Impacts of Afforested Mangroves in Tadri River – Geospatial Assessment of Past and Present Changes

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Abstract:- *The paper focused to assess the impacts of the afforested mangroves in the banks of Tadri river in Uttara Kannada district of Karnataka. Temporal satellite images of 1990, 2011 and 2019 were used for the assessment. As per the study, afforestation activities along the river were noticed from 1991. With the introduction of Coastal Regulation Zone Act, (CRZ) 1991 to protect the coastal resources and the coastal zone, several attempts continue to publicize the importance of mangroves and their service to the estuarine environment for its betterment of productivity and biodiversity. In this regard, afforestation of Tadri estuary was undertaken by the state forest department along with other private organizations. Site and species selection of mangroves were based on the availability of the suitable areas and salinity conditions. The study indicated gradual betterment of both the spatial extent and diversity of mangroves at different locations of the river. Further, the study also assessed the impacts of the afforestation both to the estuarine system and to the dependent locals. Advance tools and techniques of remote sensing and GIS were utilized for the study. The study indicated net spatial gain of mangroves as 4.21 km² in the last 28 years.*

Keywords*:* **Afforestation, mangroves, Tadri river, temporal changes, CRZ, estuary productivity, biodiversity, livelihood dependence**

1. INTRODUCTION

Mangroves are extremely important to the coastal ecosystems they inhabit. Physically, they serve as a buffer between marine and terrestrial communities and protect shorelines from damaging winds, waves (Ajanta Dey and Animesh Kar, 2013[1]) and floods. Mangrove thickets improve water quality by filtering pollutants and trapping sediments from the land and reduce coastal erosion. Ecologically, they provide habitat for a diverse array of terrestrial organisms and many species of coastal and offshore fauna. Variety of fishes exclusively rely on mangroves for their breeding, spawning, and hatching. Owing to high salt tolerance, mangroves are often among the first species to colonize mud and sandbanks flooded by seawater. But abnormal increase in coastal development and altered land use lead to decline in their existence, diversity and population. Absence of these coastal bioshields imposes threats to the coast in the form of hazards claiming high to severe damages to lives and properties. To combat the hazards variety of coastal protection measures are being implemented worldwide. However, no artificial measures match these natural green protectors. In view of their significance, several programs in the form of act, policy and awareness campaigns are in progress globally to revive these fast declining coastal protectors. India has also imposed Coastal Regulation Zone act (CRZ) in 1991 to restrict human interventions to coastal resources.

2. STUDY AREA

The selected study area is a river environment in the Uttara Kannada district of Karnataka as shown in Fig 1. The river is known as Aghanashini or Tadri as the Aghanashini and Tadri villages are located on the southern and northern banks of the river. It is one of the four major rivers flowing through Uttara Kannada district. The river traverses a distance of 117 km from its origin to Arabian sea.

However, the length of the river considered for the study is 24.4 km up to which mangroves were found. The major activities around the river include agriculture, salt pans, aquafarms and habitations. The natural features around the river include mudflats, mangroves and forests. The river supports substantial livelihood for fisher and non-fisher communities. The river is one of the two free flowing rivers of the district. It has no damping features from its origin to drain, which is rare.

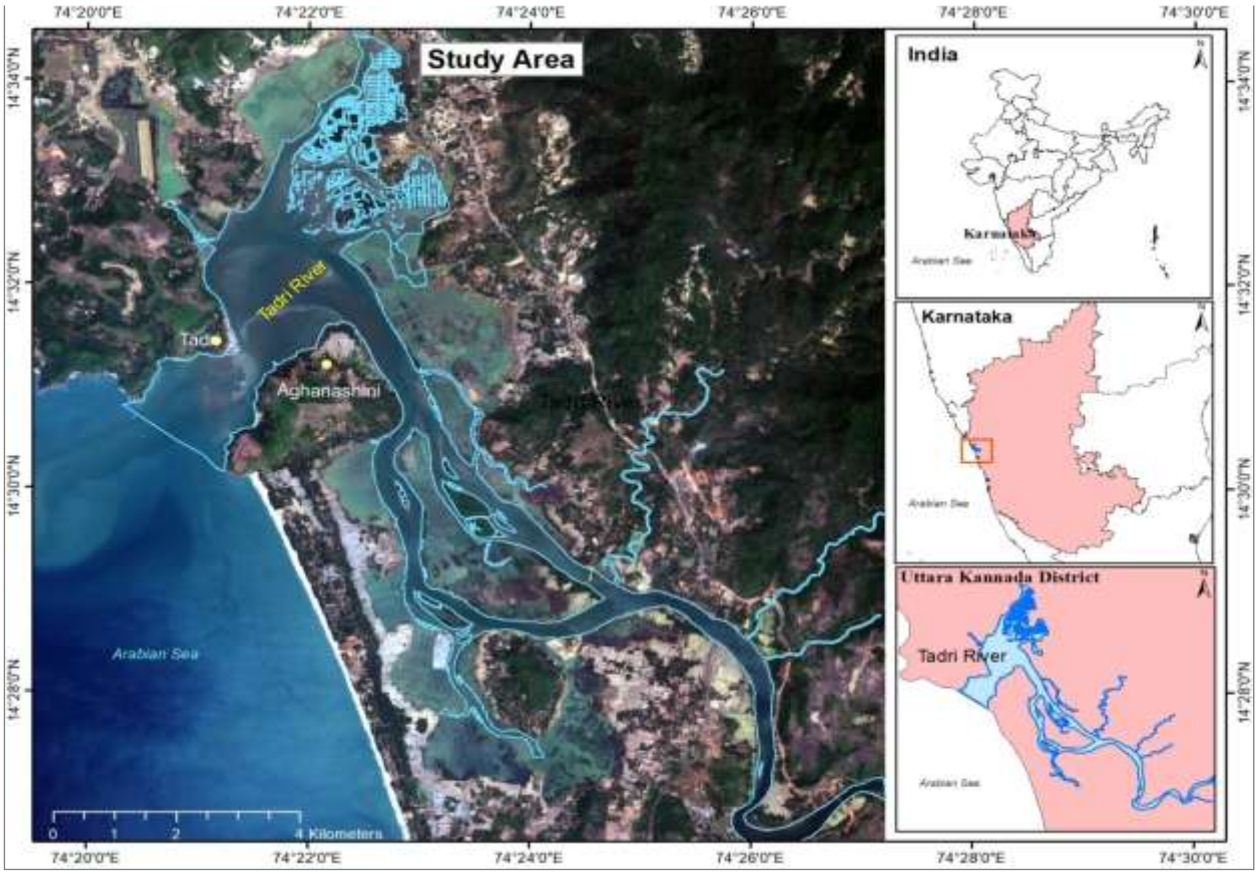

Fig 1: Location of Tadri River, Uttara Kannada District

3. DATA AND METHODS

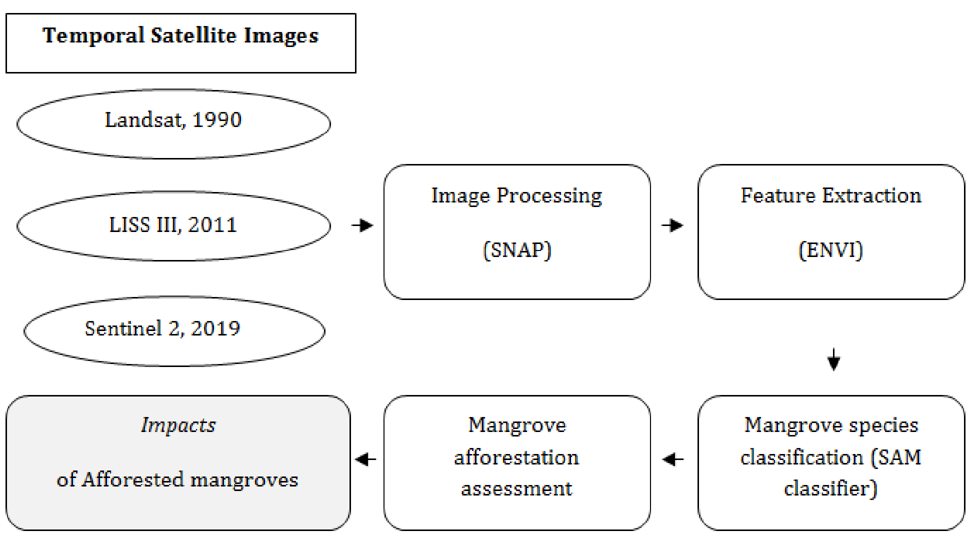

Fig 2: Methodology of the study

Mangrove distribution map was done using Landsat imagery (1990) LISS III imagery (2011) and Sentinel 2A imagery (2019). In this study mangrove species mapping has been done using LISS III for 2011 and Sentinel 2A imagery for 2019.

LISS III imagery from IRS 1C/1D has been atmospherically corrected using FLASH algorithm in ENVI. Sentinel Application platform (SNAP) was used for the preprocessing of Sentinel 2A data. The SNAP architecture is ideal for Earth Observation processing and analysis. The Sentinel 2A data was atmospherically and radiometrically corrected using this software. As the image has different resolution i.e. 60 m, 20 m and 10 m, it has to be subjected to resolution merge. The scale down of the bands was carried out in SNAP platform using sen2res plugin. This super resolution processor increases the resolution of 20 m and 60 m bands to 10 m.

To reduce the dimensionality of the dataset, the Minimum Noise Fraction (MNF) platform was used. This reduces the noise in the data for the case of further processing. MNF bands were used to get the pure pixels of the image using Pixel Purity Index (PPI) calculation. End members have been identified in reference with pure pixel image. Endmembers are the 'pure' or relatively 'pure' spectra of a particular class having no mix with other endmembers occurring within a pixel (Rogge et al., 2007 [9]). Spectral separability analysis was done for producing high accuracy maps. The separability of the end members were calculated using JM distance (Jeffrics- Matusita), which yield the value between 0 to 2 for each pair of region of interest (ROI). ROI pairs having value less than 1.99 has to be merged with each other due to the inseparability of their respective spectra.

Spectral Angle Mapper (SAM) classifier was used for the mangrove classification in ENVI software. A set of endmembers are given as reference data in SAM classifier and each pixel in the image is classified into classes having spectral similarity (Sreekala K.C and Aparna S Bhaskar, 2019[11]). This algorithm has been widely utilized for remote sensing image as it determines the spectral similarity between two spectra by calculating the angle between the spectra and treating them as vectors in a space with dimensionality equal to the number of bands (Rashmi et al., 2014[7]). Spectral Angle Mapper (SAM) is a physically-based spectral classification that uses an n-D angle to match pixels to reference spectra. This technique, when used on calibrated reflectance data, is relatively insensitive to illumination and albedo effects.

End member spectra used by SAM can come from ASCII files or spectral libraries, or you can extract them directly from an image (as ROI average spectra). SAM compares the angle between the end member spectrum vector and each pixel vector in n-D space. Smaller angles represent closer matches to the reference spectrum. Pixels further away than the specified maximum angle threshold in radians are not classified. For delineating mangrove species SAM classification would yield better results (Salghuna, 2017 [10]). The classified image has been subjected to accuracy assessment using Stratified Random Sampling (SRS) method which produces a post classification confusion matrix.

3.1 Digital Shoreline Analysis System (DSAS)

The Digital Shoreline Analysis System (DSAS) is used to calculate the change in the shoreline or boundary over a period of time from multiple historical shoreline or boundary positions. The model provides information of several changes such as *Shoreline Change Envelope (SCE), Net Shoreline Movement (NSM)*), *End Point Rate (EPR), Least Regression Rate (LRR) and Weighted Least Squares Regression (WLR).* Out of the various rate calculations, LRR determines the rate-of-change statistic by fitting a least-squares regression line to all the considered shoreline points for a transect.

The linear regression rate is the slope of this best fit line. The method of linear regression is effective because of the following reasons: (1) all the data are used, regardless of changes in trend or accuracy (2) the method is purely computational (3) the calculation is based on accepted statistical concepts and (4) the method is easy to employ. Based on the maximum and the minimum changes derived by the model, the rate of change statistics of the river bank is further classified into different levels of erosion and accretion. The insignificant level of changes in the river bank during the study period is classified as 'Stable' as shown in Table 1. This classification provides better understanding of river bank status in the study.

Table-1: Classification of shoreline status

Range	Classification
>- 5m	High Erosion
-5m to -2 m	Medium Erosion
-2 m to -0.5 m	Low Erosion
-0.5m to +0.5 m	Stable

0.5m to 2 m	Low Accretion
2m to 5 m	Medium Accretion
>5m	High Accretion

-sign indicates loss of land   + sign indicates gain of land

4. RESULT AND DISCUSSION

4.1 Mangrove colonies along the River-Past

Natural mangrove areas around the river was about 0.29 km^2 during 1990's (Fig 3) which is much less than the extent of mangroves in 2019 which is about 4.50 km^2 as per the study. The reason being that prior to 1990's mangroves were considered as '*Economically unproductive areas*' and were often cleared for reclamation for human intervened activities. As per the reports, the estuarine areas of Uttara Kannada district were predominantly used for growing salt tolerant rice variety known as *"Gazni"* besides salt farming. Mangroves were planted as embankments for the above activities. In due course, mangroves were removed and replaced by stone bunds. Also establishment of shrimp farms further deprived the mangrove areas around the river. However, after the introduction of Coastal Regulation Zone Notification (CRZ 1991) by the government of India, several awareness campaigns were conducted on the significance of mangroves. As a major outcome of the awareness programs, various schemes were formulated and implemented by the State and Central governments for planting mangroves in the estuary with a vision to increase the productivity and biodiversity of the estuary. Mangrove afforestation along intertidal zone was foreseen to improve coastal environment and enrich marine biodiversity (Reem S. Al-Nafisi et al., 2009 [8]).

4.2 Mangrove colonies along the river- Present

Almost 3 decades of combined efforts of the state Forest department and other private organizations to populate the estuary environment with different variety of mangroves as per the gradient of salinity, the area under mangroves in 2019 as per the study is about 4.50 km^2. The locations with new mangrove cover are indicated in Fig 4.

4.3 Exploitation

Tadri is one of the two free flowing rivers of Uttara Kannada district. The river has no damping features such as dams, reservoirs from its origin to drain. Ecologically such free flowing rivers render certain ecological functions such as nutrient rich soils, fish spawning and uninterrupted sediment flow (Parineeta Dandekar, 2019 [5]). In view of such salient features, the estuary region of the river was gradually utilized for cultivation of salt tolerant rice variety along with shrimp farming and salt making activities. As per the salinity levels of the estuary, existence of mangroves was recorded in 1990 but in meager extent from the study. Local communities develop bunds for the rice fields and shrimp farms in the river environment. Traditionally mangroves were planted as bunds but gradually they were replaced by stone bunds. With increasing exploitation of the river flow area, the estuary indicated decline in its productivity and biodiversity.

4.4 Need for Mangrove Afforestation

Increased fragmentation and thinning of mangrove areas in the estuarine environment due to human impacts is an age old activity for which river Tadri is *'No exception'*. Most of the mangrove areas were cleared for cultivation of salt tolerant rice variety named "*Gazni*" in the alluvial plains of the estuary which later extended into the estuarine areas also. Contemporary growth of salt farms and shrimp farms imposed severe stress on the population of mangroves in the estuary. The Coastal Regulation Zone (CRZ) 1991 was the initiative by the central and state governments to notify and declare some of the coastal features as Ecologically Sensitive Areas (ESA) of which mangroves forms a part. To rejuvenate the lost mangroves and also to stabilize the estuary environment with rich productivity and biodiversity, "*Afforestation of Suitable mangrove species*" became inevitable.

4.5 Site selection for mangrove Afforestation

Mangrove species are differentially distributed along complex salinity gradients in the environment (Flowers and Colmer, 2008[4]). Level of salinity of water in the estuary is a major factor to be considered for selection of species and location for afforestation activity. Salinity levels at various stations of the estuary was studied and reported by Ramachandra et al 2012[6]. The level of salinity descends from station 1 to 5 as indicated by the month-wise data of Table 2.

True mangroves species suitable for different salinity levels were listed in Appendix A. Also, innumerable species grow in mangrove environment as 'Associate Vegetation' for which salinity ranges are not a pre-requite criteria. To a maximum, they require certain level of salinity and not specific to salinity ranges. True and associated mangrove species that exist in Tadri estuary are listed in Appendix B.

Table -2: High tide salinity of Tadri river (2011-12)

Station Name	Salinity (ppt)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Aghanashini	32	32	36	28	29	35	4	6	30	32	35	31
Gudkagal	28	29	31	30	31	28	5	6	6	28	26	32
Kodkani	19	20	26	28	28	27	3	4	4	15	15	17
Dundakuli	7	8	17	18	18	15	2	2	2	14	8	12
Divgi	4	9	16	16	16	15	1	1	1	2	4	9

***Values rounded to nearest whole numbers*

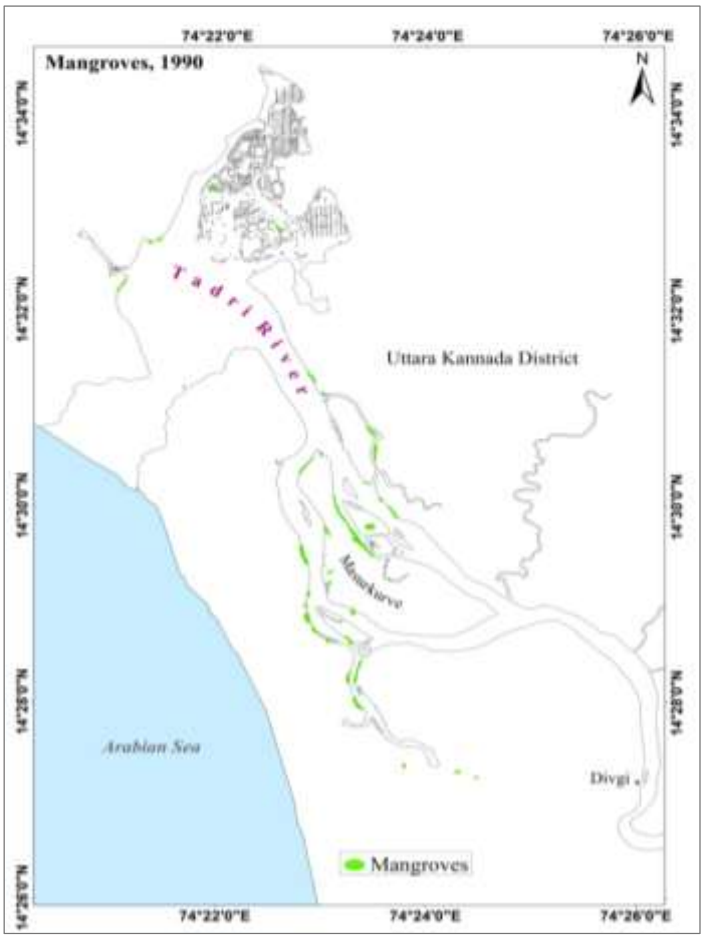

Fig 3: Mangroves in Tadri Estuary, 1990

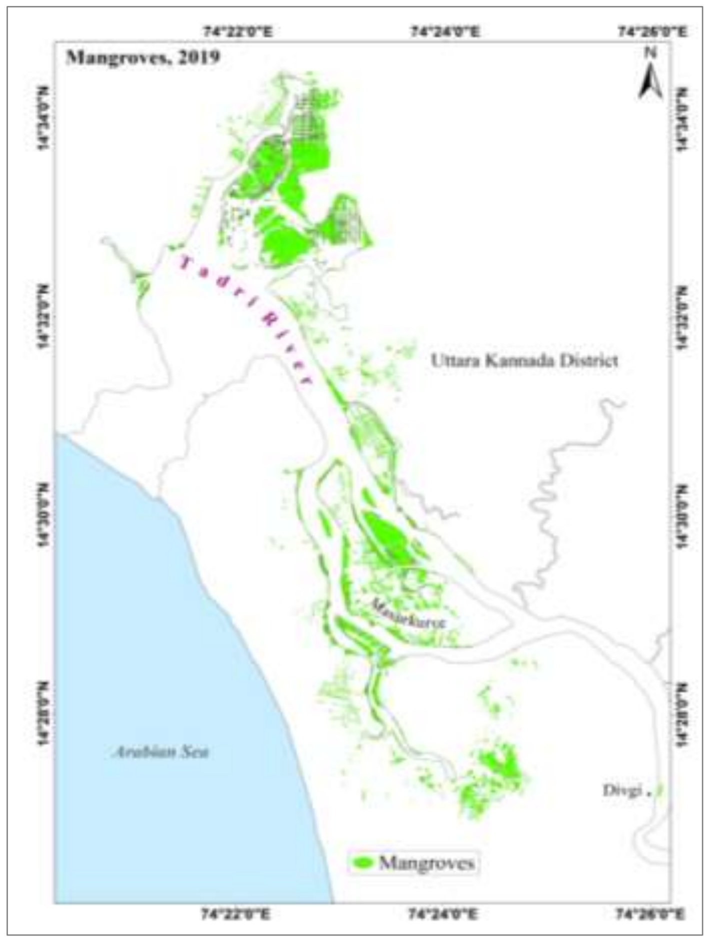

Fig 4: Mangroves in Tadri Estuary, 2019

Fig 5: Salinity recorded locations in Tadri river

Availability of potential areas prevailing with salinity ranges and land availability were investigated for afforestation. Abandoned shrimp farms and rice fields were also taken into consideration by the Honavar Forest division for mangrove plantation (Ramachandra et al, 2012[6]). As per the study, the sites considered for mangrove plantation are from station 1 to station 3 (Fig 5).

4.6 Mangrove communities of Tadri estuary

Mangrove species classification using LISS III (2011) and Sentinel 2A images (2019) were processed using SNAP and ENVI software. End members have been identified and spectral separability analysis was done for producing high accuracy maps. Spectral Angle Mapper (SAM) classifier was used for the mangrove classification in ENVI software. The mangroves species

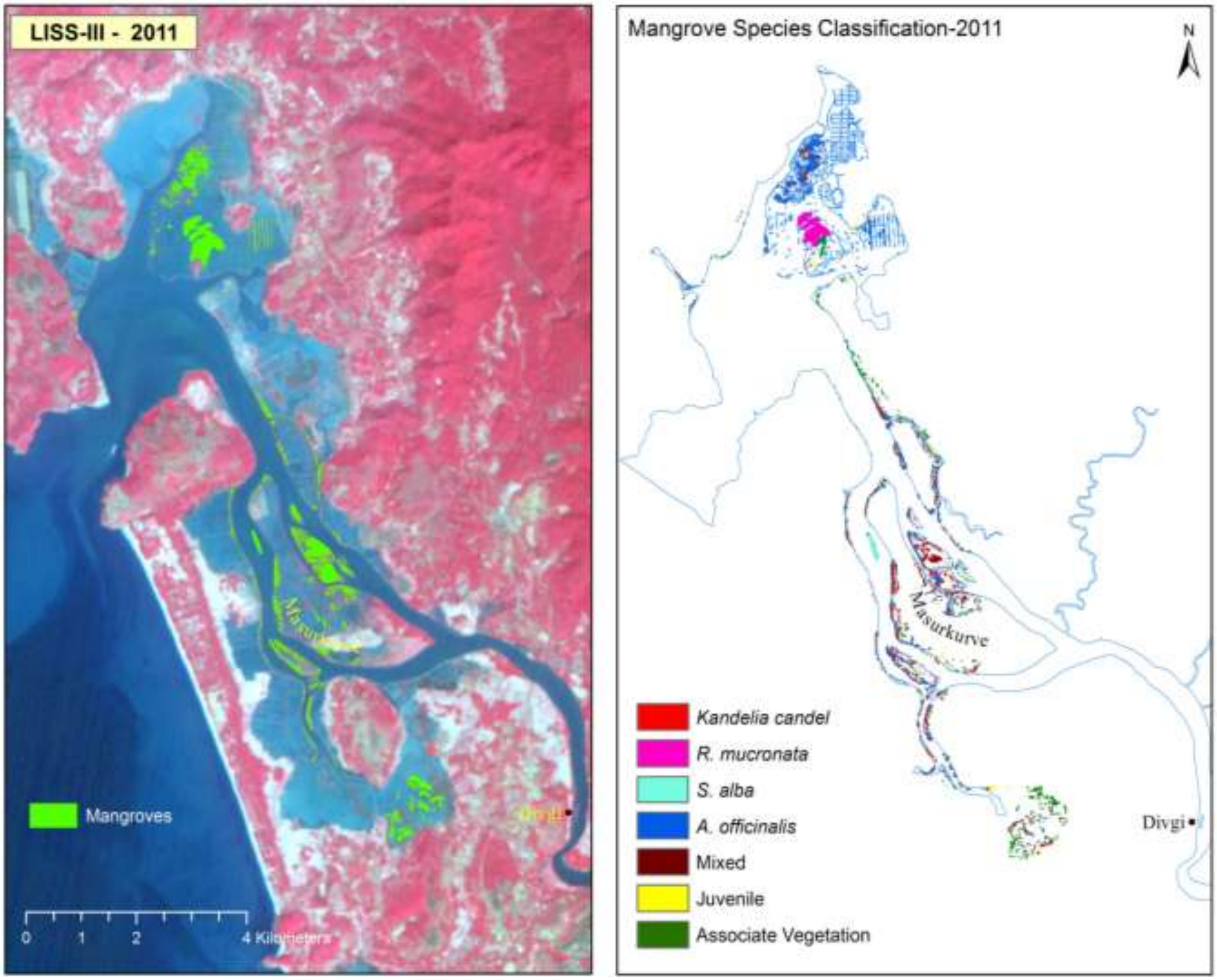

Fig 6: Mangrove Species Classification- LISS III (2011)

distribution in Tadri river were shown in Figures 6 and 7. The study indicated systematic improvement in mangrove areas in the estuary at different periods. Afforestation activities were found in the estuary and Masurkurve island area which has high to medium salinity ranges. As per the survey and documentation of mangroves in Coastal Karnataka, different mangrove species occurs at different salinity range along this estuary. The species classification shows that the estuary is dominated by high to medium salt tolerated mangroves such as *Kandelia candel*, *R. mucronata, S. alba, A. officinalis* and mixed stands of other true mangrove species indicated in Appendix B. Medium salinity region is mostly dominated by *R.mucronata* and high salinity region is dominated by *S.alba*, *A.officinalis* and *E.agallocha*. Young plants of all true mangrove species were also found and are indicated as juvenile in the maps. Natural growth of low salinity mangroves is found near Divgi in 2019 as shown in Fig 7. Mangrove associates were found in all the mangrove areas.

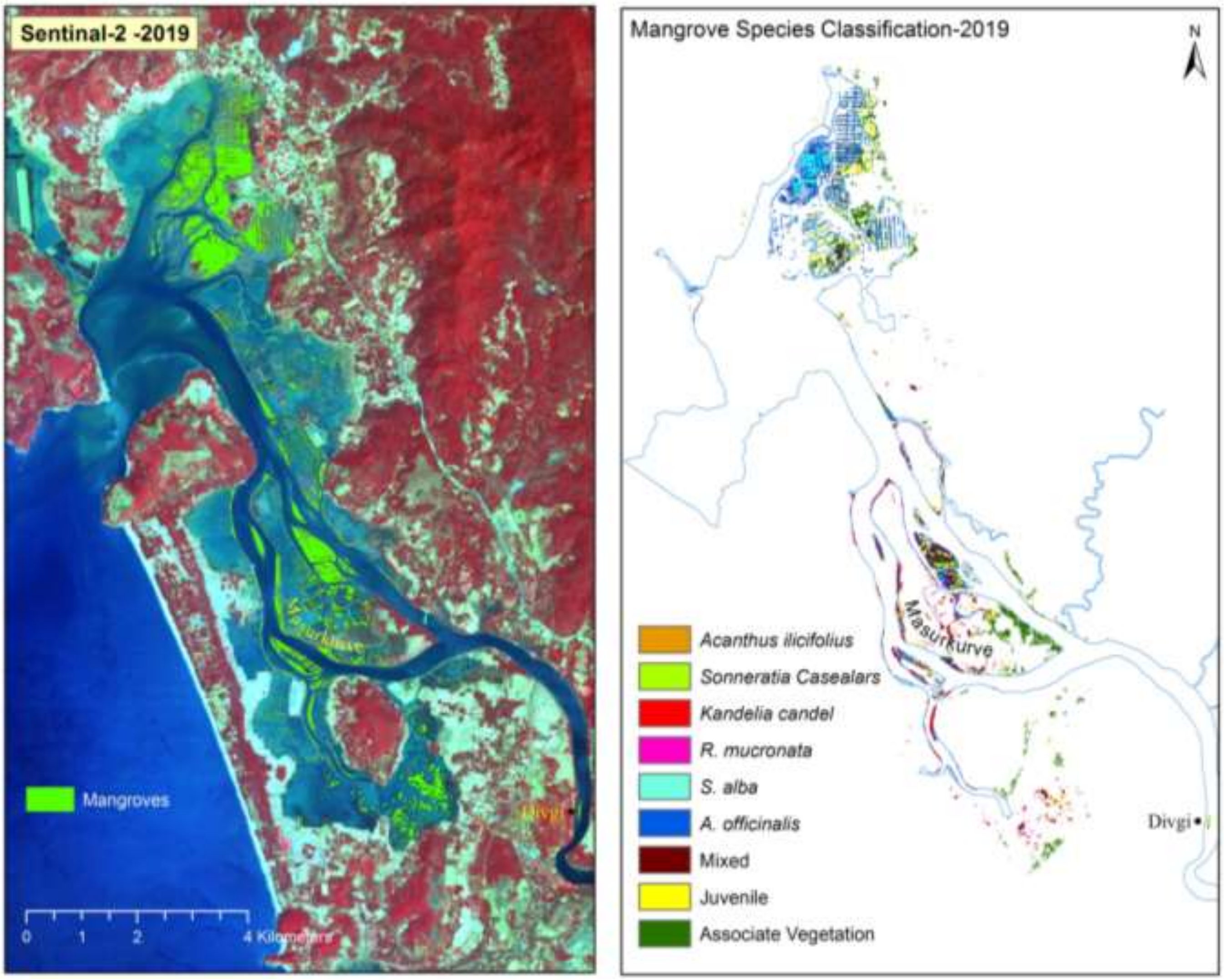

Fig 7: Mangrove Species Classification- Sentinel 2 (2019)

4.7 Accuracy assessment

Accuracy assessment has been done using Stratified Random sampling method. The accuracy assessment report shows the overall accuracy, kappa coefficient, confusion matrix, commission and omission errors and user's and producer's accuracy for each class. Overall accuracy of mangroves species classification shows 88% and its kappa coefficient measures a value of 0.86. Overall accuracy is the quotient of total number of correctly classified pixels and total number of pixels. The kappa coefficient measures the agreement between classification and truth values. A kappa value of 1 represents '*Perfect agreement*', while a value of 0 represents '*No agreement*'.

The confusion matrix table is used to explain the performance of a classification algorithm. It is calculated by comparing each class of ground truth pixel with the respective class in the classification image. Commission error represents pixels that belong to other class that are predicted as the class of interest. Omission error represents pixels that belong to the class of interest but the algorithm has failed to classify them. The outcome of the accuracy assessment is shown in Fig 8.

Confusion Matrix: Classification\Data\Tadri river\2019\SAM

Overall Accuracy = (88/100) 88.0000%
Kappa Coefficient = 0.8585

Ground Truth (Pixels)

Class	S. alba	Mixed	A. officinali	K. candel	Associate veg	Sonneratia Ca	Acanthus ilic	Juvenile	R. mucronata	Total
Unclassified	0	0	0	0	0	0	0	0	3	3
Region #1 [Gr	25	0	0	0	0	0	0	0	0	25
Region #2 [Bl	0	3	2	0	0	0	0	0	0	5
Region #3 [Ye	0	0	5	0	0	0	0	0	0	5
Region #4 [Cy	1	0	0	4	0	3	0	0	0	8
Region #5 [Ma	0	0	0	0	4	0	0	0	0	4
Region #6 [Ma	0	0	0	0	0	18	0	0	0	18
Region #8 [Pu	0	0	0	0	0	3	9	0	0	12
Region #9 [Co	0	0	0	0	0	0	0	10	0	10
Region #10 [A	0	0	0	0	0	0	0	0	10	10
Total	26	3	7	4	4	24	9	10	13	100

Ground Truth (Percent)

Class	S. alba	Mixed	A. officinali	K. candel	Associate veg	Sonneratia Ca	Acanthus ilic	Juvenile	R. mucronata	Total
Unclassified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	23.08	3.00
Region #1 [Gr	96.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.00
Region #2 [Bl	0.00	100.00	28.57	0.00	0.00	0.00	0.00	0.00	0.00	5.00
Region #3 [Ye	0.00	0.00	71.43	0.00	0.00	0.00	0.00	0.00	0.00	5.00
Region #4 [Cy	3.85	0.00	0.00	100.00	0.00	12.50	0.00	0.00	0.00	8.00
Region #5 [Ma	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	4.00
Region #6 [Ma	0.00	0.00	0.00	0.00	0.00	75.00	0.00	0.00	0.00	18.00
Region #8 [Pu	0.00	0.00	0.00	0.00	0.00	12.50	100.00	0.00	0.00	12.00
Region #9 [Co	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	10.00
Region #10 [A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	76.92	10.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Class	Commission (Percent)	Omission (Percent)	Commission (Pixels)	Omission (Pixels)
Region #1 [Gr	0.00	3.85	0/25	1/26
Region #2 [Bl	40.00	0.00	2/5	0/3
Region #3 [Ye	0.00	28.57	0/5	2/7
Region #4 [Cy	50.00	0.00	4/8	0/4
Region #5 [Ma	0.00	0.00	0/4	0/4
Region #6 [Ma	0.00	25.00	0/18	6/24
Region #8 [Pu	25.00	0.00	3/12	0/9
Region #9 [Co	0.00	0.00	0/10	0/10
Region #10 [A	0.00	23.08	0/10	3/13

Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
Region #1 [Gr	96.15	100.00	25/26	25/25
Region #2 [Bl	100.00	60.00	3/3	3/5
Region #3 [Ye	71.43	100.00	5/7	5/5
Region #4 [Cy	100.00	50.00	4/4	4/8
Region #5 [Ma	100.00	100.00	4/4	4/4
Region #6 [Ma	75.00	100.00	18/24	18/18
Region #8 [Pu	100.00	75.00	9/9	9/12
Region #9 [Co	100.00	100.00	10/10	10/10
Region #10 [A	76.92	100.00	10/13	10/10

Fig 8: Outcome of "*Accuracy Assessment*" of mangrove species classification

4.8 Impact of Afforested Mangrove

Improved mangrove areas in Tadri river were assessed in various aspects in this study. For instance, significant changes within the river, changes in estuarine biodiversity, improvement in livelihood opportunities, river morphology changes and adaptation to environment. The impacts of each aspect discussed below.

4.8.1 River Environment Impact Analysis (REIA)

The river environment was assessed in two ways namely (i) Status of river bank and (ii) status of features within the river. The approach of assessment is indicated in Figure 9 and their impacts are detailed.

(i) Status of river bank

Mangroves play a vital role in the alteration of the physiography of the location in which they exist, which is one of their salient characteristics. The physiography of the river and the estuary environment has indicated certain remarkable changes *'Prior'* and *'During'* the afforestation of mangroves. The status of the river bank was assessed using DSAS model for the period 1972 – 2019.

The river bank was studied for two different set of years such as 1972 – 1990 which is considered as *'Period Prior'* to afforestation of mangroves in the estuary and for the years 1990 – 2019 which is considered as *'Period During'* afforestation of mangroves in the estuary. The result of river bank status was shown in Figure 10. The study indicated about 43% of bank erosion of various magnitude in the river during 1972 – 1990. The river bank status during afforestation indicated a significant decrease in the river bank erosion from 43% to 4%. The improved mangrove vegetation in the estuary played a dominant role in stabilizing the river bank from erosion as indicated by the study. However, proportion of medium erosion of the river bank was found to increase from 20% to 28% during the study period in areas that are deprived of mangroves.

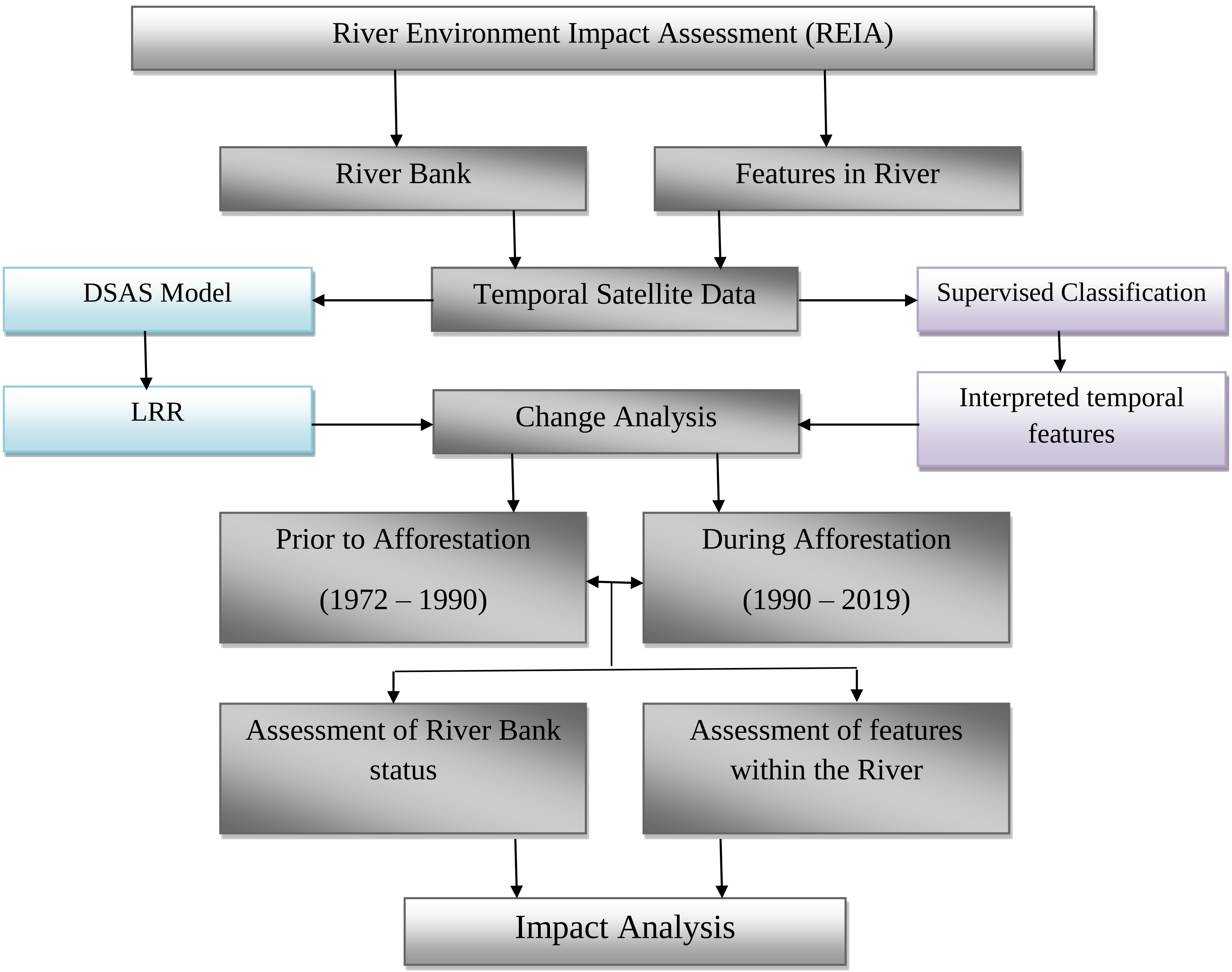

Fig 9: Approach for REIA

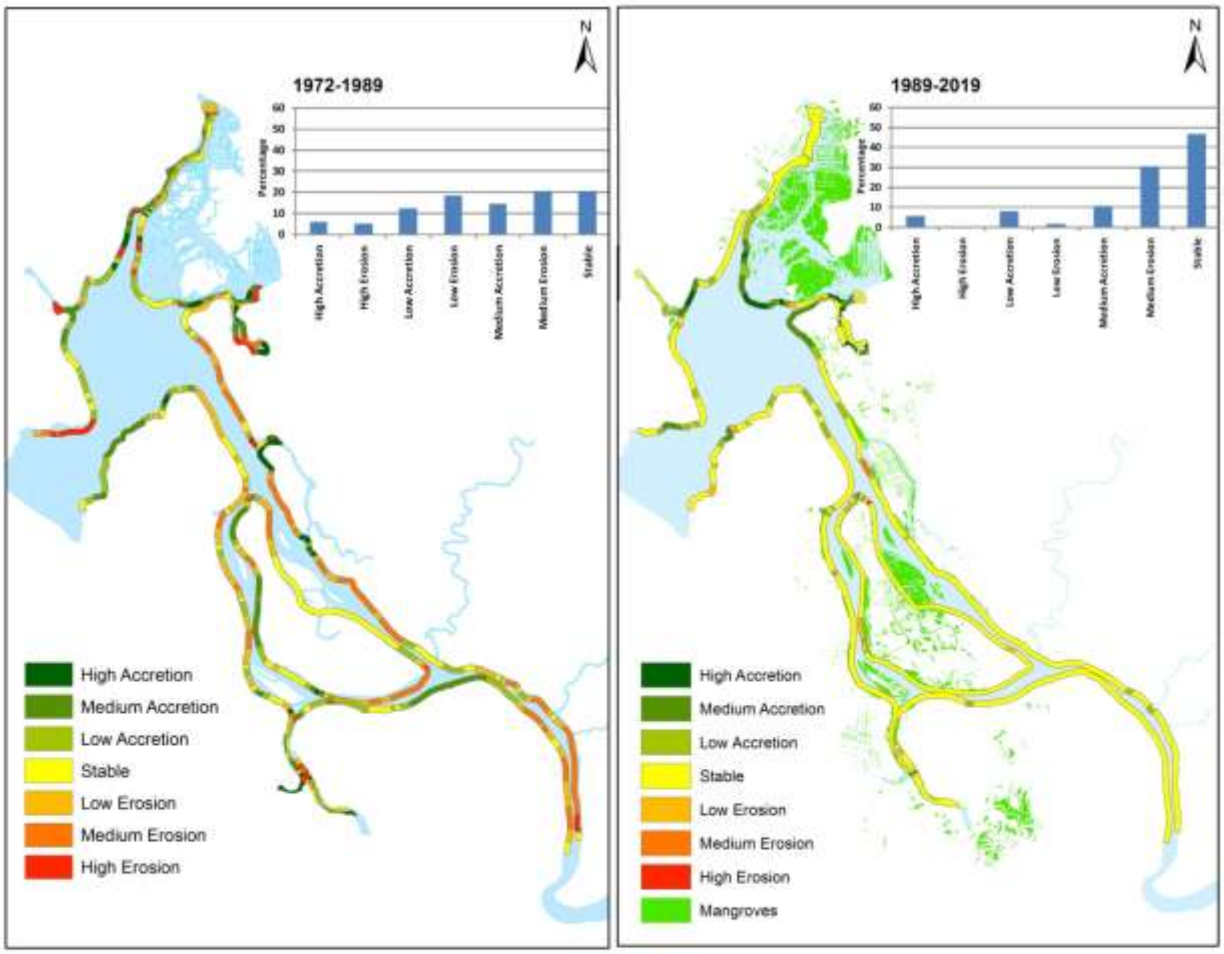

Fig 10: Tadri river bank status using DSAS model (a) 1972 – 1990 (b) 1990 – 2019

(ii) Status of features within the river

The land use features within the river including the features in Masurkurve island were mapped using satellite images for the years 1990, 2011 and 2019. The change analysis of the land features are shown in Figures 11 and 12. The major land features interpreted within the river are agriculture lands *('Gazni'*), scrub lands, plantation, settlement areas, mangroves, mudflats and waterlogged areas besides river flow area.

Figure 11 indicated an extensive afforested mangrove area upon converted abandoned saltpans and rice fields over the years while Figure 12 indicated improvement of mangrove vegetation especially in the periphery of the island mostly to stabilize the island.

The study indicated improvement and loss of certain features in this estuarine environment over the years. The improved features include mangroves and mudflats and deprived features includes water spread areas, crop lands and saltpans. Changes in the Tadri river based on its response to afforestation of mangroves are detailed in Table 3.

Conversion of abandoned saltpans and rice fields to mangroves can be considered as highlights of the afforestation program. Certain mudflats adjacent to Masurkurve island were afforested to mangroves (Fig 12) as an erosion protection measure of the island. However, mudflats supporting bivalves were found excluded from mangrove afforestation as they provide high economic service to the local communities.

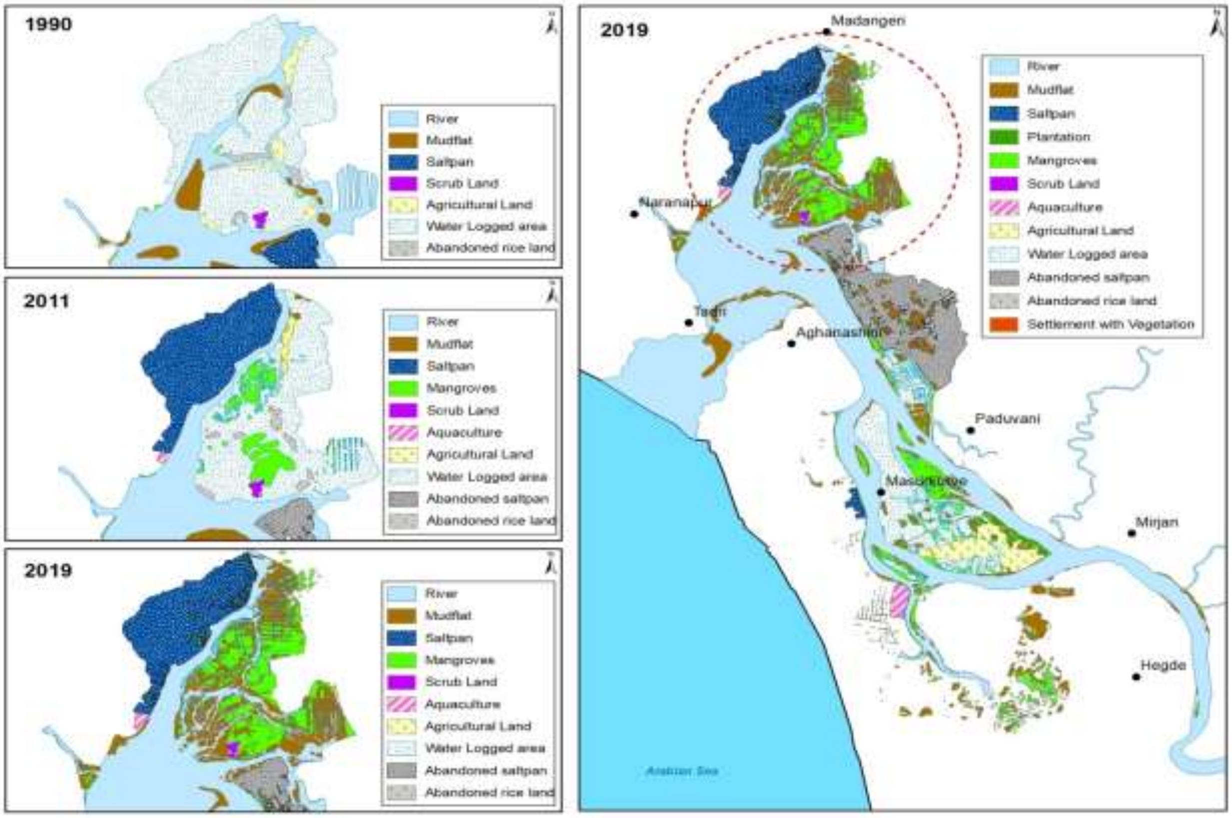

Fig 11: Land features with in Tadri River (*Zoom: Changes in Features in Estuarine region*)

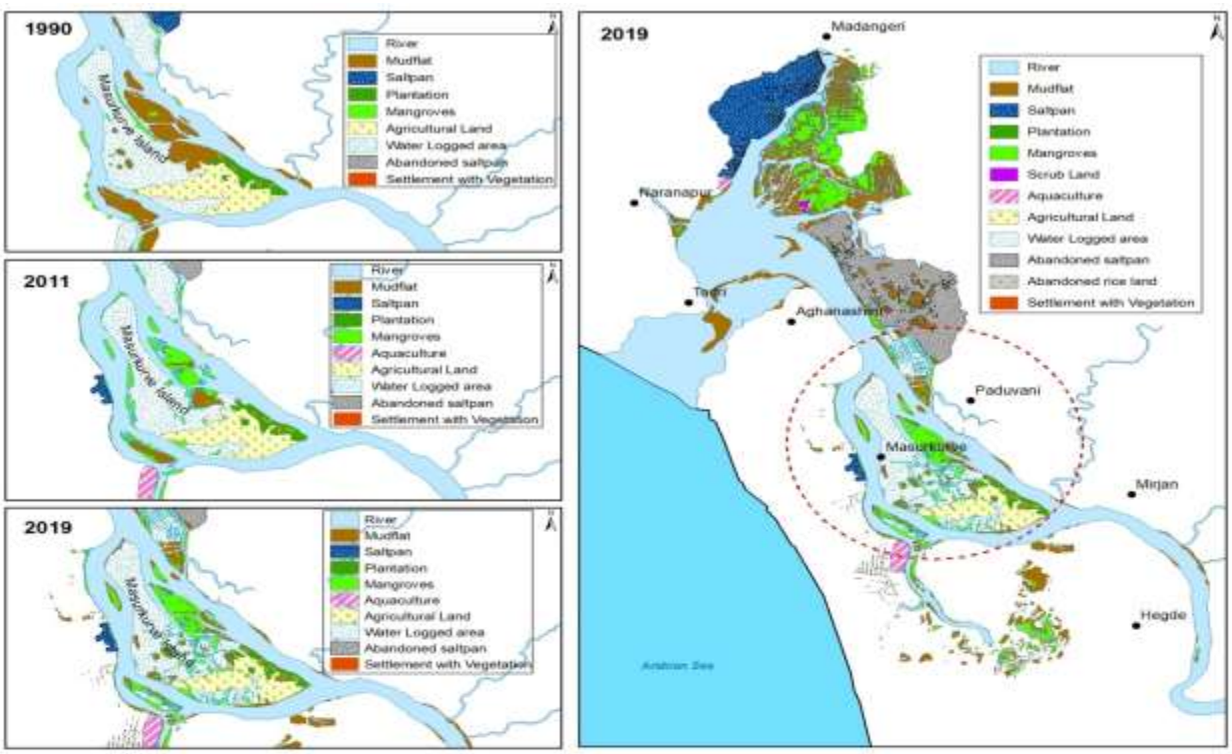

Fig 12: Land features with in Tadri River (*Zoom: Changes in Features near Masurkurve Island*)

Table-3: Change in riverine features (*'Prior' and 'During' afforestation*)

Changes	**Area (km²)**			
	Water area	***Mangrove***	***Mudflat***	***Other Lands***
Prior (1990)	17.62	0.29	3.79	3.70
After (2019)	17.29	4.50	2.42	1.19

The improved mangrove areas are designated as CRZ1A as per the Coastal Regulation Zone (CRZ) act, which has its own restrictions to conserve this Ecologically Sensitive Areas (ESA).

4.8.2 Improvement in Estuarine biodiversity

The re-establishment of mangrove areas at appropriate sites at various locations of the Tadri river has optimistic reciprocation from the estuary in the form of increased biodiversity and productivity capacity than ever since 1990's. The flora and fauna diversity has improved to an encouraging extent benefitting both the estuary environment and the locals. The improved and sighting of new fish species has increased the number of inland fishers and fish related dwellers. More than 120 species of birds reside in the estuary (Vidyadhar Atkore, 2017[12]). The catalogue of the Tadri estuary biodiversity has been widened and expanded in the recent years.

4.8.3 Improved livelihood opportunities to dependents

There are about 20 fishing villages primarily dependent on the fishing activity in Tadri estuary. The improved mangrove areas in the river have improved fish diversity. As per the report on fish diversity and livelihood of the Tadri river by Ramachandra et al 2012, nearly 80 fish species were found in the high salinity zone and about 27 species in the low salinity zones of the river. The yearly fishing man days were also being increased by 277 days yielding an average annual income of around Rs.88000/ha/year. The healthy functioning of the afforested mangrove systems has produced substantial quantity of bivalves engaging a good number of male and female folks for their livelihood. The abundance of fish diversity has also reduced the pressure on marine fishing in the area.

4.8.4 Changes in river morphology

The coast is exhibited as a rocky outcrop intervened by the Tadri river in the west coast. As per the study, this morphology witnessed no significant change, however with improved sediment traps in the head region of the estuary (St 1, Fig 5) new mudflats were found in the confluence of the river with the sea. The estuary has gradually turned greener than being muddy and grey lands as shown in Figures 4 and 5 (Abandoned areas). The availability of sediment at the mouth of the estuary has increased the sediment deposit at the northern coastal bank of the river in the recent years. However, the concern of the Tadri port located in the northern end of the river is the high sedimentation in the river mouth which hurdle the movement of vessels to and fro the sea.

4.8.5 Adaptation of the environment

The continuous improvement of the mangrove diversity in new locations of the estuary indicated the adaption of the species to the saline and soil conditions of the environment. The temporal change assessment of the estuarine features by this study indicated no major cases of afforestation failures in the estuary.

4.9 Tadri Estuary Impact Assessment (TEIA)

The impact of improved mangrove areas by afforestation was assessed on various aspects as gradient of improvement and gradient of degradation in the past 2.8 decades based on the data from the study. The impacts on different aspects were integrated to respresent the impact of afforested mangroves in Tadri estuary. The study indicated a significant improvement in the estuarine environment in the last 28 years as shown in Fig 14.

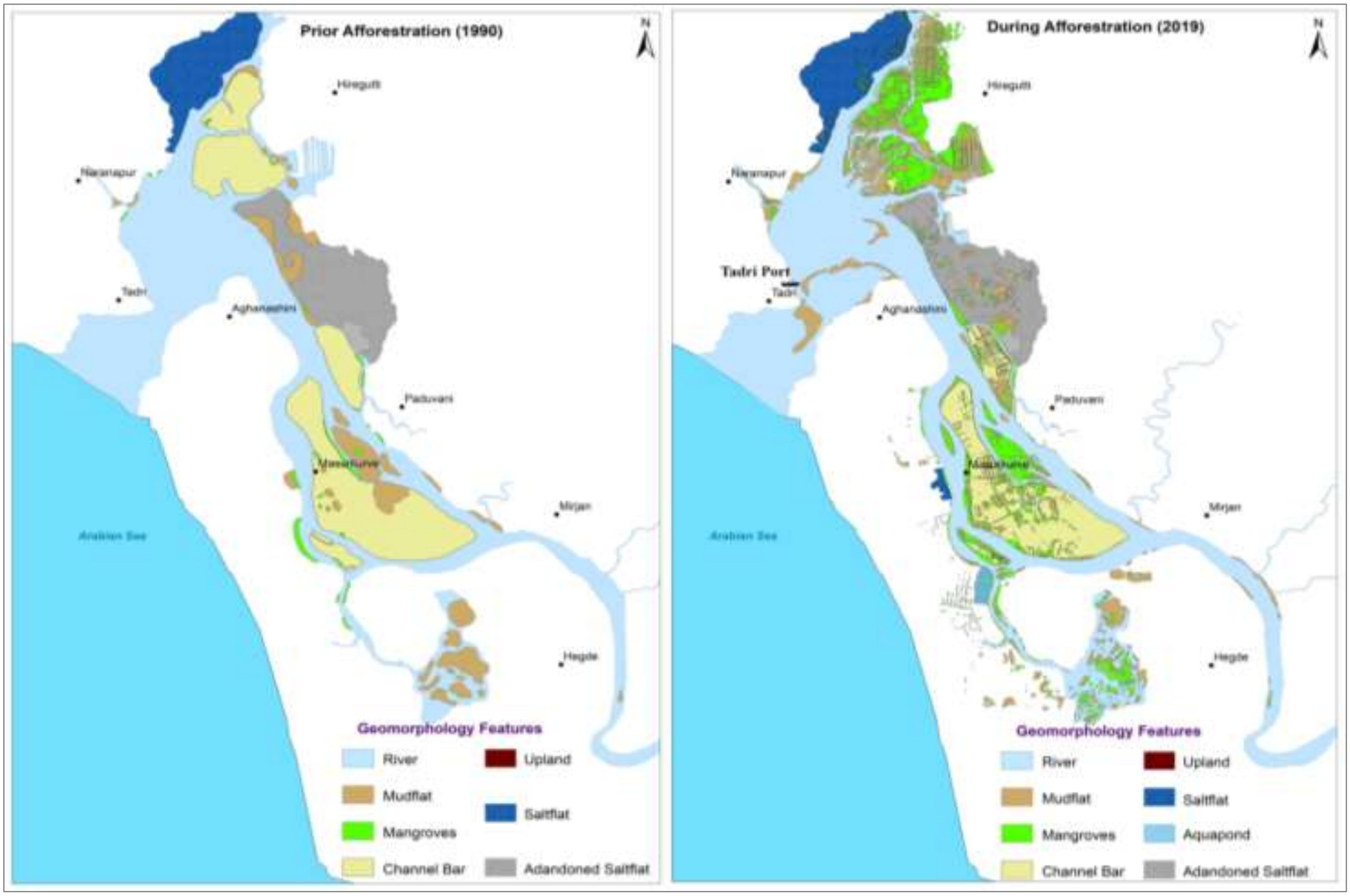

Fig 13: Changes in Tadri river morphology

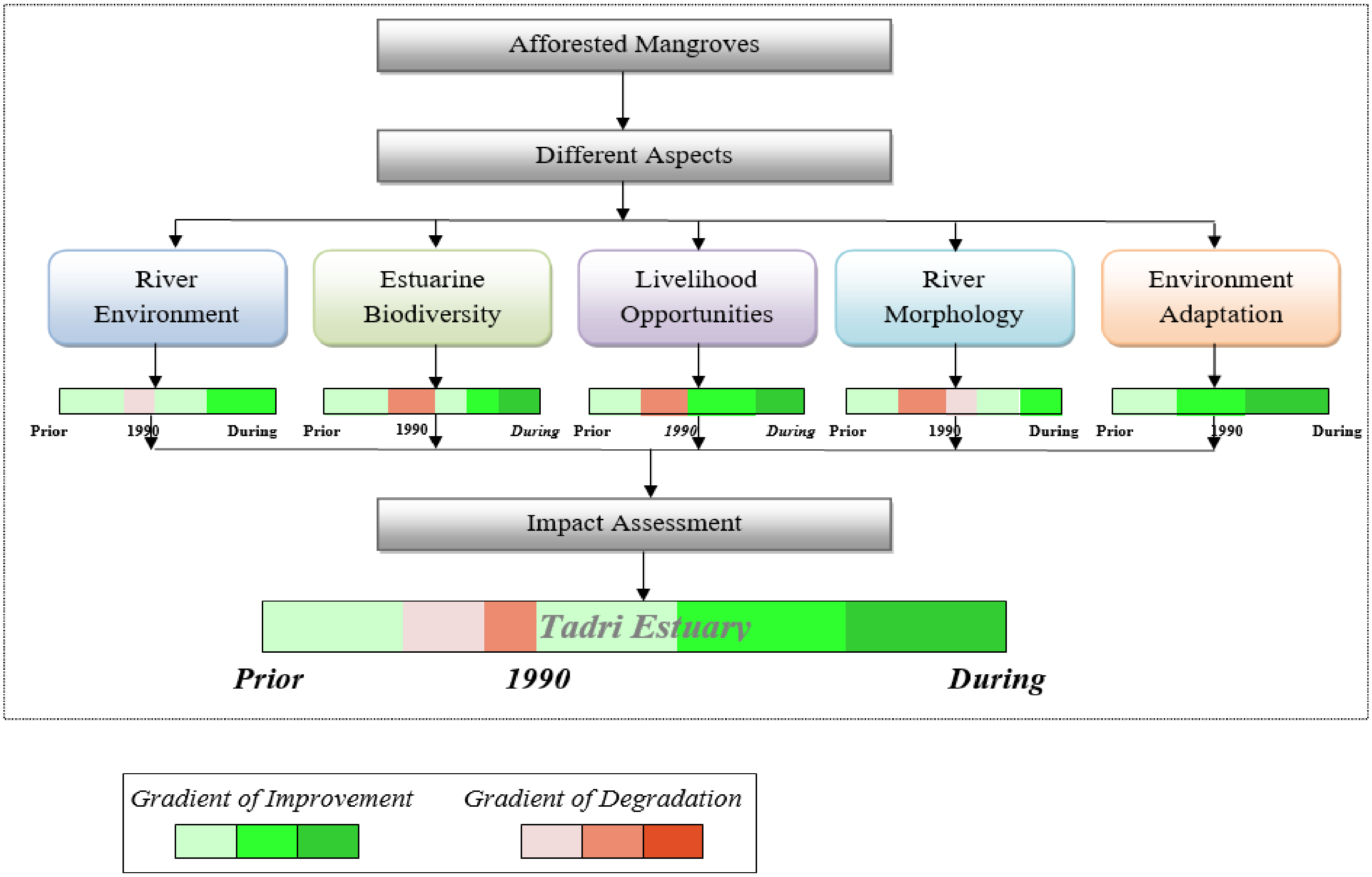

Fig 14: Tadri Estuary Impact Assessment (TEIA)

5. Conclusions

This study examined the effectiveness of temporal satellite images used to assess the changes and growth of mangroves in Tadri estuary. The impact of afforested mangroves in different aspects such as river environment, estuarine biodiversity, livelihood dependency, river morphology and Environment adaption were highlighted by the study. The spectral image classification using SAM classifier was used to assess the distribution and growth of mangrove species at different locations in the estuary over a period of 2.8 decades. The study indicated a significant improvement in the mangrove areas from 1% to 18% prior 1990 and 2019 by afforestation in abandoned saltpans and rice fields within the river. Major mudflats of the river especially in its head region were *'Not considered'* for afforestation as they support abundant high quality bivalves which is a direct livelihood activity of the dependent locals. However minor mudflats silted in close proximity to Masurkurve island were afforested as a coastal erosion protection measure for the island. The dawn of realization of mangroves as "*Economically Important Areas*" from their traditional perception as "*Economically Unproductive Areas*" started in 1990's. The Coastal Regulation Zone act 1991 imposed the initial awareness, conceptualized by the government and implemented with the joint effort of many public and private organizations along with people's participation.

Afforestation of Tadri estuary is one such programme implemented under various stages. The outcome of the project has mirrored the estuary as greener than during the past few decades and revived the functioning, productivity and biodiversity that any healthy estuarine environment ought to possess. The benefit of this estuarine recovery is equally fractioned between the resources and the dependent communities. The sustainability of the present scenario requires regular monitoring of the health of the resources and their exploitation by the stakeholders. Different amendments of CRZ notifications visioned to protect such fragile environments have shown its importance in Tadri estuary. Most of the estuaries in India have similar issues which can be attempted in the similar way with appropriate *in situ* modifications.

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Appendix A

Mangrove species and their salinity ranges

High (> 15 ppt)	Medium (15 – 5 ppt)	Low (< 5 ppt)
• *Acanthus ilicifolius* • *Avicennia marina* • *Avicennia officinalis* • *Excoecaria agallocha* • *Kandelia candel* • *Rhizophora apiculata* • *Rhizophora mucronata* • *Sonneratia alba*	• *Acanthus ilicifolius* • *Aegiceras corniculatum* • *Avicennia officinalis* • *Bruguiera gymnorrhiza* • *Kandelia candel* • *Rhizophora mucronata* • *Sonneratia alba* • *Excoecaria agallocha* • *Sonneratia caseolaris*	• *Acanthus ilicifolius* • *Acrostichum aureum* • *Sonneratia caseolaris*

Source: Sahyadri Conservation Series 20, 2012 Ramachandra TV et al. (Appendix A & B)

Appendix B

True and associated mangroves in Tadri Estuary

True species	Associated Species
Acanthus ilicifolius	*Calophyllum inophyllum*
Acrostichum aureum	*Cerbera manghas*
Aegiceras corniculatum	*Capparis spp.*
Avicennia marina	*Clerodendrum inerme*
Avicennia officinalis	*Caesalpinia crista*
Excoecaria agallocha	*Derris trifoliate*
Kandelia candel	*Dolichandron spathacea*
Porteresia coarctata	*Erythrina indica*
Rhizophora apiculata	*Ficus racemosa*
Rhizophora mucronata	*Pandanus fascicularis*
Sonneratia alba	*Pongamia pinnata*
S. caseolaris	*Premna corymbosa*
	Premna corymbosa
	Sporobolus virginicus

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