intensified by the anthropogenic activities occurring in the park (Murphy *et al*. 2013). Similarly, the invasion of IAPS in the core area of PNP has already warned the park authorities for the possible threats to the natural habitats of endangered animals, like, *Rhinoceros* and *Panthera tigris* (Chaudhary *et al*. 2020). Another PA in Nepal with a high threat of IAPS is Jalthal forest area, which harbors, 150 species of trees, 145 species of herbs, 230 species of birds, 32 species of reptiles, 43 species of fishes and 27 species of mammals within 22 different management units (Sharma *et al*. 2021). Jalthal forest is the only remaining patch of the dense sub-tropical forest of Eastern Nepal. It provides an endless ecosystem service, ecotourism opportunity and is a source of subsistence livelihood to the rural communities. So, it is crucial to know the current invasion level in order to implant an adequate management approach. Our study will help the forest managers or responsible institutions to implement the appropriate control mechanism to maintain the biodiversity and forest vitality of this widely important natural landscape.

MATERIALS AND METHODS

Study area

The Jalthal forest of Jhapa district is the moist dense subtropical forest of the Eastern Nepal. The climate of the study area is tropical monsoon type with an annual average rainfall of 2130.4 mm and temperature varying from 10.05 ºC to 33.35 ºC (Bhattarai 2017). It lies in between 87º 55' and 88º 03' E longitude and 26º 27' and 26º 32' N latitude and covers an area of about 6000 ha (**Figure 1**). It consists of a wide variety of habitat such as lakes, rivers, grasslands, and is the home for the several threatened species of fauna and flora like *Eliphas maximus, Manis crassicaudata, Gavialis gangeticus, Rauvolfia serpentine*, *Cycas pectinata*, *Artocarpus chaplasha*. Initially, this forest patch was ecologically healthy and biologically diverse but with different anthropogenic and natural threats during last few years, it becomes more suitable for non-native plant

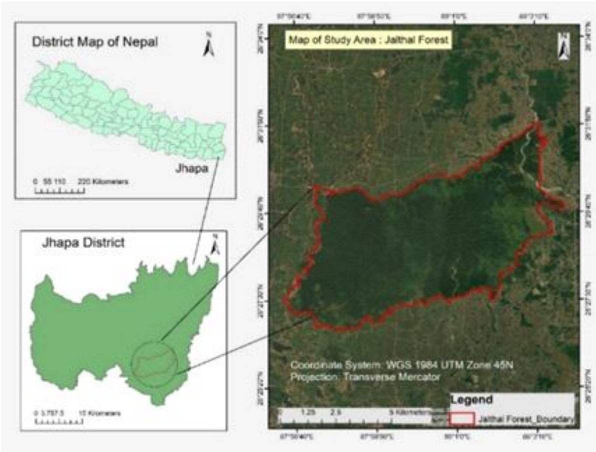

Figure 1. Map of the study area

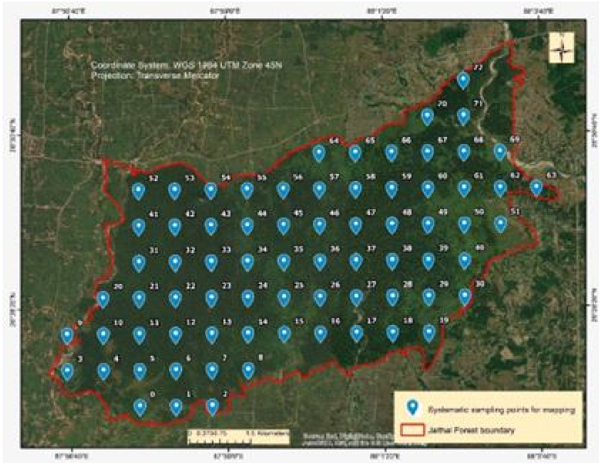

Figure 2. Systematic sampling points all over the forest

species. Currently, the forest is heavily invaded by the exotic plants like *Mikania micrantha* and *Chromolena Odorata* resulting a higher threat to the natural habitats of Asian elephant. Apart of that, the landscape also has a social significance as, - a notable portion of the community forests user groups rely to the forest product for their subsistence livelihood.

Data collection

The field data were collected during the flowering period of invasive plants, in the month of October 2019. The study area included 22 community forests of Jalthal. A regular spacing of 1000 x 1000 m was set up by selecting create fishnet in ArcGIS 1 to represent the overall samples of the forest **(Figure 2)**. It was then divided in four different quadrants and the availability of the invasive plants were measured on each plot based on their presence. GPS coordinates and the percentage of IAPS as 25, 50, 75 and 100% was recorded if the invasion was observed in 1, 2, 3, and 4 quadrants, respectively. In the field, the coverage of sample sites was mostly affected due to the river, lakes, wetlands and occasionally by dangerous wild animals such as Elephant and Python.

Remotely sensed data

We obtained ZIYUAN-3A (ZY3A) satellite images from Department of Survey (DOS), Government of Nepal (GON) which was provided by Chinese government under Memorandum of Understanding (MoU) signed with each other. ZY3A is equipped with three high resolution panchromatic camera (also called Three-line Array Camera, TAC) with push broom array imager that has a spatial resolution of 2.1 m and the multispectral camera with 5.8 m resolution. The four bands of ZY3A gave the multispectral composite image, which helped to interpret and visualize the vegetation. The sensor specific detail of ZY3A is shown in **Table 1**.

Table 1. Sensor specifications of ZY3A

Bands	Bandwidth	Spatial Resolution	Applications
B1	450 – 520 nm	5.8m	Blue
B2	520 – 590 nm	5.8m	Green
B3	630 – 690 nm	5.8m	Red - Vegetation
B4	770 – 890 nm	5.8m	Infrared - Vegetation

Image pre-processing and NDVI calculation

Image was extracted for the study using sub-setting function in ERDAS Imagine software. A High Pass Filter (HPF) resolution merge was performed under the tool PAN sharpening in the satellite data containing the information of the study area and finally a 2.3 m colored multispectral image was obtained. The brightness as well as the contrast of the study image was improved after performing histogram equalization in ERDAS IMAGINE to better interpret the image. Then the Normalized Differential Vegetation Index (NDVI) of the study area was calculated.

The major land cover species presented at the site were invasive plants, forest, water, agricultural lands, and bare lands during the time of study. So, we divided the forest area into four classes- forest, invasive, water, and other lands (agricultural, bare lands, open spaces). The classification scheme for the agriculture land, bare land and open spaces is the ideal system of classification as our main objective was to classify the invasive plants using high resolution satellite data so we listed them under the single heading of 'Other Lands' during image analysis. To find the spectral reflectance value of different parameters, we calculated the NDVI using the following equation.

$$NDVI = \frac{\mathrm{IR} - \mathrm{R}}{\mathrm{IR} + \mathrm{R}}$$

where the IR and R are the infrared and red bands of the satellite image which gives the

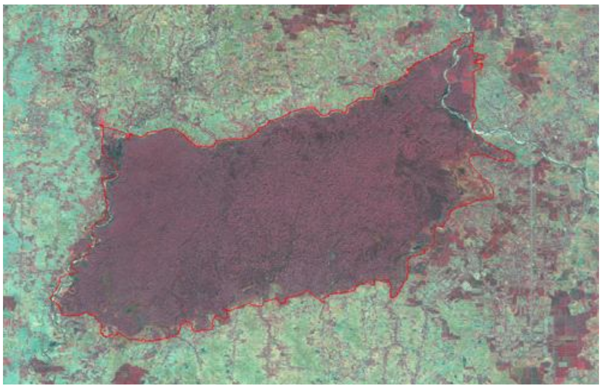

Figure 3. Image obtained after PAN sharpening

information presented in the band 4 and band 3 of ZY 3A. The reflectance value for each class were calculated. Then the image was finally projected to Universal Transverse Mercator (UTM) 45 zone and the training samples were created in ArcGIS. The field data and the GPS coordinates were laid on the image of the study area. For each class, at least ten training samples were created by drawing a polygon. Then a signature file was created from the training sample which was later used for the classification of the image.

Maximum likelihood classification

It is based on the Bayes Classification. In this classification, the classes are represented as C_i, where i = 1 to N, N represents the number of classes (Sisodia *et al.* 2014). The acquired satellite data was classified with (MLC) using the training samples as discussed above. The Maximum likelihood classifies the pixels based on the known properties of individual cover types and with acceptable results with the reference map (Ahmad and Quegan 2012). NDVI was used as a classification parameter while classifying the image with an aim to improve the mapping accuracy. The dense forest, water bodies and bare lands bear bright signatures **(Figure 4)** because of the high reflectance value as compared to the invasive plants. Overall, the NDVI values had helped to differentiate the classes and made the classification simple.

Accuracy assessment

Accuracy of the classified image was tested using the ground collected GPS points and confusion matrix. A field verification for the accuracy assessment was affected due to COVID- 19 pandemic during the later stage of the study. A total twenty-three number of random samples were used to assess the accuracy. The major land cover found for accuracy assessment were forests followed by the invasive plants based on its availability. The confusion matrix presented the overall accuracy and quality of the classification and of the individual class (Campbell and Wynne 2011).

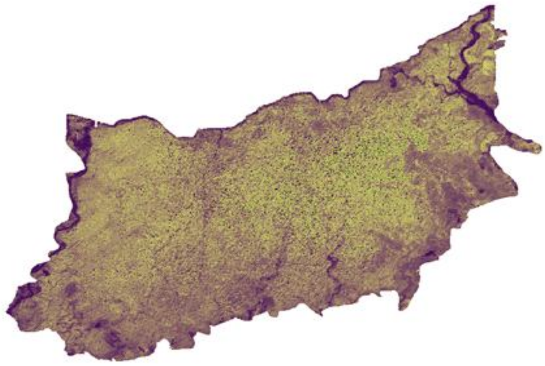

Figure 4. NDVI calculation of the study area

The parameters that give the information of confusion matrix were used to compare the results of different classification methods (Lewis and Brown 2001). Kappa coefficient was calculated and used for the measurement based on original agreement. The confusion matrix was used to calculate for the image classified through MLC. The producer and user accuracy of all classes were also calculated.

$$Kappa = \frac{2\times(TP\times TN - FN\times FP)}{(TP+FP)\times(FP+TN)+(TP+FN)\times(FN+TN)}$$

Where TP, TN, FN, FP represents the true positives, true negatives, false negatives and false positives.

RESULT AND DISCUSSION

NDVI Value of different land cover

The NDVI reflectance measurement values ranged from -1 to +1. It is clear from **Figure 5** that the dense forest has the highest reflectance value ranging from 0.941 to 0.070, which was because of the higher biomass as compared to the other classes like invasive plants (0.1532 to -0.0156), water (-0.015 to -0.714) and other lands (-0.0076 to -0.1889). In mapping, the NDVI with high spatial resolution image played a crucial role in the detection of the invasive plants. NDVI helped in giving more precise results by differentiating the scattered vegetation from a multispectral remote sensing image (Bhandari *et al.* 2012). It aims to assess the biomass quantity and offers the mean for the assessment of the phenological characteristics of the vegetation (Ghorbani *et al.* 2012, Szabo *et al.* 2016). The higher NDVI values represent the healthier and denser vegetation of the forest. For instance, the forest vegetation has the value ranging from 0.80 to 0.876 (Zaitunah *et al.* 2018) or 0.500 to 0.575 depending upon the vegetation coverage. The forest represents healthier and denser vegetation of the individual area. The other land cover classes such as water and soil have sparse vegetation ranging from 0.0175 to -0.328 and -

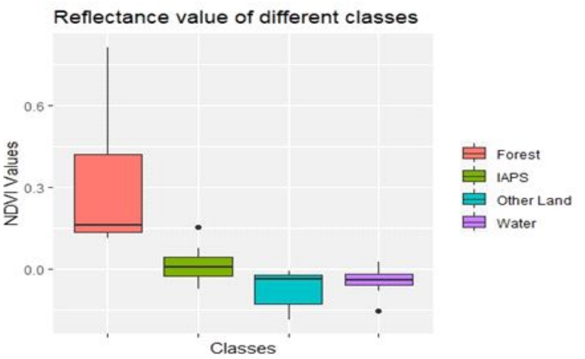

Figure 5. Box plot showing the spectral profile of different classes

0.001 to 0.166, respectively (Jeevalakshmi *et al.* 2016). Han *et al.* 2022) has found the median value of maximum NDVI to be 0.56 within one year of invasion.

Distribution of different land cover classes

Overall, the Jalthal forest is dominated mostly with the forests cover with the coverage of 53.7% (**Table 2**), whereas the Water bodies and other lands such as bare and agriculture were found to be covered 5.4% and 8.9% of the study area respectively. The area and percentage coverage by each class of Jalthal forest is shown in the (**Table 2**)

It was clearly observed that the invasion was more concentrated on the periphery of the Jalthal forest area, where the forest cover was comparatively less **(Figure 6)**. These areas are near the roadways, rivers where the interaction of human is abundant. Similarly, while delving in the heart of the forest, it was found that the invasions were prevalent in the open area where there was no tree canopy. It was also noticed that the chance of invasion is higher near the water bodies and agricultural lands. Of the total forest area, the invasive plants covered almost 37% of the forest, spreading in an area of 1932 ha.

This study revealed that the growth and spread of the invasive species is highly influenced by the anthropogenic activities around the surrounding environment. Most of the invasive plants were in the areas near to the road, at the border of agricultural land, in the area close to the rivers and in the opening of the forest. This observation is in alliance with the study of (Pilu *et al.* 2012), who found that the invasion by the plant *Arundo donax* was mainly located in a riparian as well as in simplified ecosystem

Table 2. Area covered by different classes of classified image

Class	Area (ha)	Area Coverage in (%)
Dense forest	3262	53.79
Invasive species	1932	31.86
Water	328	5.40
Other lands	542	8.93
Total	6064	100

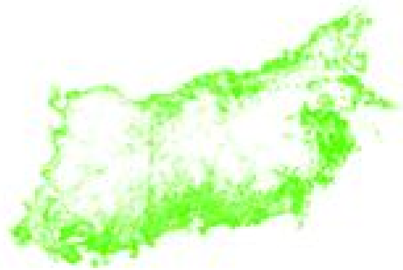

Figure 6. Invasion prone area of Jalthal forest

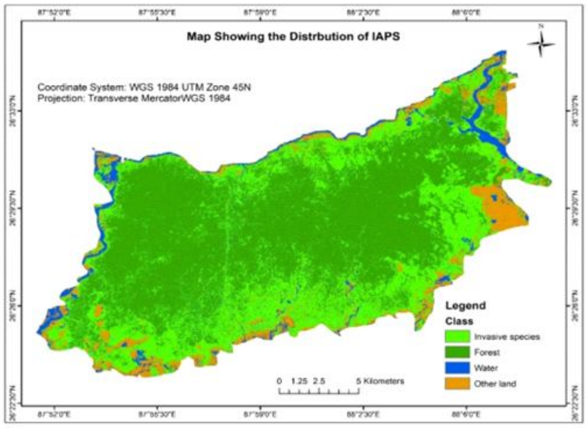

Figure 7. Map showing the distribution of Invasive plant in Jalthal

such as roadside where it could easily grow and flourish, surpassing the native plants. Moreover, the river banks are the preferred habitat of the invasive plants like *Mikania micrantha* in its native region as stated by Sapkota (2007). In the study area, the spread of IAPS inside the forest was most prevalent where there is no tree canopy. This is mainly because the forest has been experiencing immense pressure from outside. Fire, illegal cutting, overgrazing, population pressure for the high demand of the forest product and poaching are some of the disturbances that have been acting as a drivers of forest depletion in the study area. These reasons create a suitable environment for the non-native plant to adapt and grow in the area affecting the forest regeneration and growth. This observation of the present study is also supported by Shrestha and Dangol (2014) who observed the invasion of *Mikania micrantha* in CNP to be dominant in an area where the native vegetation is heavily disturbed. Once invaded the ground cover, the invaders can completely exclude and outcompete the growth of native plants leaving fewer resources for them to grow and thrive (O'Loughlin *et al.* 2021).

Accuracy assessment and Kappa statistics

A field verification from Google earth was used to prepare the error matrix. The user accuracy for the invasive plants were found relatively low as compared to other classes while we obtained an overall good producer accuracy for all other classes. The land cover such as 'Forest' and 'Other Lands'

Table 3. Error matrix

Class	IAPS	Forest	Water	Other lands	Total	User Accuracy (%)
IAPS	4	2	0	1	7	57.14
Forest	1	9	0	0	10	90
Water	0	0	2	0	2	100
Other lands	0	0	0	4	4	100
Total	5	11	2	5	23	Overall accuracy = 82.60%
Producer Accuracy (%)	80	81	100	80		
Kappa coefficient = 0.74						

created the confusion with the IAPS class as they were predicted wrongly. Overall, the error matrix showed good accuracy of 82.60% with the Kappa coefficient 0.74 (**Table 3**).

The results from accuracy assessment and Kappa statistics helped to conclude that the high spatial resolution multispectral sensor is suitable to detect the invasive alien plant species. The improved spectral resolution provides the superior classification of invasive plant because of their biochemical and structural properties (Royimani *et al.* 2019). Like our result, the accuracy in the detection of Bracken fern when using high spatial resolution in the study done in South Africa was found to be 91.67%, which falls down to 72.22% with the use of medium spatial resolution (Ngubane *et al*. 2014). Moreover, the study done with the comparison of mapping invasive plant performed with very high spectral resolution VHR (less than 5 m) to that with the medium spectral resolution MR (15 m), shows that the VHR image produced overall high accuracy with high Kappa values than image produced from medium resolution imagery (Carrión-Klier *et al.* 2022). The strategically positioned bands in high spatial resolution multispectral sensors have better performance in the differentiation of the vegetation than that of low spatial resolution multispectral sensors (Royimani *et al*. 2019). The multi spectral image of ZY3A has a high resolution of 5.8m, and NIR wavelength of up to 890 nm which makes it suitable for the differentiation of the different vegetation types.

Obtaining the cost effective and relevant data in terms of large scale with high spatial information bears considerable challenges. Mapping invasive plant with high resolution data of ZY3A with NDVI produce good accuracy of 82.60%. The invasive plant species covered an area of about 37% in Jalthal forest. Mapping invasive plant in Jalthal forest gives the current invasion trend of the forest which can be beneficial in managing the future invasion of the study area. ZY3A data highlights the importance of high spatial remote sensing technique in mapping of invasive plant. The use of Maxent model and other classification technique can also be tested to further improve the accuracy of the image to know the future level of invasion of the study area.

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