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Expansion of Prosopis Juliflora and Land use Land Cover change in Korahey Zone of Somali Regional State, Eastern Ethiopia

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Abstract

This study used a Landsat Satellite data acquired over three reference years (1989, 2001 and 2019) to analyze land use land cover change and to calculate the extent of *Prosopis juliflora* expansion. Pre-processing activities like geo-referencing, layer stacking, mosaicking and masking were performed for the satellite images data and classified by supervised random forest classification method. The classified maps were assessed and compared with a referenced data and confusion matrix was developed for the calculation of accuracies kappa coefficients for the certainty of the classification result. The result of overall classified accuracies for the three reference years are 81.65%, 85.74% and 88.42% with the Kappa statistics of 0.7394, 0.8265 and 0.8390 respectively. The finding showed that *Prosopis juliflora* coverage increased from 8523.18ha in 1989 to 350000ha in 2019. Over periods of 30 years the annual rate of *Prosopis* per year is about 3.3 percent, which is equivalent to 11382.56 ha per year. Over the study period, bush land, grass land and bare land were decreased by 56527.22ha, 245488.4ha and 10416.8ha respectively. This study found that *Prosopis* highly attacked the grazing land which is the major source of food for livestock.

1. Introduction

Prosopis juliflora (here after Prosopis), an evergreen shrub, is one of the most invasive alien species causing economic and environmental harm in arid and semi-arid areas and spreading rapidly in the rangelands, croplands and forests and in particular is threatening pastoral and agro-pastoral livelihoods, the rapid expansion of *Prosopis* is considered as a major threat mainly for pastoralist livelihood and environment due to its invasive nature [1]. The plant is very fast-growing and an evergreen tree native to South America, Central America and the Caribbean and is one of the worst woody invasive plant species on this planet [2, 3].

To assess the land use land coverage and the invasive species, visual interpretation of high spatial resolution satellite images which provide highly precise results is required [4], similarly RF non-parametric machine learning algorithm should be used to ensemble random grown tress which helps us to predict an individual tree, which then averaged [5]. In developing countries where data accessibility is very low, freely available Landsat data are useful in assessing spatial temporal land use land cover changes, since commercial data and software is economically inaccessible. However, in Ethiopia only limited studies used even such free satellite data to map and quantify the extent of *Prosopis* invasion and its expansion rate, despite rapidly spread of this invasive plant in various rangeland areas in Ethiopia affecting crop production and pastoralists' livelihoods severely and can further intensify food insecurity

[6]. For example study by [7] showed that in Afar region the plant has spread from its original source across the middle and upper awash river valleys and is now covering over 1.2 million hectares with 20 out of 32 districts invaded.

Currently an aggressive invasive character of *Prosopis* that invading pasture land, irrigated cultivated land and irrigation canals causing an irreversible displacement of natural pasture grasses as well as native tree species [8, 9] are one of the main concerns of researchers in this area. Invasion of *Prosopis* as an alien invasive species tend to have adverse impact on the lives, livelihoods, native biodiversity, natural ecosystems, pastoral and agro-pastoral lands in Africa and Asia [10, 11, and 12]. Land being as one of the scarce resources belongs to human being, land allocation and land use as well as its ownership types is changing in pastoral areas of Somali regional state [13]. Hence, the analysis of invasive species at the landscape level has received considerable attention recently, because the spatial and temporal invasion patterns can be correlated to proximate causes in pastoral areas [14].

Prosopis is evergreen, unlike the deciduous Vachellia; hence, it tends to maintain a higher vigor and canopy than the native vegetation during the dry season which was introduced and naturalized in many parts of the world (Africa, Asia, and Australia) during the last 100-150 years. It was first introduced to Africa in 1822 through Senegal; subsequent introductions into Africa were in South Africa (1880), Egypt (1900), and Kenya (1970) [15, 16 and 17]. *Prosopis* was first introduced to Ethiopia in the early 1980s. Since then the most affected areas in the country include Afar, Somali, Dire Dawa City Administration, Amhara, Oromia, Southern Nations Nationalities and Peoples (SNNP) and Tigray Regions of Ethiopia [, 18, 19, 20 and 21]. Study by [22], reported that *Prosopis* species continues to spread at rates of 20,000-50,000 hectares per year in Afar region. This shows the reliable estimate of *Prosopis* invasion over time and its expansion rate was lacking in many parts of the country. Thus, the quantification of extent of the *Prosopis* invasion and its expansion rate was essential for proper management and monitoring of the *Prosopis* particularly in the study area where it highly attacks the range and grass lands that pastoralists and agro-pastoralists communities rely on for their livelihoods.

Therefore, this study aimed to quantify and map spatial and temporal extent of *Prosopis* invasive species to show its expansion rate in Somali region specially Korahey zone which will help to tackle its expansion on non-invaded lands as a strategy for a design of effective adoption of sustainable livelihoods of pastoralists.

2. Material and Methods

2.1. Description of the Study area

Somali regional state is the second or first largest region in Ethiopia with a total area of 350,000 Kilometer Square. Having eleven administrative zones and 93 districts, It is bordered with Oromia and Afar to the west, as well as Djibouti to the north, Somalia to the north, east and south and Kenya to the southwest. Korahey is one of eleven administrative zones of the Somali region which is well known for its endowment with huge potential of natural resources, the natural gas field of Calub lies in this zone, making petrochemical extraction potential area in the country. The topography of the study area is predominantly lowland plain with an average altitude of 493 m above sea level with a few foothills of higher altitude by having latitude and longitude of 6044’25’’N, 440 16’38’’E, respectively. The climate of Korahey zone is characterized as tropical semiarid in which temperature ranges from 23 to 36 oC. The area has bimodal rainfall pattern with two main rainy seasons in which the first is ‘Gu’ that occurs from mid-April to the end of June. The second rainy season known as ‘Deyr’ occurs from early October to late December.

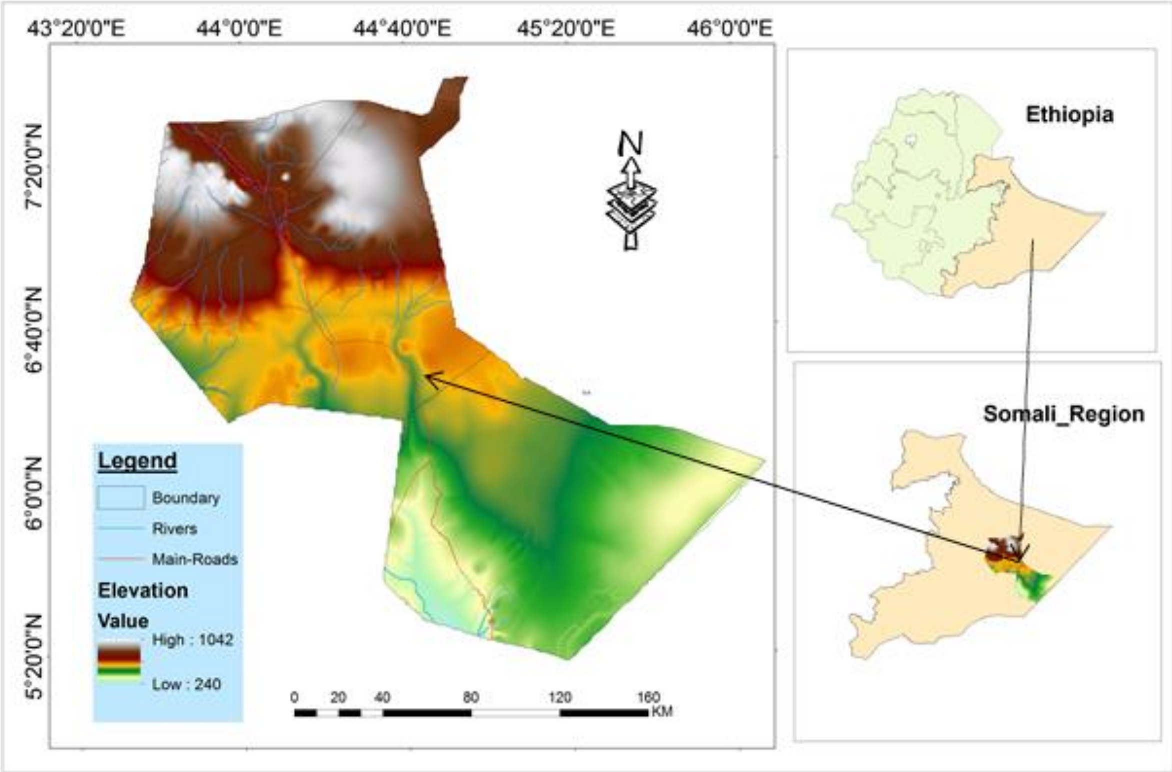

Figure 1 : Location of the study area.

2.2. Data acquisition and analysis

The spatial extent of *Prosopis* and land use/land cover change assessment over the study periods was conducted using three Landsat imageries of, 1989, 2001 and 2019 (despite *Prosopis* was introduced to Ethiopia in 1980, the study period was selected in order to cover the change of land use land cover over the last 30 years. The required satellite images were downloaded from the USGS (United States geological survey) Earth Explorer (https://earthexplorer.usgs.gov/). To ensure quality of the data, the best images (cloud free) was manually selected based on the main criteria i,e the acquisitions date and the absence of cloud cover.

Table1: Characteristic of satellite data used.

Index Year	***Sensor***	***Path/Row***	***Spatial resolution(m)***	***Acquisition date***	***Source***
1989	Landsat 5(TM)	163-56	30	26-01-1989	USGS
		164-55	30	02-02-1989	USGS
		164-56	30	17-01-1989	USGS
		165-55	30	24-01-1989	USGS
2001	Landsat 5 (TM)	163-56	30	27-01-2001	USGS
		164-55	30	22-01-2001	USGS
		164-56	30	02-01-2001	USGS
		165-55	30	25-01-2001	USGS
2019	Landsat 8(OLI)	163-56	30	29-01-2029	USGS
		164-55	30	01-02-2029	USGS
		164-56	30	20-01-2029	USGS
		165-55	30	27-01-2029	USGS

2.3. Image Processing and Enhancement

In order to prepare an image for display, a number of pre-processing activities like layer stacking, geometric correction, image enhancement and mosaicking were performed to the satellite data to extract useful information from the image. In addition to this, in order to enhance the ability of the data to detect the species in the study area, the normalized difference vegetation index (NDVI) was calculated. This step was done mainly to reduce the limitation posed by multispectral sensors such as Landsat in mapping vegetation species and to maximize the spectral differences between *Prosopis* and other native vegetation of the study area. *Prosopis* is evergreen than any other types of trees in dry low land areas. In this regard, the spectral reflectance of the Prosopis in the study area is identified from the reflectance of other vegetation based on the selected dry season satellite image due to the fact that, *Prosopis* is the only plant that is ever green during the dry season that make the species to have different spectral reflectance from other deciduous vegetation of the study area.

2.4. Image Classification

After enhancing the qualities of the data to the required standard, image classification was performed. The classification was performed using the Supervised Random Forest (RF) algorithm, which was implemented using the function provided in the random forest package in R statistical software (version 3.4.4). In this study, RF model is built using reliable reference training samples collected from the field and visual interpretation of VHR (very high resolution) satellite imagery from Google Earth Pro. The reference data was also collected from local expert's knowledge and vegetation occurrences characteristics for historical dates where VHRs was not available. After the visual interpretation, small polygons i.e. regions of interest (ROIs) were digitized for each land use land cover class. Then, 80% of the manually delineated ROIs was used for training each RF model, and then applied it to the corresponding satellite data stack and (20%) of training samples were used for validation purposes. The classified land use land cover classes were *Prosopis*, bush land, grazing land settlement area and bare land and were developed by considering the study objective and dominant land use land cover of the study area (Table 2).

Table2: Land use land covers categories of the study area and their description.

Land use class	***Description***
Prosopis Juliflora	This is alien invasive plants and usually evergreen than deciduous bushes predominating the study area.
Bush land	This is areas covered by small trees that is less dense than forests and includes bushes, and shrubs, mixed range lands, mosses and lichens.
Gazing land	Areas with temporary or permanent grass cover, forbs, grassy areas which are used for communal grazing.
Settlement	An area of small towns and scattered rural settlements of pastoralists.
Bare land	Land dominantly covered by bedrocks and sand having limited ability to support life.

2.5. Land Use Land Cover Change analysis

The patterns of land use land cover in general and the expansion rate of *Prosopis* within the study periods was assessed by creating cross-tabulation matrices for the intervals from 1989-2001, 2001-2019, and 1989-2019. Land use land cover gains and losses were calculated and result was visualized through charts and tables. The magnitude of change for each land use land cover class was calculated by subtracting the area coverage of the initial study year from that second year. Percentage change for each land use land cover type was then calculated by dividing magnitude change by the base year and multiplied by 100. Furthermore the annual *Prosopis* spread in hectare (ha) was calculated by dividing the acquired magnitude of increase of each year by the each interval year (equation1) and percentage annual rate of change (ARC) of *Prosopis* was calculated by dividing the annual *Prosopis* spread (ha) by magnitude of *Prosopis* increase for each interval year and multiplying by 100 (equation 2).

Annual *Prosopis Juliflora* spread (ha) = $\frac{\text{magnitude of prosopis increase}}{\text{interval year}}$ Equation 1.

Annual rate of change (ARC) = $\frac{\text{Annual prosopis spread (ha)}}{\text{magnitude of prosopis increase}}$ *100 Equation 2.

2.6. Accuracy Assessment

Cross-validation accuracy assessment was performed to understand the representation of the classified images on the ground. The validation is performed on a pixel level, so that each pixel inside a validation polygon is compared with the reference class. In this study the classified maps were assessed and compared with a referenced data and ground truth using an error matrix. Confusion matrix was developed for the calculation of accuracies kappa coefficients for the certainty of the classification result.

3. Results and discussion

3.1. Spatial Extent of Land use land cover and Prosopis Rate Changes from 1989-2019

The result of the developed land use land cover during 30-year periods indicates the increase in spatial coverage of *Prosopis* and settlement land, whereas the continuous decline in area coverage of grazing land and bush land respectively. In terms of area coverage, grazing land and bush land was the dominant land use with percentage share of 37.74% and 35.24% respectively in 1989 (Figure 2). Settlement area and *Prosopis* invaded land covers small area of 0.17% and 0.27 % and bare land shares a percentage of 26.58% from total area. In 2001, grazing land continued to dominate the land use land cover (36.1%) followed by bush land (34.5%) whereas settlement remain covers small proportion of land (0.27%). During this period *Prosopis* and bare land accounted for total area of 4.92% and 24.21% respectively. In the last study period (2019), the dominant land use was become bush land covering 33.47% of total area. Grazing land and bare land was the second and the third dominant land use land cover types covering 30.03% and 25.01% respectively. In this period the small proportion of the land was covered by *Prosopis* invaded land and settlement area with percentage share of 10.99% and 0.49% of total area respectively (figure 2 and table 3).

The land use land cover change detection scenario (change rate) from 1989- 2019 shows numerous loss and gains of different land use category. Over 1989-2001 the maximum loss was for bare land (-75414.6ha) followed by grazing land (-51957.45ha) and bush land (-23699.8ha) while *Prosopis* and settlement were increased by 147920.82ha and 315.03ha respectively (Table 4). The significant decline in area coverage of grazing land, bush land and bare land mainly result from the drastic invasion of *Prosopis* that were converted these land use over the period. From 2001-2019, grazing land and bush land again shows tremendous loss to other land use mainly to *Prosopis* invaded land by 193530.95ha and 32827.42ha respectively. In this period the *Prosopis* invaded land; bare land and settlement area were increased by 193556ha, 25536.6ha and 7265.77ha respectively.

In general, the land use land cover for 30 years (1989-2019) showed negative trends for grazing land and bush land by 245488.4ha and 56527.22ha respectively. However, *Prosopis* and settlement area showed positive trends by 341476.82ha and 10416.8ha respectively.

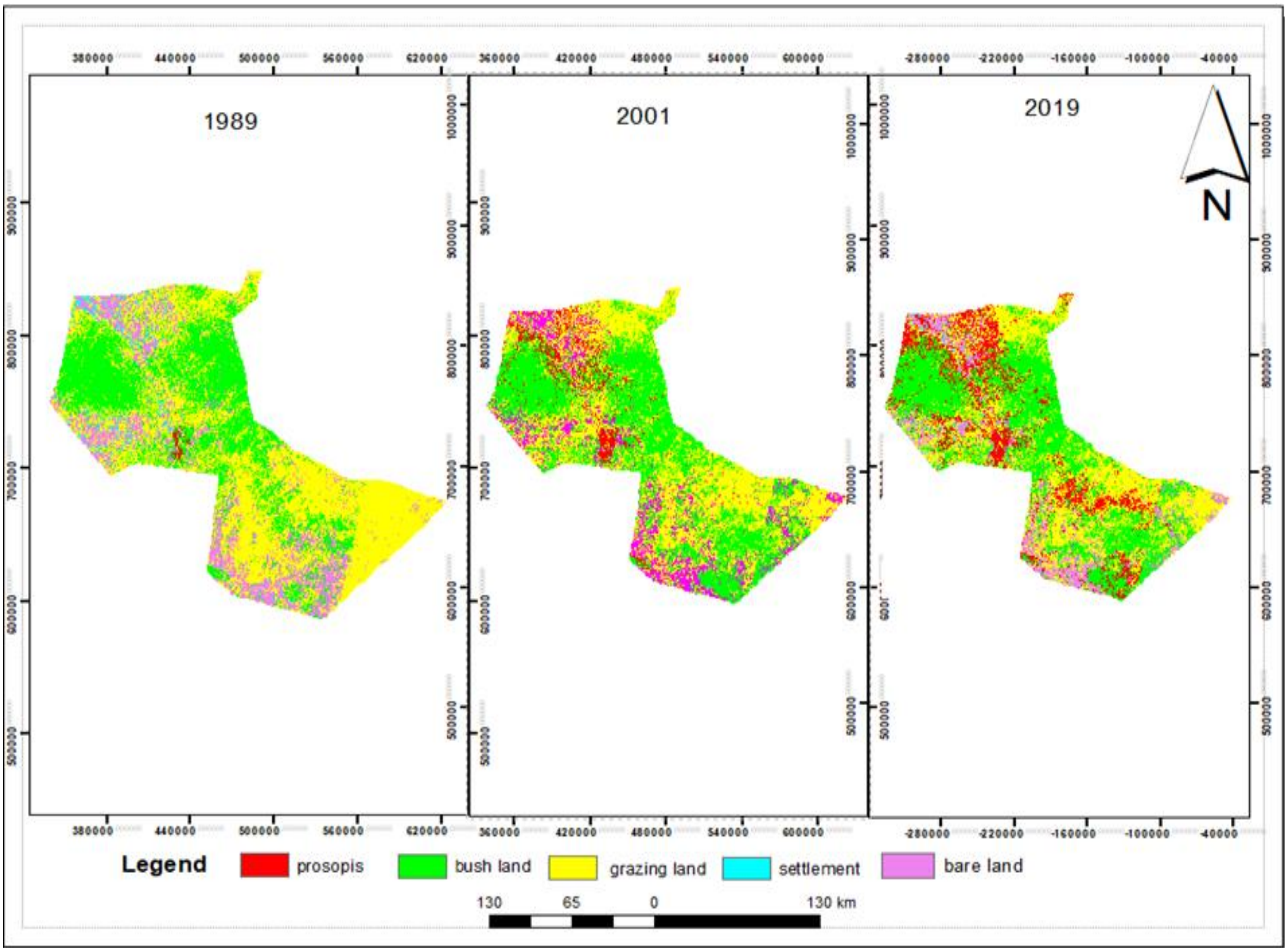

Figure 2 : Land use land cover map of the years 1989, 2001 and 2019.

Table3: Spatial extent of land use land cover and rate of change from 1989-2019.

Land use land cover class	Land use land cover area coverage						Land use land cover change rates		
	1989		2001		2019		1989-2001	2001-2019	1989-2019
	Ha	%	ha	%	ha	%	ha	Ha	Ha
Prosopis	8523.18	0.27	156444	4.92	350000	10.99	+147920.82	+193556	+341476.82
Bush land	1122343.52	35.24	1098643.72	34.5	1065816.3	33.47	-23699.8	-32827.4	-56527.22
Grazing land	1201963.5	37.74	1150006.05	36.1	956475.1	30.03	-51957.45	-193530.95	-245488.4
Settlement	5412.5	0.17	8563.53	0.27	15829.3	0.49	+315.03	+7265.77	+10416.8
Bare land	846477.3	26.58	771062.7	24.21	796599.3	25.01	-75414.6	+25536.6	-49878
Total	3184720	100	3184720	100	3184720	100			

Note: +Sign denotes increase and - sign denotes decrease of magnitude of change of land use category.

The spatial extent of bare land decreased from first study periods to the second one by -75414.6ha, but started to increase in the final study period by 25536.6ha, this study in line with the study results of [23]. The increase of area coverage of bare land within the final study period was resulted from the increasing drought occurrence over recent time. Overall, the continuous increase in expansion of *Prosopis* over study periods mostly invades the grazing land which is the major source of food for livestock of pastoralists (Figure 3).

Figure 3: Gains and loss of land use land cover in hectare for 1989-2001, 2001-2019 and 1989-2019.

3.2. Patterns of Prosopis expansion and its spread rate from 1989- 2019.

In the initial study period, the dominant land use land covers in the study area were grazing land and bush land. At that time, there was stable *Prosopis* coverage and its prominent pathway was mostly along Fafen river valley. *Prosopis* continued to spread into the surrounding areas covering largely grazing land and bareland predominantly to north western and eastern parts from the corridor. Contrary to the northen parts of the study area, the expansion of the *Prosopis* to the southern direction is much slower. Generally, over the entire study period, there was steady increase in *Prosopis* coverage from 8523.18 ha in 1989 to350000ha in 2019. However, *Prosopis* did not spread at the same rate over that time in three years interval. The spread rate and annual rate of change (ARC) of Prosopis during the study periods was summarized (Table 4).

Table 4: Spatial extent of land use land cover and rate of change from 1989-2019.

Study years	*Annual rate of Prosopis Juliflora spread*		
	Magnitude of increase (ha)	*ARC (ha/year)*	*% equivalent*
1989-2001	147920.82	12326.74	8.3
2001-2019	193556	10753.1	5.6
1989-2019	341476.82	11382.56	3.3

The annual spread rate of *Prosopis* per year varies over the study period. From the first study period 1989, invasion spread rate of *Prosopis* is 12326.74ha or 8.3 % per year up to 2001. Between 2001 -2019 its annual rate of change is about 10753.1ha or 5.6 % per year. In general, over periods of 30 years the annual rate of *Prosopis* per year is 3.3%, this is equivalent to 11382.56 ha per year (Table 4, and Figure 4). *Prosopis* highly attacks grazing land and agricultural land in the study area. In Korahey zone It's already invaded around 11382.56 ha per year from 1989-2019 which was negatively affected pasture land, irrigated cultivated lands, and pastoral livelihoods as general. The spread of *Prosopis* in the study area infested irrigation canals, destroyed very important historical place figure 6 and figure 7 respectively. According to interview with pastoralists and local administrates during our survey, around 23000 households were internally displaced due to the spread of this invasive plant species.

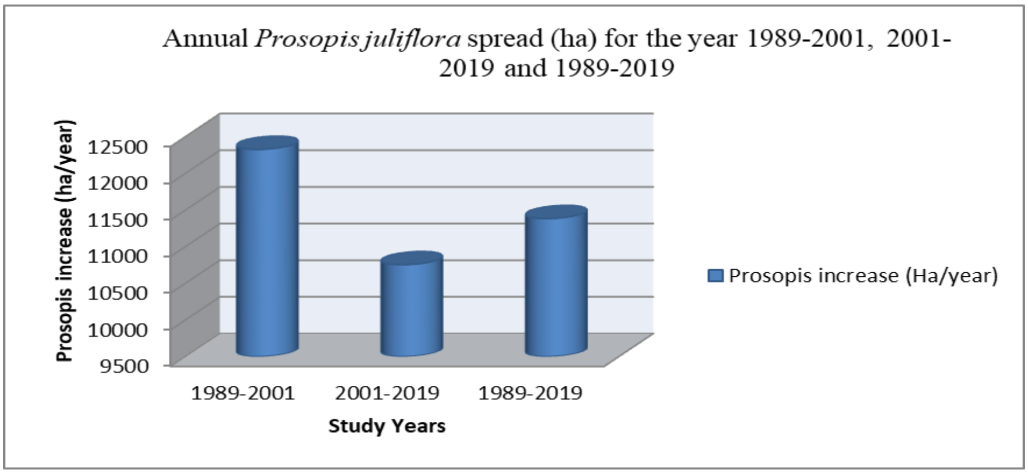

Figure 3: Graphical presentation of annual *Prosopis* spread for 30 years in the study area

Figure 4: *Prosopis juliflora* encroachment in Kebridahar district (Banka Korahey)

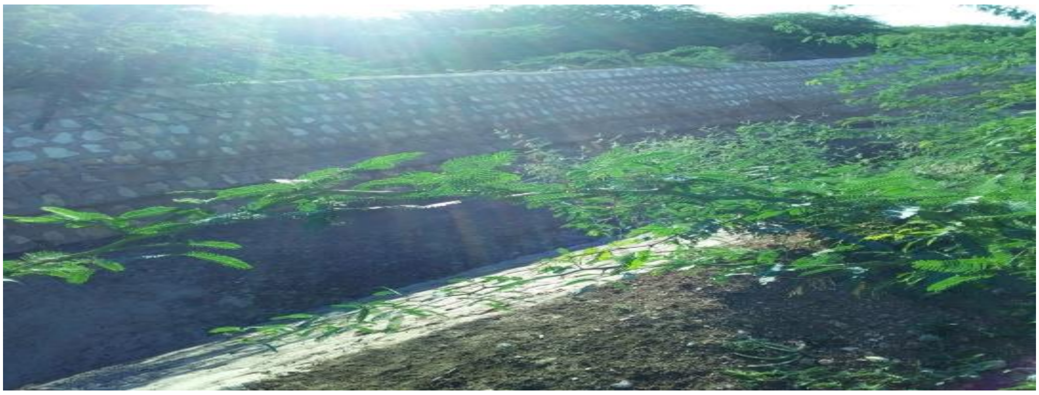

Figure 5: Infested irrigation canal at Mara,ato canal

Figure 6: Devastated historical place (Sayid Mohamed Abdule Palace)

3.3.Accuracy Assessment of the Classification

The supervised random forest classifier achieved to good user and producer accuracies of above 75% for all land use land cover classes. The result of overall classified accuracies for the three reference years: 1989, 2001 and 2019 are 81.65%, 85.74% and 88.42% with the Kappa statistics of 0.7394, 0.8265 and 0.8390 respectively. This shows the highest and the lowest classification accuracies were realized in 2019 and 1989, respectively.

Conclusion

The study analyzed the expansion rate of *Prosopis* and land use land cover in Korahey zone. The study found that *Prosopis* coverage increased from 8523.18 ha in 1989ha to350000ha in 2019. This indicates the invasion spread rate of *Prosopis* is 11382.56 ha/ year. The result of land use land cover dynamics also shows the highest negative changes in two land use land cover classes over study years i,e grazing land (-245488.4ha), bush land (-56527.22ha). The area of these two land use classes were over taken by continuous invasion of the *Prosopis*. Settlement area shows positive trends by +10416.8 ha over the study periods. The spatial extent of bare land decreased from first study periods to the second one by -75414.6ha, but started to increase in the final study period by 25536.6ha. The highly increasing spread rate of *Prosopis* more affected grazing land and agricultural land, and displaced many pastoral households in the study area. It is therefore urgent need to tackle the expansion of the *Prosopis* species and assist pastoral communities to cope with the effects of the *Prosopis* invasion by concerned bodies of different level.

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