



Research Article

Spatio-Temporal Distribution of Invasive Species (*Prosopis juliflora*, *Arundo donax*) in Kundian Irrigated Plantation, Mianwali

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Abstract | Invasive alien species are the species that are not native to the certain ecosystem and have adverse effect on the native plant species. *Prosopis juliflora* and *Arundo donax* are invasive plants in Kundian irrigated plantation and produce competition for native plants. There was no research on drivers of Invasive species (*Prosopis juliflora* and *Arundo donax*) and current and temporal spread of these species spread in the study area. The main objective of this study is to access time wise distribution of these species (10 years) and current distribution in the study area. This research also intends to identify the main drivers of invasive species (*Prosopis juliflora*, *Arundo donax*) in the study area. To map spatio temporal distribution of selected invasive species Random forest (RF) classification on Landsat 8 images 2014, 2019, 2023 for temporal and 2024 for current distribution was done. Total 7 Land use land cover classes were identified by classification which include water body, crop land, other vegetation, built up, bare land, *Prosopis juliflora* and *Arundo donax*. Drivers of invasive species (*Prosopis juliflora*, *Arundo donax*) are identified through a questionnaire and analyzed in SPSS. RF was successful to classify current distribution (2024) of *Prosopis juliflora* and *Arundo donax* with Kappa statistics of 0.79 and temporal distribution of these species have Kappa statistics value of 0.78, 0.70, 0.71 and overall accuracy of 81.81%, 74.5%, 75% and 82.5% for the years 2014, 2019, 2023 and 2024. It was noted that *Prosopis juliflora* increased from 1927.13 ha to 3337.92 ha and current distribution shows that it is still increasing and *Arundo donax* increased from 645.95 ha to 1639.87 ha and current distribution shows that now *Arundo donax* is decreasing (1424.10 ha). Main driver which was indicated for spread of selected species is anthropogenic activities. Results obtained by this study would help to identify the area covered by these species and can save native plants, water resources and cropland.

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Introduction

Invasive alien species (IAS) they are the organisms that are not native to the certain ecosystem and they are have adverse effect on human health and environment (Ljubojević, 2022). The rapid and often uncontrolled expansion of invasive species has instigated heightened concern among scientific communities (Polley *et al.*, 1997).

Invasive species primarily comprise nonnative organisms that have been introduced into natural or established habitats, either accidentally or deliberately by humans. In doing so, these species pose significant threats to the environment, economy, and potentially public health. Over the course of the last few centuries, thousands of such alien species have managed to establish themselves in various regions around the globe. This phenomenon, often referred to as biological pollution, stands as the second most substantial potential menace to natural biodiversity, following closely behind habitat loss. While Pakistan has not experienced the same level of invasive species proliferation as certain other nations, there exists a deficiency in terms of invasion biology literature (Qureshi *et al.*, 2014). Many multi-purpose trees have been carried over the world, and numerous species are now naturalized and invasive (Rejmanek and Richardson, 2013). *Prosopis juliflora* is indigenous to north and Central America (Hailu *et al.*, 2004). It is perennial, prickly deciduous bush or a little tree weed and is a member of Leguminosae family. In some countries, it is planted as fast growing and drought tolerant species and in some countries, it got out of control as alien species. When fully grown plant reach a height of 12 meters and trunk diameters of 1.2 meter producing spiky thickets that are impossible to penetrate (Berhanu and Tesfaye, 2006). Invasion of *Prosopis juliflora* has detrimental consequences on the well-being of pastoral and agro-pastoral communities (Zeray *et al.*, 2017).

Despite its notable strengths and benefits, *Prosopis juliflora* also possesses significant drawbacks. Thorns on *Prosopis* trees can inflict injuries to human flesh, and in some cases, these injuries have tragically led to fatalities. Animals reliant on *Prosopis* pods experienced issues such as dental erosion leading to eventual tooth loss, gum buildup on their jaws hindering chewing (Maundu *et al.*, 2009).

Arundo donax has been spread worldwide by human so, it can be found in various regions, including Asia, Southern Europe, North Africa, the Middle East, North and South America, and Australasia (Perdue,

1958; Bell, 1997). *Arundo donax* is recognized for its medicinal properties. In traditional practices, the rhizome or rootstock of this plant was utilized to address dropsy, while a preparation of the root or rhizome boiled in wine and honey was applied in cases of cancer. Moreover, *Arundo donax* found application in treating condylomata and breast indurations. The root infusion was valued for its diverse therapeutic effects, serving as an antilactagogue, depurative, diaphoretic, diuretic, emollient, hypertensive, hypotensive, and sudorific agent. Beyond this, *Arundo donax* has been employed as a hemostatic agent, in alleviating toothache, and in the treatment of pertussis and cystitis (Al-Snafi, 2015).

The widespread dissemination of *Arundo donax* can be attributed to its rapid vegetative growth. New shoots emerge significantly faster than the seedlings of indigenous plants that rely on sexual reproduction (Herrera and Dudley, 2003). The invasive nature of the giant reed (*Arundo donax*) poses a significant challenge to riparian habitats, representing a prominent issue in riparian management (Spencer *et al.*, 2008).

Remote sensing encompasses the non-contact acquisition of electromagnetic spectrum data, employing mechanical, photographic, numeric, or visual sensors situated on mobile platforms (Fussell *et al.*, 1986).

Conventional vegetation mapping is carried out using either quadrant or transect techniques, where in details about plant attributes like species, stem dimensions, and height are documented within each designated area (Gillison, 2006). Mapping through manual field surveys is a time-consuming and labor-intensive approach. A more viable alternative is remote sensing, which can efficiently cover extensive areas and swiftly evaluate even inaccessible locations (Cancela *et al.*, 2014). The feasibility of utilizing remote sensing technology for mapping biological invasions has increased, thanks to the accessibility of high-resolution multi-spectral and multi-temporal data (Joshi *et al.*, 2006). The main aim of this study was to determine the current and temporal distribution of invasive species (*Prosopis juliflora* and *Arundo donax*) in Kundian irrigated plantation Mianwali and to find out drivers of selected invasive species in the study area.

Materials and Methods

Study area

The research was conducted in the Mianwali district

of Punjab, Pakistan, which is divided into three tehsils: Mianwali, Piplan, and Isa Khel. The focused area was the Kundian Irrigated Plantation, situated in the Piplan tehsil, under MC Kundian. It lies between latitude 32° 20' to 32° 30' north and longitude 71° 30' to 71° 38' east about 10 km south of Mianwali city in the north- western Punjab. The M.M Alam Road which links the Mianwali with other districts of Thal runs through the middle of the plantation. The land of the plantation has an average altitude of 760 feet with some areas rising to over 800 feet. Ecologically the plantation is situated in tropical arid zone belt of Punjab which is characterized by extremes of temperature, low relative humidity and irregular rainfall. The temperature varies widely throughout the year with the range between 2-49 °C. There are two distinct rainy reason. The main season falls in the months of July, August and September which is called the monsoon season while there is a minor season as well which extends from January to march. July and august are wettest months when precipitation reaches its climax with maximum of 286 mm. The natural vegetation of plantation is xerophytic in character. These species include *Acacia nilotica* (Kikar), *Prosopis cineraria* (Jand), *Tamarix aphylla* (Frash), *Zizyphus mauritiana* (Ber), *Salvadora oleoides* (Wan). (Kundian Plantation History file)

Data sets preparation

To detect the spatio-temporal distribution of invasive species (*Prosopis juliflora* and *Arundo donax*) in Kundian irrigated plantation Landsat 8 (30m resolution) data downloaded by USGS website was used. Total 4 Landsat 8 images of the years 2014, 2019, 2023 for temporal distribution and 2024 image for current distribution were obtained for checking the distribution of selected invasive species. *Arundo donax* flowering season is end of summers to autumn (Tucker, 1990) *Prosopis juliflora* usually has one or two main flowering periods in its natural habitat. These usually coincide with the season of precipitation, which runs from December to February. If there is a delay, there may be two more blossoming seasons, one from July to September and the other from March to April (Hussain et al., 2020). By this reason data was downloaded for the month of September so that both plants could recognize easily. A questionnaire survey was conducted out to obtain primary data on the factors of invasive species (*Prosopis juliflora* and *Arundo donax*) in the study area. The study included 5 union councils, with 10 respondents from each

council selected at random for questioning. A total of 50 people were interviewed from the study region. Table 1 shows the attributes of satellite images.

Table 1: Attributes of satellite image.

Sensor	Date of acquisition	Path/Row	Spatial resolution
Landsat 8	24 September 2014	151/37	30m
Landsat 8	22 September 2019	151/37	30m
Landsat 8	25 September 2023	151/37	30m
Landsat 8	20 September 2024	151/37	30m

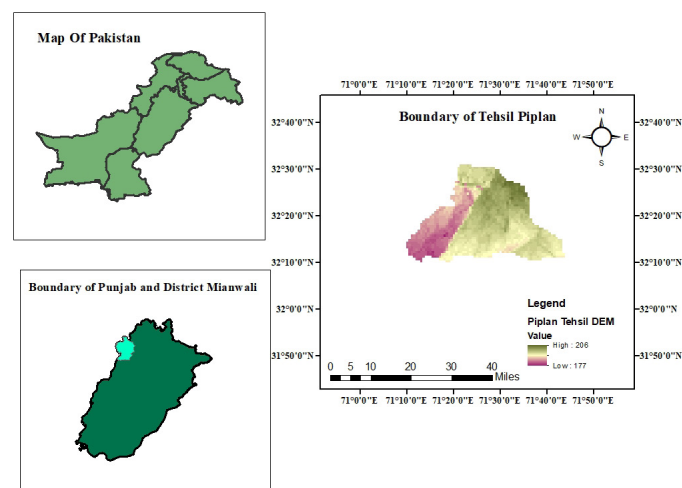


Figure 1: Map of Tehsil Piplan.

First of all image preprocessing was done on all the images (2014, 2019, 2023, 2024) and atmospheric and radiometric corrections were performed and then data was extracted with the help of shape file.

Image classification

Supervised classification approach requires training sample as for classification input. Training samples and ground truth data were used to train the classifier and generate accurate maps. For current distribution and for multi-temporal distribution random forest was used for classification of Landsat 8 imagery. Reference points for current distribution of invasive species (*Prosopis juliflora* and *Arundo donax*) was collected in field in the September 2024 using GPS. Total 90 GPS points were collected for Water body, Cropland, Other vegetation, Bare land, Built up, *Arundo donax* and *Prosopis juliflora*. So, reference data is randomly divided into training data and validation data with ratio of 70% and 30%. Reference data for historical Landsat 8 imagery was acquired through visual interpretation of images from the years 2014, 2019, 2023 accessed via Google Earth Pro software.

Accuracy assessment of the random forest classified images
Accuracy assessment of random forest was conducted with the reference points in the study area. The GPS points and satellite points overlaid with classification image and corresponding classified points to calculate confusion matrix. Figure 2 showing reference points for year 2024 (current distribution) for accuracy assessment and Figures 3, 4, 5 showing reference points for year 2014, 2019, 2023 for temporal distribution.

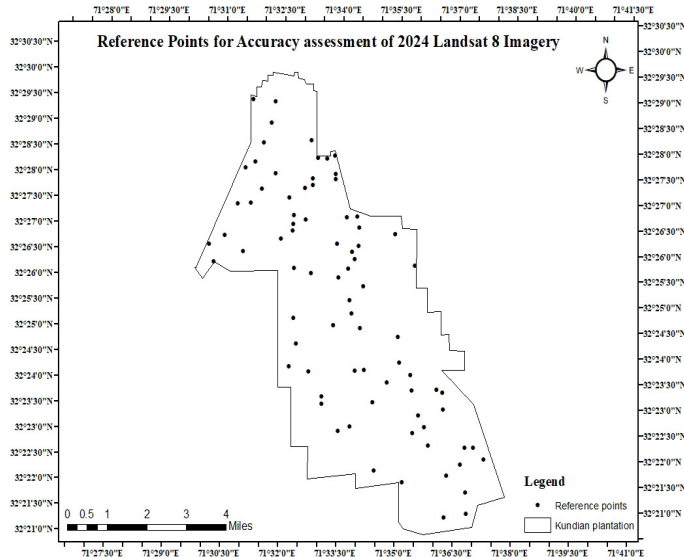


Figure 2: Reference points for accuracy assessment of year 2024.

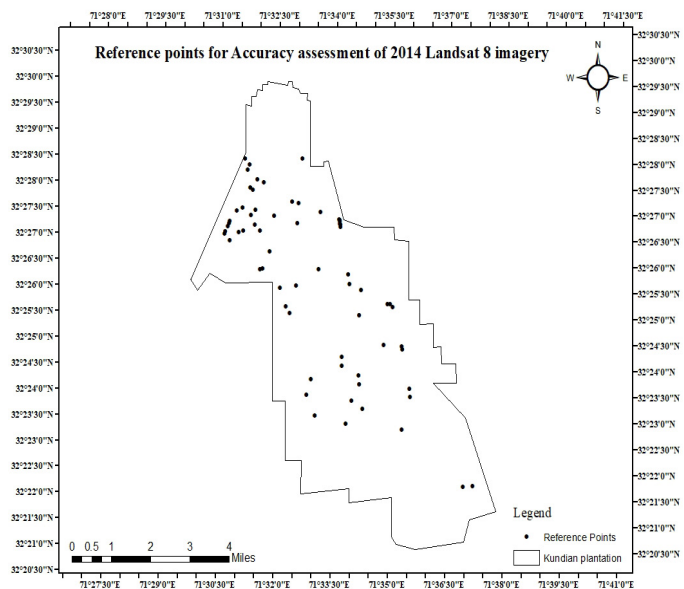


Figure 3: Reference points for accuracy assessment of year 2014.

Confusion matrix

Confusion matrix of the year 2024 (current distribution) for reference points and classified points were shown in Tables 2, 3, 4, 5 showed the confusion matrix for the year 2014, 2019, 2023 (temporal distribution). Figure 6 shows current distribution of

selected invasive species in study area and figure 7,8,9 showing temporal distribution (2014, 2019, 2023) of selected invasive species in study area.

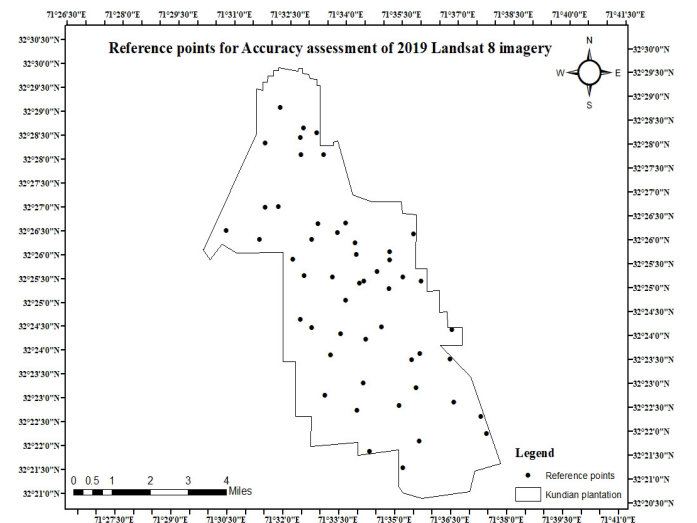


Figure 4: Reference points for accuracy assessment of year 2019.

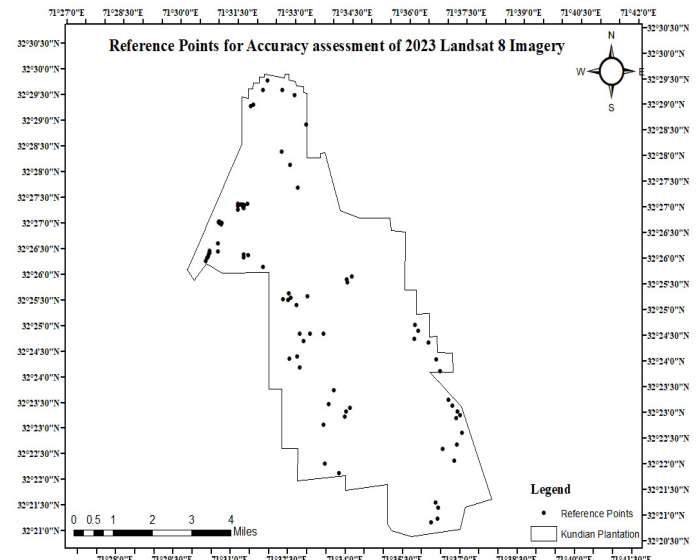


Figure 5: Reference points for accuracy assessment of year 2023.

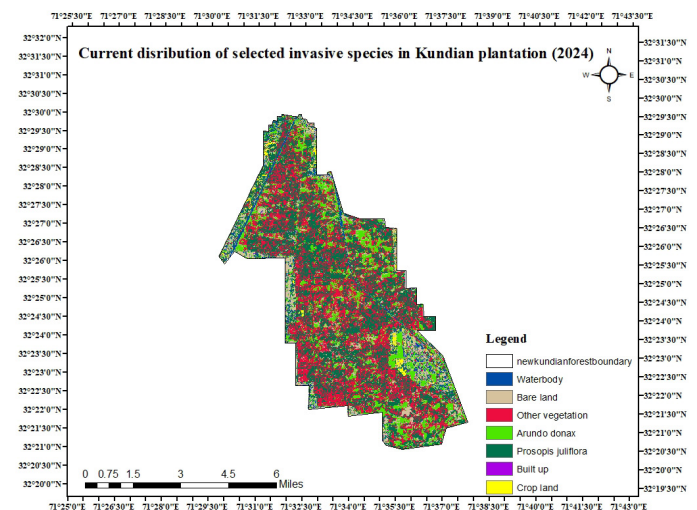


Figure 6: Current distribution of *Prosopis juliflora* and *Arundo donax* in study area (2024).

Table 2: *Confusion matrix table for 2024.*

Classified	Water body	Crop land	Other vegetation	Bare land	Built up	Arundo donax	Prosopis Juliflora	Total reference points
Water body	8	0	0	0	1	3	0	12
Cropland	0	10	0	0	0	0	0	10
Other vegetation	0	0	8	0	0	0	1	9
Bare land	0	0	0	4	0	0	0	4
Built up	1	0	0	0	4	0	0	5
Arundo donax	2	0	0	0	0	13	1	16
Prosopis juliflora	0	0	3	2	0	0	19	24
Total classified points	11	10	11	6	5	16	21	80

Table 3: *Confusion matrix of 7 classes of 2014.*

Classified	Water body	Crop land	Other vegetation	Bare land	Built up	Arundo donax	Prosopis juliflora	Total reference points
Water body	12	0	0	0	0	1	0	13
Cropland	0	3	1	0	0	0	0	4
Other vegetation	0	0	11	0	0	0	2	13
Bareland	0	0	0	10	0	0	0	10
Builtup	1	0	0	0	5	0	0	6
Arundo donax	3	0	0	0	0	5	0	8
Prosopis juliflora	0	0	4	0	0	0	8	12
Total classified points	16	3	16	10	5	6	10	66

Table 4: *Confusion matrix of 7 classes of 2019.*

Classified	Water body	Crop land	Other vegetation	Bare land	Built up	Arundo donax	Prosopis juliflora	Total reference points
Water body	5	0	0	0	2	0	0	7
Cropland	0	5	3	0	0	1	0	9
Other vegetation	0	0	7	0	0	0	1	8
Bare land	0	1	0	4	0	0	0	5
Built up	1	0	0	0	4	1	0	6
Arundo donax	2	0	0	0	0	6	0	8
Prosopis juliflora	0	0	1	0	0	0	7	8
Total classified points	8	6	11	4	6	8	8	51

Table 5: *Confusion matrix of 7 classes of 2023.*

Classified	Water body	Crop land	Other vegetation	Bare land	Built up	Arundo donax	Prosopis juliflora	Total reference points
Water body	10	0	0	0	1	0	0	11
Cropland	1	7	0	0	0	0	0	8
Other vegetation	0	1	12	0	0	0	3	16
Bare land	1	0	0	9	1	0	0	11
Built up	0	0	1	2	7	0	0	10
Arundo donax	0	3	1	2	0	8	0	14
Prosopis juliflora	1	0	1	0	0	1	7	10
Total classified points	13	11	15	13	9	9	10	80

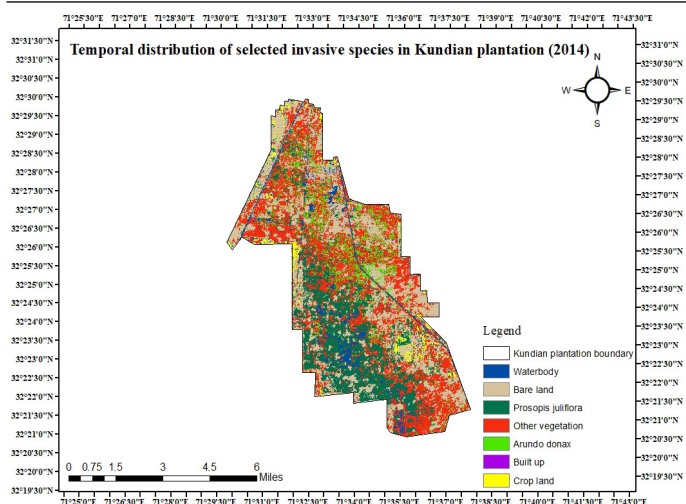


Figure 7: Temporal distribution of *Prosopis juliflora* and *Arundo donax* in study area (2014).

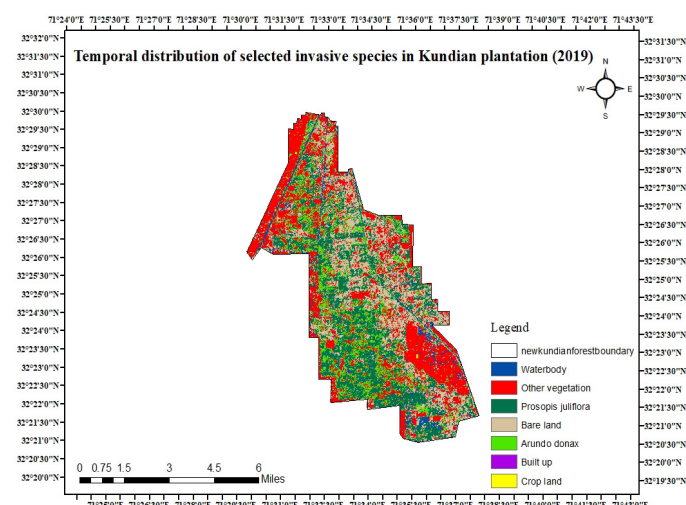


Figure 8: Temporal distribution of *Prosopis juliflora* and *Arundo donax* in study area (2019).

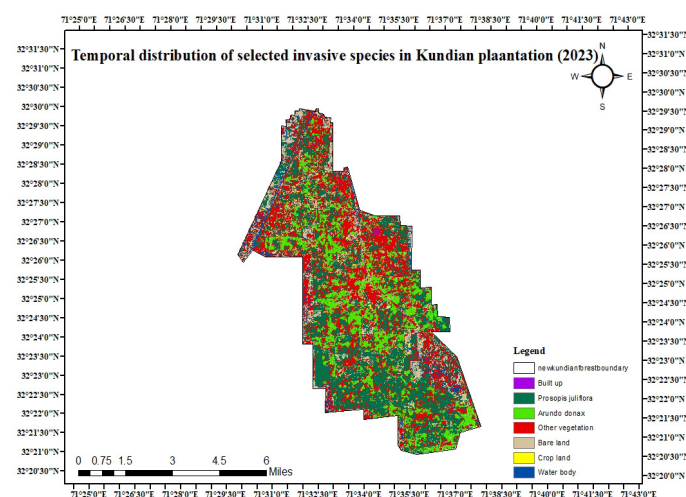


Figure 9: Temporal distribution of *Prosopis juliflora* and *Arundo donax* in study area (2023).

Kappa analysis

Kappa analysis was used to assess image classifying agreement. This methodology is a discrete multivariate method used to check accuracy. It generates Kappa

statistics, which estimate KAPPA and serve as an indicators of agreement or correctness (Rwanga and Ndambuki, 2017).

The Kappa value assesses the agreement between classification and reference data after removing chance-related differences. Kappa values (range from -1 to 1) classified into following categories: (>0.80) almost perfect strength of agreement between classification and reference data, considerable strength of agreement (0.61-0.80), and moderate strength of agreement (0.41-0.60), fair strength of agreement (0.21-0.40), slight strength of agreement (0.00-0.20) and poor strength of agreement on <0.00

Results and Discussion

Mapping current distribution (2024) of *Prosopis juliflora* and *Arundo donax*

In this research current distribution maps were created by supervised classification algorithms i.e., random forest (RF). Following are the LULC classes that were identified after classification; water body, cropland, other vegetation, bare land, built up, *Arundo donax* and *Prosopis juliflora*. According to the findings, there was a significant change in the vegetation cover of kundian plantation.

Area measurements for the classifications were provided in hectares (ha) and percentage terms, according to the pixel counts. The dominant land cover was *Prosopis juliflora* with 37.73% and covering area of 3523.02 ha. This was followed by other vegetation which occupied 31.67% of the area (2957.36 ha). *Arundo donax* came next with 1424.10 ha (15.25% of the whole area), then comes bare land (943.6 ha) with 10.10%. After bare land there is water body which occupied 3.73% area (348.57 ha), then crop land with 1.13% and cover area of 105.95 ha and at the last there came built up area which covered smallest area of 33.93 ha (0.36 % of total area).

Mapping temporal distribution of *Prosopis juliflora* and *Arundo donax*

The random forest classifier was used to classify Landsat 8 images of years 2014, 2019, 2023.

Temporal distribution analysis (2014)

Random forest classifier was used to classify the image of 2014 and 7 classes were developed. Area measurements for the classifications were provided in

hectares (ha) and percentage terms, according to the pixel counts. The largest category is other vegetation, which is 34.42% of the study area and in hectares (ha), this corresponds to 3213.22 ha. Bare land followed as the second-largest category, comprising 31.19% of the region with an area of 2912.02 ha. Then comes *Prosopis juliflora* which covers 20.64% (1927.15 ha), followed by *Arundo donax* cover 6.91 % (645.95 ha) area. After *Arundo donax* there is water body which covers an area of 4.48 % (417.93 ha) then crop land with 2.34% (218.78 ha) while built up is the smallest class covered an area of 0.006% (0.61 ha).

Temporal distribution analysis (2019)

The dominant land cover was other vegetation with 32.01% and covering area of 2988.73 ha. This was followed by *Prosopis juliflora* which occupied 25.89% of the area (2417.18 ha). Bare land came next with 2245.29 ha (24.05 % of the whole area), then came *Arundo donax* (1284.29 ha) with 13.75%. After *Arundo donax* there was water body which occupy 4.20 % area (392.29 ha), then crop land with 0.07% and cover area of 7.29 ha and at the last there was built up area which covers smallest area of 0.80 ha (0.0086 % of total area).

Temporal distribution analysis (2023)

The *Prosopis juliflora* category covered 35.75% of the region, 3337.92 ha, making it the largest LULCC class. Other vegetation followed with 31.47% (2938.01 ha), then *Arundo donax* with 17.56% (1639.87 ha). Bare land accounted for 11.18 % (1043.79 ha), and water body covered 2.94 % of the area (274.52 ha). Water body is followed by crop land area 0.91 % (84.84 ha) and smallest area is covered by built up 0.18% (17.09 ha).

Accuracy assessment for current mapping (2024)

Accuracy assessment was performed for Landsat 8 image of 2024 and an analytical accuracy report was prepared by the confusion matrix. For water body the user accuracy was 66.7 percent. Crop land had a user accuracy of 100 percent, other vegetation had 88.9 percent, while bare land had 100 percent, built up had 80 percent, *Arundo donax* had 81.25 percent and *Prosopis juliflora* had 79.17 percent. The producer accuracy for cropland was 100 percent, and for *Prosopis juliflora* was 90.47 percent, for *Arundo donax* was 81.25 percent. Built up had producer's accuracy of 80 percent while water body and other vegetation had 72.7 percent producer's accuracy, and bare land

had 66.67 percent.

The classification of the 2023 image achieved an overall accuracy of 82.5% by dividing the total number of correctly classified pixels by total number of true reference points. The Kappa coefficient for the 2023 LULC classified map was 0.79 which showed that classification strength of 2024 was considerable because it falls between 0.61-0.80.

Accuracy assessment for temporal distribution mapping (2014)

Accuracy assessment was performed for Landsat 8 image of 2014 which was classified by random forest and an analytical accuracy report was prepared by the confusion matrix. For water body the user accuracy was 92.3 percent. Crop land had a user accuracy of 75 percent, other vegetation had 84.62 percent, while bare land had 100 percent, built up had 83.3 percent, *Arundo donax* had 62.5 percent and *Prosopis juliflora* had 66.67 percent. The producer accuracy for crop land, built up and bare land was 100 percent then comes *Arundo donax* with producer's accuracy of 83.3 percent. The producer's accuracy of *Prosopis juliflora* is 80 percent and water body was 75 percent and in the last there was other vegetation which had producer's accuracy of 68.8 percent.

The classification of the 2014 image achieved an overall accuracy of 81.81 % by dividing the total number of correctly classified pixels by total number of true reference points. The Kappa coefficient for the 2014 temporal distribution classified map was 78.18% (0.78) which showed that classification strength of 2014 Landsat 8 image is considerable because it falls in between 0.61-0.80.

Accuracy assessment for temporal distribution mapping (2019)

Accuracy assessment was performed for Landsat 8 image of 2019 which was classified by random forest and an analytical accuracy report was prepared by the confusion matrix. For water body the user accuracy was 71.4 percent. Crop land had a user accuracy of 55.6 percent, other vegetation had 87.5 percent, while bare land had 80 percent, built up had 66.67 percent, *Arundo donax* had 75 percent and *Prosopis juliflora* had 87.5 percent. The producer accuracy for bare land was 100 percent then *Prosopis juliflora* with producer's accuracy of 87.5 percent. The producer's accuracy of crop land was 83.3 percent and *Arundo donax* was 75

percent, then came built up with 66.7 percent, other vegetation with 63.6 percent producer's accuracy and in the last there was water body which had producer's accuracy of 62.5 percent.

The classification of the 2019 image achieved an overall accuracy of 74.5% by dividing the total number of correctly classified pixels by total number of true reference points. The Kappa coefficient for the 2019 temporal distribution classified map was 0.70 which showed that classification strength of 2019 Landsat 8 image is substantial because it falls between 0.61-0.80.

Accuracy assessment for temporal distribution mapping (2023)

Accuracy assessment was performed for Landsat 8 image of 2023 which was classified by random forest and an analytical accuracy report was prepared by the confusion matrix. For water body the user accuracy was 90.9 percent. Crop land had a user accuracy of 87.5 percent, other vegetation had 75 percent, while bare land had 81.8 percent, built up had 70 percent, *Arundo donax* had 57.14 percent and *Prosopis juliflora* had 70 percent. The producer accuracy for *Arundo donax* was 88.89 percent, and for other vegetation was 80 percent, for built up was 77.77 percent. Water body had producer's accuracy of 76.9 percent while *Prosopis juliflora* had 70 percent bare land had 69.23 percent and then comes crop land 63.6 percent. The classification of the 2023 image achieved an overall accuracy of 75% by dividing the total number of correctly classified pixels by total number of true reference points. The Kappa coefficient for the 2023 current distribution classified map was 0.71 (70.75%) which showed that classification strength of 2023 Landsat 8 is substantial because it falls between 0.61-0.80.

Drivers of invasive species

Socio-economic characteristics: Gender, Age and Marital status distribution: Cultural limitations required that only male respondents be included in this study. The participants who were between the ages of 46 years and above made up the greatest percentage of the group (32%), followed by those who were 26 to 35 of age (28%), while others were of ages between 36 to 45 (24%) and 18 to 25 (16%). The proportion of married participants were 72%, while 16% of the respondents were unmarried and 12% were divorced.

Education and occupation

A large percentage of responders were uneducated

(34%) and had matriculation degree (22%). In particular, 20% of participants were done with their primary education, 14% had completed their intermediate education and 10% obtained master's degrees. Based on the data, 10% of the respondents held government jobs, 14% pursued other occupations, and 76% of the respondents engaged in business which include timber production and agriculture production.

Knowledge of identifying Prosopis juliflora and Arundo donax

94% of respondents were aware of presence of invasive species and their features for identifying *Prosopis juliflora* and *Arundo donax* species and only 6% were unaware of the presence and identification.

Invasive species as troublesome

When asked whether these species poses any issues for you or not, 72% said that these species (*Prosopis juliflora* and *Arundo donax*) are troublesome for them and 28% said that they have no issue with these species.

Main drivers of invasive species

Rate of invasion: 62% of respondents claimed the rate of invasion was rapid, 22% said it was moderate, and 16% said it was slow. After data analysis, it was discovered that 62% of participants confirmed that the rate of invasion in the study area is considered rapid overall.

Human reliance on Invasive species: 74% of people said that *Prosopis juliflora* and *Arundo donax* are grown by people themselves because people depend on them for fuel wood. 26% said that they do not rely on these species.

Main drivers of Invasive species: The main driver of the spread of selected invasive species in the area, as indicated by the respondents, is anthropogenic activities (ecological) which accounted for 54% of the responses. This suggests that human plants these trees for shade purpose, covering bare lands and they play a significant role in facilitating the spread of invasive species like *Arundo donax* and *Prosopis juliflora* in the Kundian irrigated plantation in Mianwali. The absence of effective control measures was cited as the second most significant factor contributing to the spread of invasive species, with 20% of responses. 9% said that natural mitigation patterns are responsible for spread

of invasive species while 17% identified others divers, e.g unintentional introduction, as drivers of invasive species in the study.

Impacts of invasive species

Impacts of invasive species on water: 24% said that these species do not have any effect on water but 76% state that these species consume large amount water and lead competition to native flora.

Economic impact: 56% responded that the invasion of *Prosopis juliflora* and *Arundo donax* can lead to the loss of productive land for crops or grazing, affecting agricultural productivity and livelihoods while 44% responded opposite.

As *Prosopis juliflora* and *Arundo donax* were planted for green purpose but later on these species became invasive in the study area. These species are damaging the water availability of area and make competition for other species to survive. The native species of the study area are damaged because of selected invasive species as they give competition to native species for survival. In 2014 there was barren land present in the Kundian irrigated plantation so these species got plot to expand. The results from this study show that in 2014, *Prosopis juliflora* invaded 20.64% of the area, which increased to 25.89% in 2019 and increased further to 35.75% in 2023. Similarly, another invasive species, *Arundo donax*, also showed an increasing trend with 6.91% in 2014, 13.75% in 2019, and 17.56% in 2023. This data shows an increasing trend for these species within a decade. However, the present mapping of distribution in 2024 has shown a further increase of *Prosopis juliflora* to 37.73% of the total area coverage, while *Arundo donax* showed a decline of 15.25% in the same year. Accurate and reliable data on the proliferation and distribution of invasive plant species are essential for their effective management. This data is vital to deciding what to do and putting the right controls in place. Over time, remote sensing has shown to be an effective method for providing this kind of data, providing insights into the dynamics of invasions. Its increasing use in mapping and tracking invasive species is demonstrated by its popularity.

These results coincides with the study of (Engda,2009) who demonstrate that from 769 hectares in 1986 to 3,849 hectares by 2001, and then swiftly rising to 11,579 hectares by 2007, the area invaded by *Prosopis juliflora* increased dramatically over time. *Prosopis*

juliflora surpassed almost every type of land use and land cover during this time, with shrub land suffering the greatest damage from the species invasion of 2,742 hectares. Another study of (Tadros *et al.*, 2020) the total estimated area invaded by *Prosopis juliflora* was roughly 92 ha, while the area covered by *Prosopis* in that exact area in 2017 was almost 413 ha. Study of (Kweka *et al.*, 2023) describe that main cause of spread of *Prosopis juliflora* is anthropogenic activities as people plant these species for shade purpose because these species are fast growing plant. Masakha and Wegulo (2015) also stated that this species is the main source of fuel wood so people plant it and it is increasing rapidly. This is the first research on mapping *Arundo donax* by using Landsat image and machine learning technique and there was no research conducted before on identifying drivers of selected invasive species in study area. All given data is purely based on perception of local community and officials. Another driver identified through consultations with local stakeholders was the absence of effective control measures implemented by the forestry department. There was a general lack of awareness about the adverse impacts of *Prosopis juliflora* and *Arundo donax* among the locals. These species change not only the ecological balance but also put great pressure on the local water resources by depleting the groundwater and reducing the availability of surface water. Also crop land and other vegetation which includes native plants damaged by these selected invasive species. Besides, a lack of public education and outreach programs has exacerbated the problem and left the community unprepared to mitigate these impacts. Therefore, the relevant authorities should take a proactive approach by incorporating awareness campaigns and stringent management strategies to control the spread of these invasive species and protect the ecological integrity and water resources of the study area.

Conclusions and Recommendations

This study used Landsat earth observation data to map the temporal and spatial range of invasive *Prosopis juliflora* and *Arundo donax* species in the Kundian irrigated plantation. This research also identified the main drivers of selected invasive species in the study area. Total seven land-use land-cover (LULC) categories were demarcated to detect a change from 2014 to 2023 and current distribution of year 2024. Using ArcMap version 10.5, the random forest classifier (RF) technique

was applied to satellite imageries for classification. The findings demonstrated that selected species can be distinguished from its coexisting species both geographically and spectrally. Landsat data effectively identified *Prosopis juliflora* and *Arundo donax* from other land-cover types, including Build-up, other vegetation, Bare land, Water body, and cropland. The results from this study show that in 2014, *Prosopis juliflora* invaded 20.64% of the area, which increased to 25.89% in 2019 and increased further to 35.75% in 2023. Similarly, another invasive species, *Arundo donax*, also showed an increasing trend with 6.91% in 2014, 13.75% in 2019, and 17.56% in 2023. This data shows an increasing trend for these species within a decade. However, the present mapping of distribution in 2024 has shown a further increase of *Prosopis juliflora* to 37.73% of the total area coverage, while *Arundo donax* showed a decline of 15.25% in the same year. Findings revealed the significant increase of the selected invasive species during the time period. The main driver of selected invasive species is anthropogenic activities (54%), the absence of effective control measures was cited as the second most significant factor contributing to the spread of invasive species, with 20% of responses. 9% said that natural mitigation patterns are responsible for spread of invasive species while 17% identified others divers, e.g unintentional introduction, as drivers of invasive species in the study.

Based on findings it is revealed that these species have impact on water resources, crop land and other vegetation which include native species of the study area. It is suggested that overcoming such threats from invasive species like *Prosopis juliflora* and *Arundo donax* would require substituting fuels, such as gas facilities, to reduce dependence on them for fuel wood, leading to overexploitation. The illicit collection of such species by organized groups has to be controlled. Awareness through campaigns on the importance of community involvement in managing these invasive plants will go a long way toward preserving ecological balance and conserving valuable natural resources.

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Novelty Statement

This study represents the first comprehensive spatio-temporal assessment of the two invasive species, namely *Prosopis juliflora* and *Arundo donax*, within the Kundian Irrigated Plantation. Despite the ecological importance of invasive species concerning alteration to native ecosystems, no previous attempt has been made to map the distribution pattern of such invasive species in the study area. The combined distribution mapping of *Prosopis juliflora* and *Arundo donax* has not been explored yet. It also presents the root causes of the invasion, such as anthropogenic, and hydrological factors that are very specific to the plantation area.

Author's Contribution

Hareem Fatima: Wrote the original draft

Lubna Ansari: Supervised the study

Sajjad Haider Zaidi: Helped in data collection

Shazia: Helped in data acquisition

Saqib Mehmood: Helped in field work

Naseem Iqbal Butt: Proof reading of article

Conflict of interest

The authors have declared no conflict of interest.

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