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Original article

Assessment of decadal land use dynamics of upper catchment area of Narmada River, the lifeline of Central India

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A B S T R A C T

India is a land of rivers and Narmada is one of the principal river systems and is ascribed as the lifeline of Central India. Freshwater ecosystems such as rivers across the globe are facing degradation due to multitude of anthropogenic stress factors. Holistic and sustainable approach is prerequisite for monitoring, risk assessment and management of such multitude of problems and critical challenges. Geographical Information System (GIS) has emerged as a powerful tool for carrying out scientific and unbiased monitoring and assessment studies as well as understanding the degradation of ecosystems. The present study focuses on decadal land use changes along the upper catchment area of Narmada river basin. Vegetation was spatially analyzed for digitally classifying numerous imageries using the maximum likelihood algorithm (MLA). Six land cover types were identified which includes dense mixed forest, Sal dominated forests, barren landscapes, agricultural fields, water bodies as well as habitation and commercial spaces. The vegetation structure and species composition are important ecological attributes of the ecosystem. Our study area has faced intensification in anthropogenic stress factors, which is observable in our temporal variations study as well. Increasing urbanization and deforestation in river valley regions is alarming and testimony of the fact. Therefore, in order to maintain the river health advocacy at policy level is needed. The current study is an attempt in that direction. It is therefore essential in developing a road-map for sustainable development of this important riparian ecosystem.

1. Introduction

The sustainable development goals (SDGs) of 2030 as adopted by United Nation member states set up by United Nations General Assembly are blueprint of better and sustainable future for all. Several countries are working hard to achieve the shared vision of development to the best of their abilities. The different aspects of various goals like 6, 11, 12, 13 and 15 have been clubbed together in this research project to accomplish the aim enumerated in goal 15. It explains to "*protect, restore and promote sustainable use of terrestrial ecosystems, sustainable management of forests, combat desertification, halt and reverse land degradation and halt biodiversity loss*". Meeting the objectives of SDGs is pivotal in order to comprehensively address the costs associated with anthropogenic impacts and ecosystem trade-offs. Some of the major cities across the globe that they have rapidly altered the land use and land cover (LULC) dynamics to achieve economic goals and urbanization in order to attain the needs of a rapidly growing population (Barros, 2004). The LULC changes study plays a crucial regulatory role in changing total atmosphere and the environment (Qian et al., 2007). Land use patterns denote to the physical features of the earth's surface like distribution of green vegetation, water, soil and other physical land features generated through anthropogenic activities. Thus, addressing SDG

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Goal 11 that is to make the urban centres and human settlements more inclusive, safe, resilient and sustainable through this initiative is pivotal. The quantitative analysis of the changes occurred through LULC is crucial to study the corresponding impact on the ecosystem service value (ESV). It could help in the decision-making process for the sustainable development of ecosystem (Lin et al., 2018). The alternations in different component of terrestrial ecosystems could be estimated and monitor through LULC (affecting the different components of the ecosystem directly or indirectly (Guzha et al., 2018). The last century has seen many natural disasters and climate changes across the globe like rise in sea surface temperature, melting of polar ice, sea level rise, change in global wind circulation & ocean currents and weather changes. This has caused detrimental impacts on the biodiversity around the world. Continued overexploitation of natural resources leads to serious threat and it represents unsustainable consumption and production patterns which hampers the Goal 12 of the SDG and adversely discourage the sustainable consumption and production patterns. Its adverse effect can be easily observed in the form of degrading freshwater ecosystems. Preserving freshwater resources for both people and wildlife is essential and is a top priority responsibility to protect the planet. In this manuscript, we have used recent scientific advance techniques to ensure sustainable and holistic development of the upper reaches of Narmada flowing across Achanakmaar Amarkantak Biosphere Reserve (AABR). In order to mitigate the effect of climate change and adapt it as per the fulfillment of goal 13 of the SDG, availability of credential data is crucial. The United Nations have recognized the inextricable link between water and climate change by making it a theme for the World Water Day of 2020. This initiative explains and emphasizes the importance of water and its potential role to mitigate the effect of climate change. Further, it urges the international community to keep water conservation at the top priority during designing the climate related policy. Protection and conservation of freshwater resources such as rivers, streams, springs and lakes distributed across the globe is the need of the time and this manuscript proposes a sound scientific data set for policy makers. It argues that, a land use land cover map of a drainage basin provides a holistic view of the river actual health conditions and also the natural and anthropogenic stress factors that impacts the river sustenance. Under such circumstances, development of the Digital Elevation Model (DEM) is crucial. The resolution of the satellite image varies with the sensors, but the DEM provides the foundations for extracting data pertaining to the drainage network. Many critical hydrological phenomena such as the size, shape and slope of the drainage area, the drainage density, the size and length of the tributaries, etc., correlate with the physiographic characteristics of drainage basins (Rastogi and Sharma, 1976). The aforementioned techniques and tools were chosen for the generation of the current scientific data set. Few limitations of LULC have been noted in hydrological modeling and evapotranspiration estimations where little or no information on the temporal dynamics of LULC classes have been reported (DeFries et al., 1999). AVHRR pathfinder time-series images have become cutting-edge procedures to capture temporal dynamics of LULC at global level (De Fries et al., 1998; Loveland et al., 2002). LULC studies of drainage basins are particularly important in case of rain-fed river systems such as Narmada. It is prone to flooding with prolonged monsoonal rains and erratic precipitation pattern under current climate change scenario (Guhathakurta, et al., 2011; Kulkarni et al., 2013). LULC analysis confirmed around 74.84% increase in built up area and 42.8% decrease in open spaces area during the years 1966–2009 due to increase in the degree of urbanization over the decades in Oshiwara river basin (Zope, et al., 2016). LULC change detection studies have profound impacts on hydrological processes and have been investigated prominently in the recent times (Fox et al., 2012).

The current study attempts to investigate the decadal changes in land use and land cover along upper catchment basin area of Narmada. The primary objective of the current research is to understand the decadal land use changes as well as to identify the anthropogenic stress factors of the study area. The vegetation mapping also ensured the study of phytodiversity of the area. DEM have been constructed for hydrological mapping and geomorphological analysis of the study area.

2. Materials and methods

A workflow of methodology for the current monitoring and assessment analysis is described in Fig. 1. The flow chart is self-explanatory and discusses the various stages of the analysis work carried out during the current research.

2.1. Study area

Upper catchment area of Narmada River was selected as the study site which is a part of Achanakmaar Amarkantak Biosphere Reserve (AABR), Central India. The study area endowed with biodiversity, medicinal, herbal and aromatic plants. There are many minor rivers of this region such as Gayatri, Savitri, Kapila, Baitarini, Arandi, Arpa, Bakan, Tipan and Karmandal. These small rivers provide a natural source of water throughout the year to the Narmada river. Besides minor rivers, many perennial streams and wetlands are found which supply the water to main stream of Narmada.

The Narmada river system originates from Amarkantak highlands located between the map coordinates 22°15′ N to 22°58′ N and 81°25′ E to 82°5′ E covering a geographical area of approximately 35.61 km^2 at a mean altitude of 1048 m from average sea level. The base map is demonstrated in Fig. 2. The climate type is sub-humid tropical monsoon with extended summers from April to June, rain from July to October and winter from November to February months. The average yearly temperature ranged from 16.1 °C to 31 °C, while April and May are the hottest, whereas December and January are the coldest months with minimum temperature drops below 5 °C. The annual rainfall varies between 1350 and 1600 mm.

2.2. Selection, image pre-processing and classification of remote sensing data

Landsat 4, 5, 7, 8 Thematic Mapper (TM) images (1980, 1988, 1998, 2008) and a high-resolution cloud free Resourcesat 2A level-1C image of path 144 and row 44, 43 April/March 2018 was used for mapping LU/LC change classes of the upper catchment areas of Narmada river from (1980 to 2018). All Landsat images were obtained freely from The United States Geological Survey (USGS) website (http://glovis.usgs.gov/). Resourcesat 2A (2018) satellite data was procured from the NRSA National Data Center (NDC), Hyderabad. The data covers the entire study area of the Narmada river basin in the upper catchment areas of Amarkantak region and the neighboring areas. The digital analysis of the data was performed using ERDAS Imagine (Version 2013) software. The secondary data collected from SOI topomaps were analyzed using ArcGIS 10.3. A base map of the study area was prepared from Survey of India toposheets (64E/16 and 64 I/4) at a 1:50,000 scale and geometric rectification of all the imageries was performed. This map was utilized for the ground control point for exactly locating samples plots in the research site. The characteristics of selected satellite data as acquired from the USGS website is demonstrated in (Table 1). Digital image processing and supervised

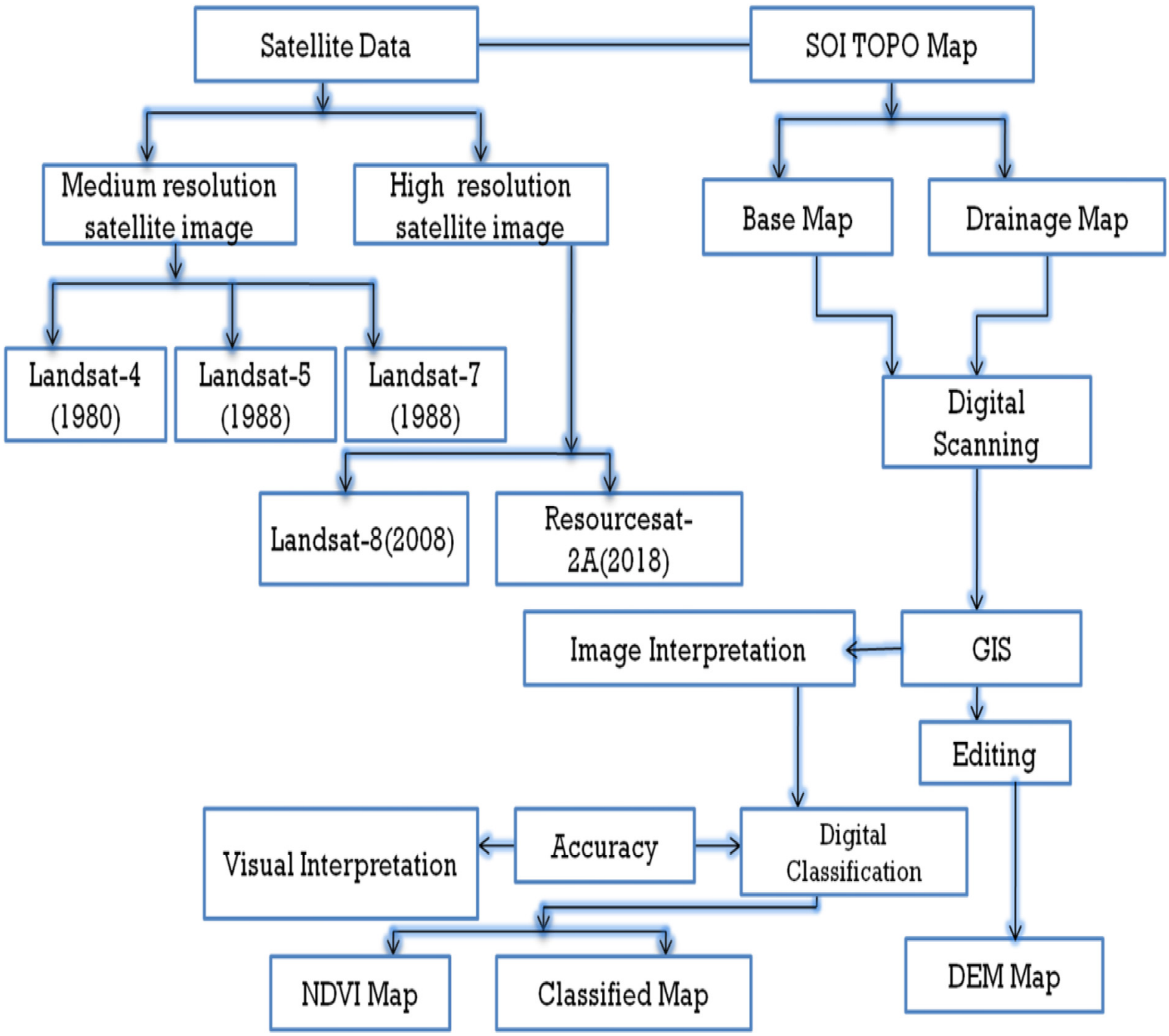

Fig. 1. Methodology workflow and data analysis.

classification has been performed for the monitoring of six land use classes using the maximum likelihood algorithm. The delineated LU/LC classes were: Dense Mixed forest (DMF), Sal mixed forest (SMF), Open Land (OL), Agriculture (AG), Habitation/commercial building (HB) and Water Bodies (WB).

2.3. Vegetation mapping and forest health monitoring using NDVI

Many remote-sensing tools are available to support forest health information needs, and forest health specialists have been making extensive use of these tools for many years. Aerial sketch mapping is extensively used in detection of forest health in USA and Canada. Color and color infrared (CIR) aerial photos have also been used for a wide range of applications. More recently, technologies such as airborne videography, digital photography, and Earth-orbiting satellite imagery have been evaluated for their ability to provide needed information. In the current paper, the vegetation mapping (during 1980 to 2018) and forest health checkup was performed with the help of NDVI (Normalized Difference Vegetation Index). It helped in vegetation classification and forest health monitoring over the time-scale employed for the study. NDVI employs the multi-spectral remote sensing data technique to find out forest types, land use land cover pattern and change detection analysis, habitation, water bodies, open area, agricultural area with few band combinations using satellite images. Previous study suggest that natural resources are easily interpreted by computing NDVI indices like LULC changes and plant health (Gandhi, et al., 2015).

2.4. Construction of DEM (Digital Elevation Model)

The quantitative representation of terrain important for earth science studies and hydrological applications is described by Digital Elevation Model (DEM) (Mukherjee, et al., 2013). The methodology adapted for the study includes the extraction of river basin image followed by extraction of drainage network data. First the DEM images were downloaded from United States Geological Survey (USGS) website (http://glovis.usgs.gov/) following which they were successfully mosaicked. The mosaicked images were then used to delineate the river basin boundary. The images of Narmada river basin was extracted using the Arc hydro tool in ArcGIS 10.3 software.

2.5. Field survey and accuracy assessment

The reference and supplementary data were collected with the help of a field survey as a ground control point with the help of GPS and direct local field measurements were performed for ground verification. Additionally, image categorization and overall accuracy assessment of the classification were carried out. Images of

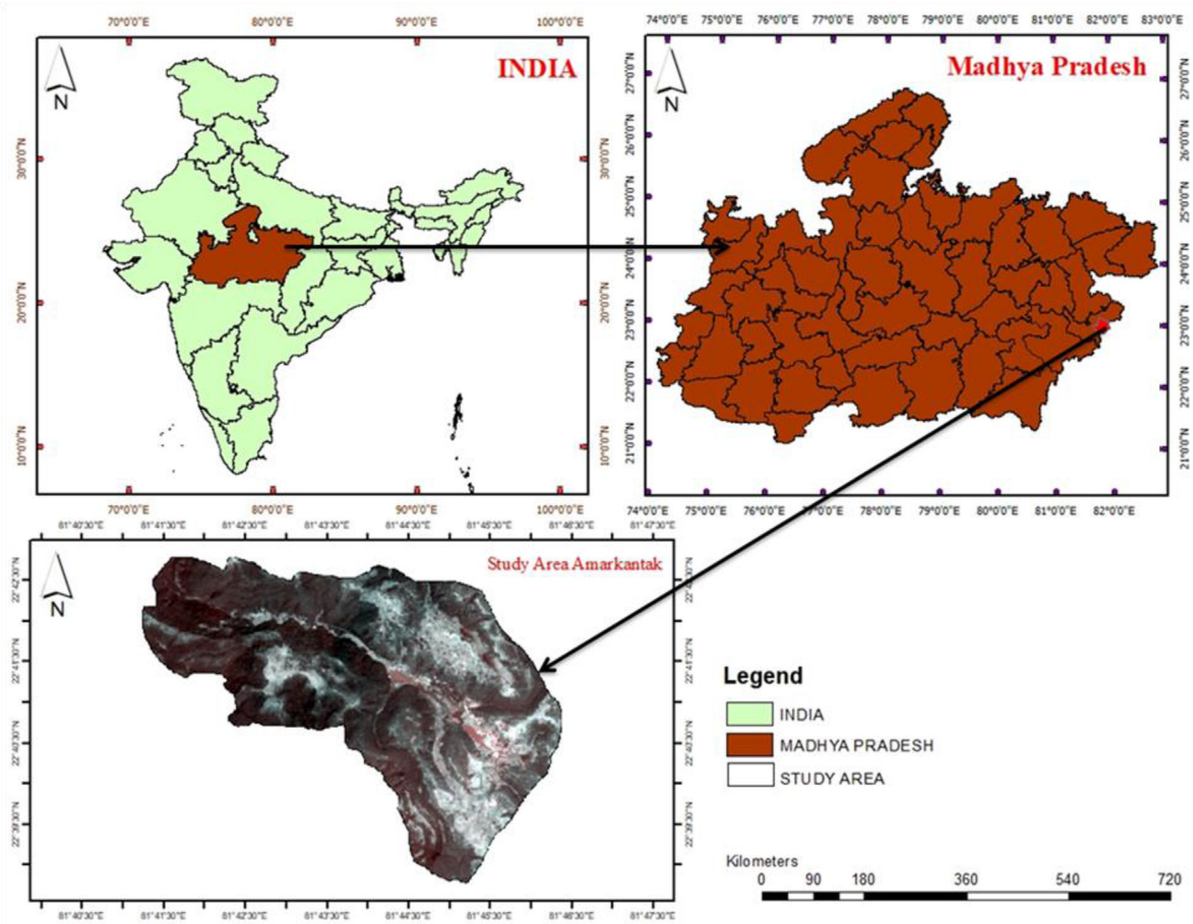

Fig. 2. Layout map of the study area.

Table 1
Characteristics of the selected Satellite data.

Satellite data	Obtain Date	Row/Path	Number of bands	Swath width (Km)	Inclined Angle	Spatial resolution
Landsat-4	30/05/1980	144/42	7	185	98.2°	30 m
Landsat-5	26/03/1988	144/42	6	185	98.2°	30 m
Landsat-7	11/07/1998	144/42	6	185	98.2°	30 m
Landsat-8	06/09/2008	144/42	4	185	98.2°	15 m
Resourcesat-2A	27/01/2018	144/43	3	740	98.72°	5.8 m

1980–2018 were evaluated through confusion matrix for the overall accuracy assessments (Congalton, 1991) and Kappa analysis (Rosenfield and Fitzpatrick-Lins, 1986). Stratified random sampling method was used for the evaluation of images in the ERDAS Imagine 2013 software. Besides field investigation, we also investigated the characteristics of understorey and groundstorey vegetation in the upper catchment area of Narmada river. During the survey, we interacted with local individuals and healers for the taxonomic identification and validation of native flora and non-timber forest produces.

2.6. LULC change detection analysis

The LULC map of 1980, 1988, 1998, 2008 and 2018 was resampled from the middle resolution of satellite data (30 m) to spatial high resolution (5.8 m) for the study of classified map and LULC change during the said period. A comparison of pixel-based study was also performed to generate changes on the pixel basis. Pairs of multispectral satellite images were compared between 1980 and 2018 using cross-tabulation to find out the information of LULC changes. Interestingly, change matrix presents significant information about vegetation changes in LULC study (Shalaby and Tateishi, 2007). All classified images change matrix were generated and analyzed using ERDAS to evaluate LULC change during 1980–2018 (Yang and Wen, 2011; Thakur et al., 2020).

3. Results and discussion

3.1. LULC and vegetation mapping

The land cover classification of the study area was done using the MLA and supervised classification, the Standard False Color Composite (SFCC) maps were employed in Fig. 3. It shows decadal changes of the study area over a period of forty years. The spatio-temporal assessment of land use categories is illustrated in (Table 2, Figs. 4 and 5). With a few exceptions, almost all the land use classes were separable in one or the other bands. Six LC and vegetation classes such as DMF, SMF, OL, AG, HB and WB were

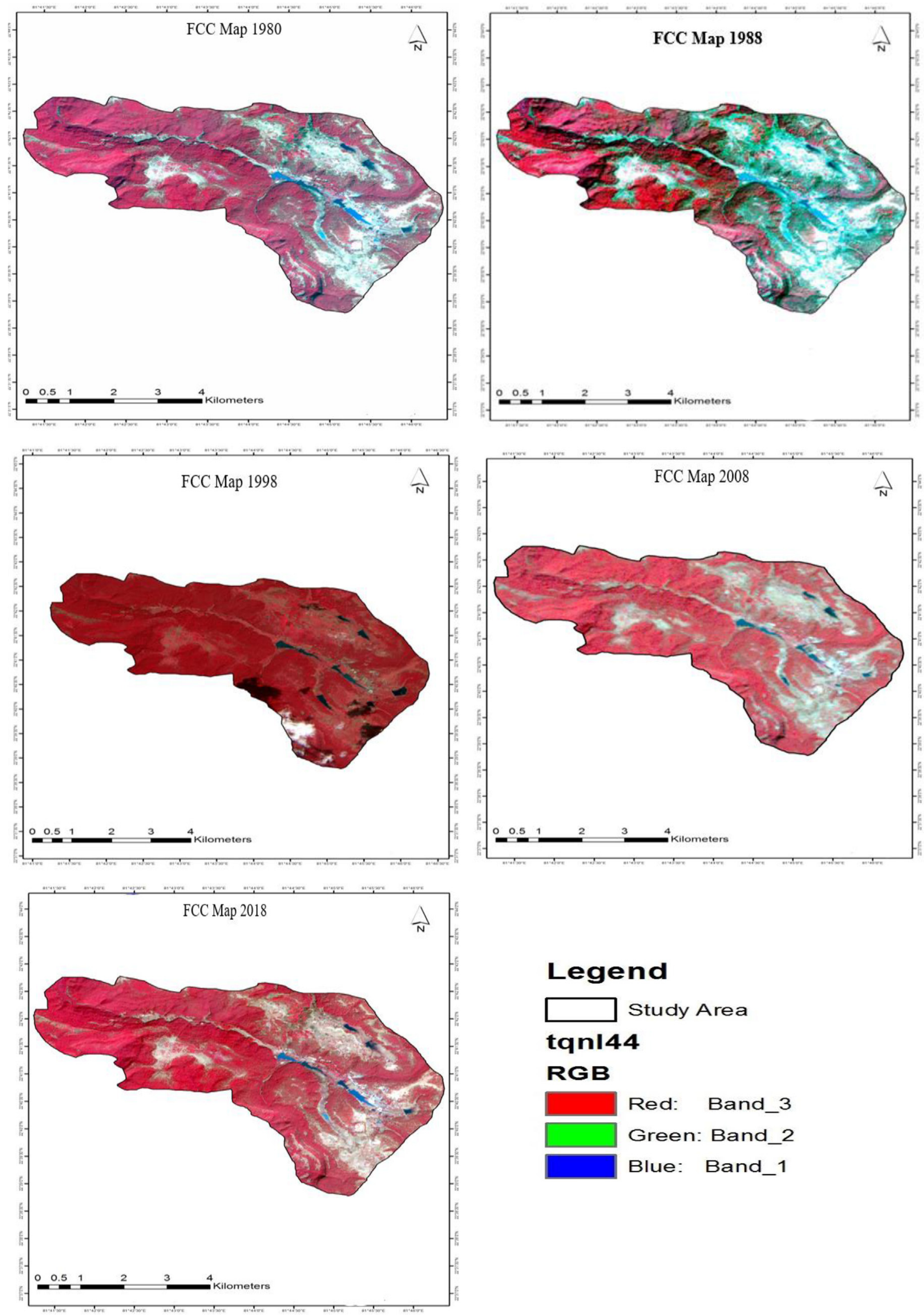

Fig. 3. SFCC maps of study area during 1980, 1988, 1998, 2008 and 2018.

delineated. The results pertaining to the spatial extent of the different forest types and change detection (during 1980 to 2018) are presented in Table 3. It indicates a steady decline in forest and water resource areas leading to shrinkage in river basin. OL, AG and HB have increased heavily with unplanned industrialization and urbanization along the river valley. The contribution of the

Table 2
Land use land cover in upper catchment area of Narmada river between 1980 and 2018.

Class Name	Area (km^2) 1980	Area (km^2) 1988	Area (km^2) 1998	Area (km^2) 2008	Area (km^2) 2018
Dense Mixed Forest	18.92 (53.13)	17.79 (49.96)	16.85 (47.32)	14.98 (42.07)	14.78 (41.50)
Sal Mixed Forest	10.65 (29.91)	11.21 (31.48)	11.57 (32.49)	9.90 (27.80)	9.90 (27.80)
Open Land	2.34 (6.57)	2.69 (7.55)	3.01 (8.45)	4.98 (13.98)	5.02 (14.10)
Agriculture	0.29 (0.81)	0.90 (2.53)	0.98 (2.75)	2.78 (7.81)	2.82 (7.91)
Habitation/Commercial Building	0.21 (0.59)	0.29 (0.81)	0.56 (1.57)	1.54 (4.32)	1.70 (4.77)
Water bodies	3.2 (8.98)	2.71 (7.61)	2.64 (7.41)	1.43 (4.01)	1.39 (3.90)
Total	35.61	35.61	**35.61**	35.61	35.61

*Parenthesis values are in percentage.

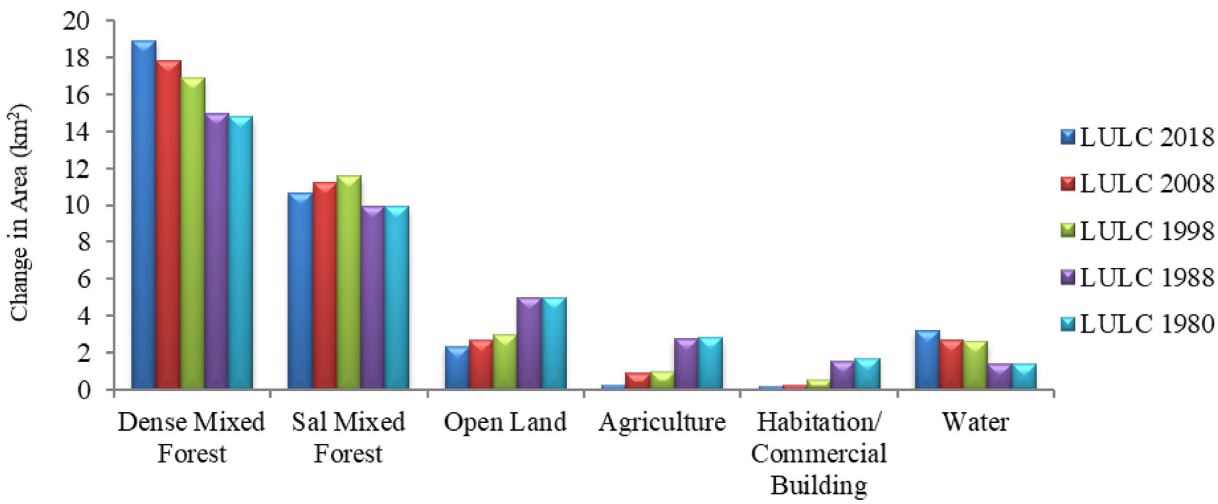

Fig. 4. LULC Classification of the upper catchment area of Narmada River (1980–2018).

changes in the different vegetation classes (during 1980 to 2018) are shown in Fig. 6 as revealed by NDVI index used to employ the vegetation classification and change detection over the years.

3.1.1. LULC pattern 1980

During 1980 to 2018, the DMF was dominating category which occupied an area of 53.13% (18.92 km^2), the SMF occupied 29.91% (10.65 km^2) area of the land use, the OL occupied an area of 6.57% (2.34 km^2), the AG was occupied by 0.81% (0.29 km^2), the HB covered approximately 0.59% (0.21 km^2) and the area under WB cover was 8.98% (3.20 km^2) respectively. The land cover area of green vegetation (including different types of forest and agriculture) was 83.85% (29.86 km^2) and rest of the land use (OL, HB, WB) were 16.15% (5.75 km^2), respectively (Table 2).

3.1.2. LULC pattern 1988

In the year 1988, the contribution of the forest vegetation and agriculture crop lands was 83.97%, WB was 7.61% and other land use (i.e. OL, HB) was covered by 8.42%. The land use covers under DMF, SMF, OL, AG, HB and commercial buildings cover was 49.96% (17.79 km^2), 31.48% (11.21 km^2), 7.55% (2.69 km^2), 2.53% (0.90 km^2) and 0.81% (0.29 km^2) of the total upper catchment area of Narmada river respectively (Table 2).

3.1.3. LULC pattern 1998

During the period of 1998, the land cover comprises maximum LU areas of 47.32% (16.85 km^2), 32.49% (11.57 km^2), 8.45% (3.01 km^2), 7.41% (2.64 km^2), 2.75% (0.98 km^2) and 1.57% (2.64 km^2) under DMF, SMF, OL, WB, AG and HB of the total land use covered in the current study area. The share of total land cover under the green vegetation (including different forest types and agriculture) was 82.56% (29.40 km^2) and rest of the land use (OL, HB, WB) were 17.44% (6.21 km^2) respectively (Table 2).

3.1.4. LULC pattern 2008

DMF covered an area of 14.98 km^2 (42.07%), SMF 9.90 km^2 (27.80%), OL 4.98 km^2 (13.98%), AG 2.78 km^2 (7.81%), HB 1.54 km^2 (4.32%) and the WB was estimated as 1.43 km^2 (4.01%) respectively in the classified map of 2008.

3.1.5. LULC pattern 2018

During recent time period, the DMF occupies an area of 14.78 km^2 (41.50%), which was close to 2008 DMF value. The SMF occupies an area of 9.90 km^2 (27.80%), OL 5.02 km^2 (14.10%), AG 2.82 km^2 (7.91%), HB 1.70 km^2 (4.77%) and the WB 1.39 km^2 (3.90%), respectively, in the classified map of 2018. The total study area was found to comprise of 35.61 km^2 (Table 2). The forest occupies more than 85% of the total area and the remaining 15% area belongs to agricultural lands, habitation/commercial spaces and water bodies. However, the forest areas are rapidly diminishing due to habitat expansion, roads constructions and other infrastructure development.

3.2. LULC change detection (1980–2018) and accuracy assessment

The results on the pattern of LULC change detection is illustrated in Fig. 7 and represent in (Table 3 and 4). Medium resolution (Landsat 4, 5, 6 and 7 images during 1980, 1988, 1998, 2008) and high-resolution satellite images (i.e. Resourcesat 2A image for 2018) have been employed for spatial distribution of the LULC changes at upper catchment areas of Narmada river between 1980 and 2018 in Fig. 8. The changes in land use are described here for each category (DMF, SMF, AG OL, HB and

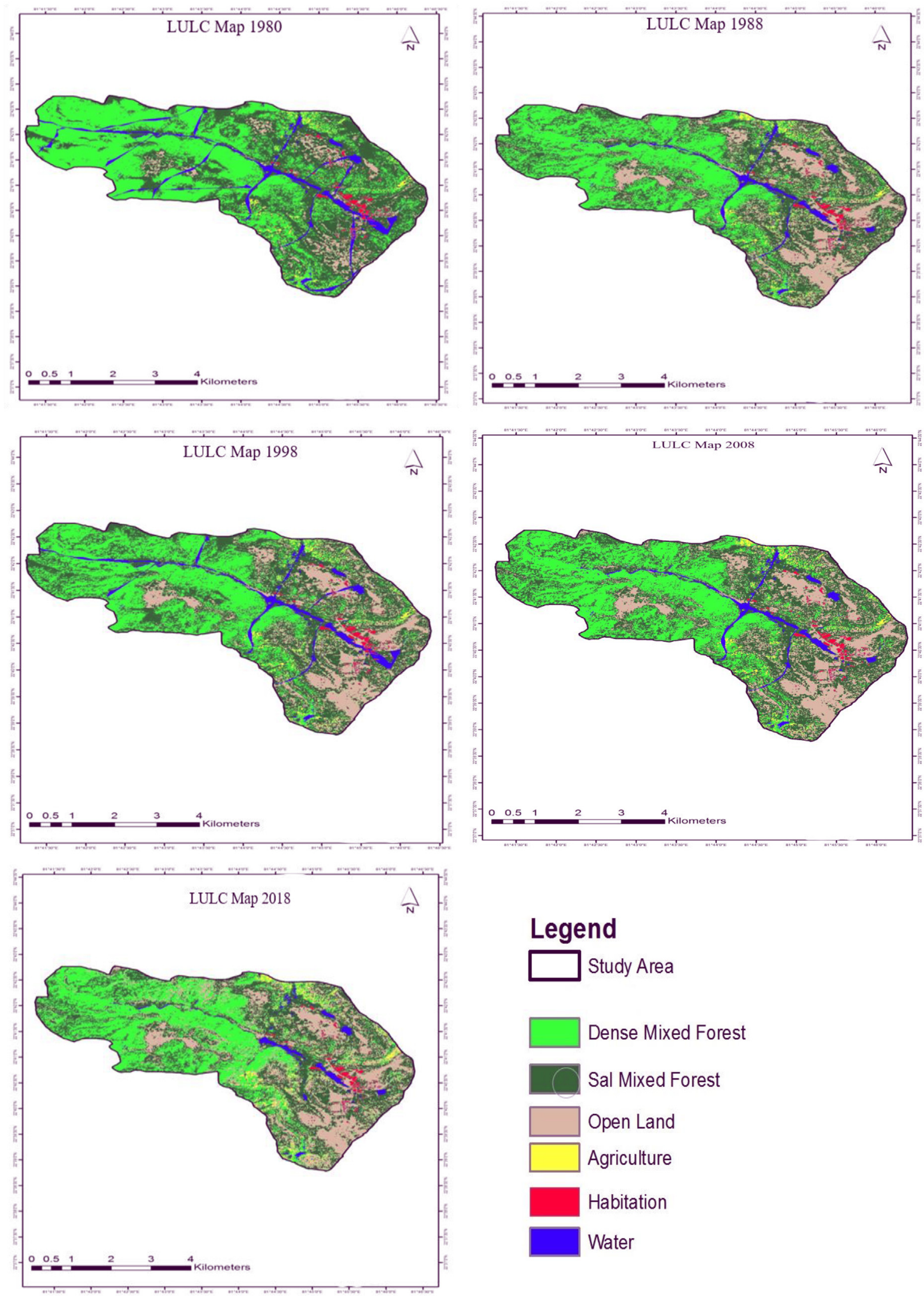

Fig. 5. Information on the LULC Classified Image of upper catchment area of Narmada river during 1980, 1988, 1998, 2008 and 2018.

Table 3
LULC change detection analysis of upper catchment area of Narmada river during 1980 to 2018

Class Name	Area (km^2) 1980	Area (km^2) 2018	Difference 2018 Vs 1980 (km^2)
Dense Mixed Forest	18.92 (53.13)	14.78 (41.50)	−4.14 (−11.63)
Sal Mixed Forest	10.65 (29.91)	9.90 (27.80)	−0.75 (−2.11)
Open Land	2.34 (6.57)	5.02 (14.10)	2.68 (7.52)
Agriculture	0.29 (0.81)	2.82 (7.91)	2.53 (7.10)
Habitation/Commercial Building	0.21 (0.59)	1.70 (4.77)	1.49 (4.18)
Water bodies	3.2 (8.98)	1.39 (3.90)	−1.81 (−5.08)
Total	35.61	35.61	

*Parenthesis values are in percentage.

WB). During study periods DMF (11.63%), SMF (2.11%) and WB (5.08%) was gradually decreased whereas, OL (7.52%), AG (7.10%) and HB (4.18%) areas were increased. Fig. 8(A–E) shows the major land use change of forest areas (DMF & SMF) 13.74% to OL, AG and HB areas. The cultivation practices and habitations have been increased respectively by 7.52%, 7.10% and 4.18% during the periods between 1980 and 2018. The expansion of OL, HB and AG account for almost 18.82% (6.70 km^2) of the total LULC changes in the upper catchment area of Narmada from 1980 to 2018 as demonstrated in Table 4.

Current study approves the reliability and accuracy of multispectral satellite images for mapping of LULC change detection in diverse areas (Aghsaei, et al., 2020; Desta and Fetene, 2020; Aslami and Ghorbani, 2018; Aggarwal et al., 2016). The LULC studies between 1980 and 2018 in upper catchment areas of Narmada basin reveals notable changes that occurred over the four decades such as shrinkage of water bodies, conversion of dense and sal mixed forest into open forest, expansion of agricultural land to delineated forest areas, increase in commercial spaces and habitation areas etc. This has further accelerated overall ecological degradation and biodiversity loss. The problems overgrazing, construction of dams, mining and illegal settlements also pose severe pressure on existing natural resources. Many native species have been replaced by non-native species and monoculture is creating ecological imbalance. Similar demonstration on LULC and change detection in the tropical regions across the globe were reported by several researchers (El-Tantawi et al., 2019; Mishra et al., 2020; Soha and El-Raey, 2019; Olmanson and Bauer, 2016; Dutta et al., 2020; Thakur et al., 2020).

Image classification accuracy assessment of 1980, 1988, 1998, 2008 and 2018 were very constructive and overall accuracy for the LULC image was found to be 85.95% for the year 1980; 87.07% for 1988; 91.86% for 1998; 93% for 2008; and 97% for the year 2018. The accuracy assessment data is mentioned in (Table 5). Similar results on accuracy assessment were reported by Olmanson and Bauer (2016), Chetan et al. (2017), Aslami and Ghorbani (2018). This study signifies the viability of the accuracy assessment data. Furthermore, the error matrix applied over the LULC classification was based on the ancillary facts (Hossen and Negm, 2016). The present study observed significant LULC change and change in matrix also shows severe changes on green undergrowth vegetation and water bodies. The change matrix in the upper catchment area of Narmada river from 1980 to 2018 is presented in (Table 6).

3.3. Factors responsible for LULC change/land degradation

The anthropogenic stresses were mostly responsible for changes in the LULC pattern of upper catchment area of Narmada river between 1980 and 2018. Our study results point to the increasing anthropogenic stress factors in the study area with land use changes, increase in habitation areas and commercial spaces, degradation of forests and overgrazing of grasslands, problems of siltation and pollutant influx in the river water leading to degradation of water quality as well as decreasing wetland spaces (Fig. 9). This has resulted in steady biodiversity loss in the area during the last few years. The increase in habitation areas have also resulted in overexploitation of river water for domestic as well as commercial purposes. Wastewater is added back to the system without any treatments leading to deterioration of water quality. Freshwater resources have depleted in the area steadily. Groundwater contamination is another emerging issue from the study area concerned. Therefore, the current holistic study was much needed.

3.4. Spatio-temporal comparison of Digital Elevation Models (DEMs)

In order to examine the increase in spatial resolution of satellite images from Landsat 4 to Landsat 7 (30 m), middle and high resolutions images from Landsat 8 and Resourcesat 2A (15 m and 5.8 m) of Digital Elevation Models, the attraction model was used. The results of the models for 30 m, 30 m, 30 m, 15 m and 5.8 m are illustrated in Fig. 10. The association of DEMs (1980, 1988, 1998, 2008 and 2018) as ideas in the attraction models determined that DEM 5.8 m (Resourcesat 2A satellite image) has better spatial resolution than 30 m images of Landsat data series. As is represented in Fig. 8, with the intensification of the value of scale factor, the sub-pixel increases more than principal pixel and variations among the elevation models are shown well. So, it can be concluded that the increases of the scale case lead to the increase in the spatial resolution. DEM helps in creating realistic models of flow patterns and networks of the drainage basin (Pan, et al., 2019). Compared to the original DEM, the computation efficiency has been improved significantly and similar findings were reported earlier (Mokarrama and Hojati, 2017). DEM can be used for increasing spatial resolution of the study area. Previous findings are in agreements with the current study which further authenticate the importance of the study (Pan et al., 2019; Liu et al., 2019).

3.5. Diversity of flora found in the upper catchment of Narmada river

Structure and composition of many vegetations, having immense commercial and economic values, have been identified. The tribal communities know the proper use of medicinal plants in health care and other uses. In current study, we reported 157 plants species (herbs, tubers, grasses, climbers) comprising a total of 47 overstorey species and 86 groundstorey vegetation. There were 24 understorey vegetation reported which are traditionally utilized by local tribal communities of upper catchment area of Narmada river (Table 7). The species diversity values of AABR were lower as compared to diversity indices values reported earlier (Thakur, 2018). This study conclusively proves the extinction various plant species due to different kinds of interferences like habitation, degradation, fragmentation, constructions, encroachments, introduction of exotic species and monoculture. Several studies have identified similar ecological consequences in tropical forest ecosystems (Thakur, 2007; Thakur et al., 2014, 2017; Brar et al., 2020). Due to population pressure, forest wealth is over exploited and mixed forests are reducing. There is ever increasing developmental pressure on forest especially upper catchment areas of Narmada River. Adverse impacts of mining are degrading forests as well.

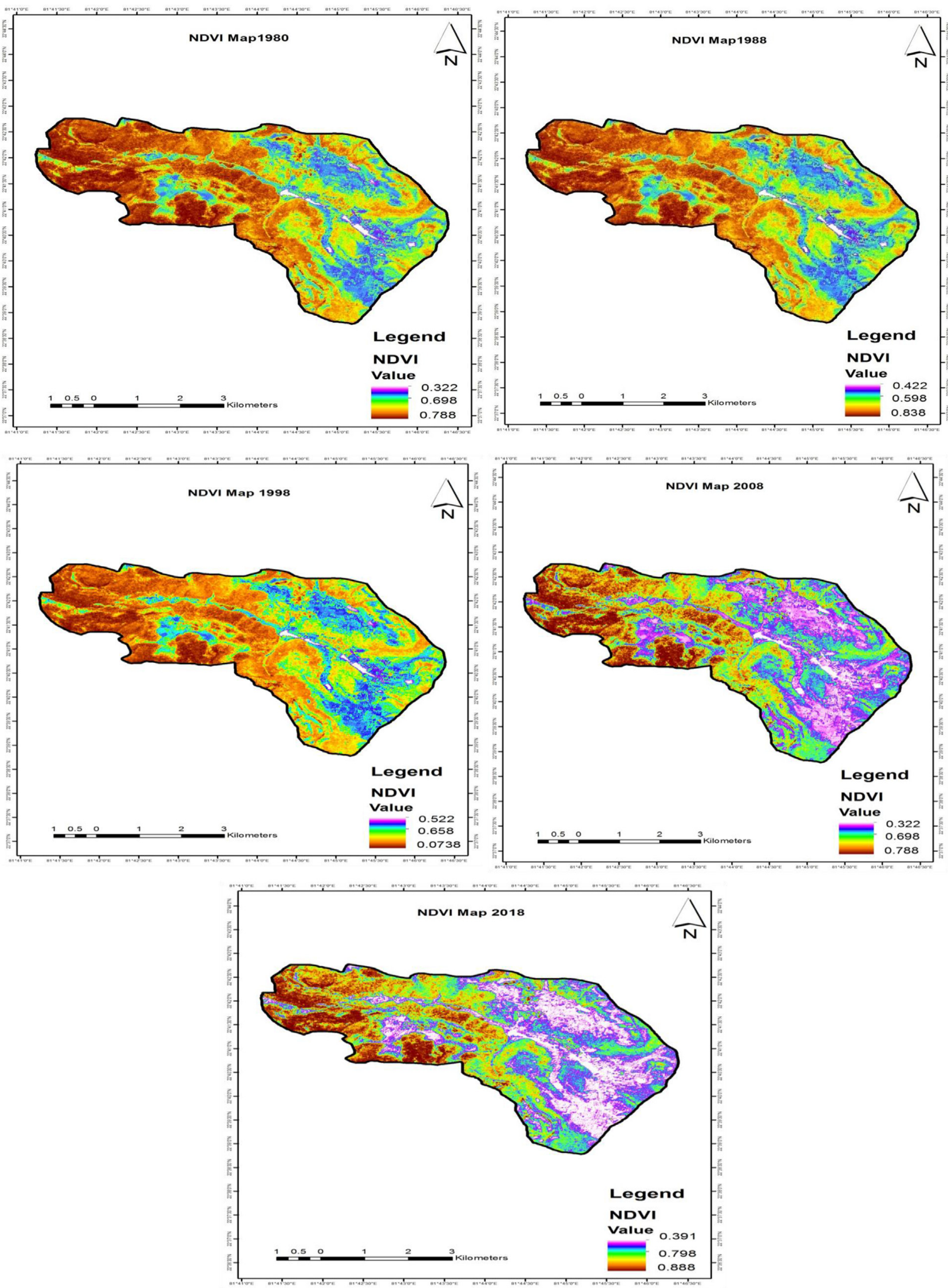

Fig. 6. Normalized difference vegetation index maps of the study area during 1980 to 2018.

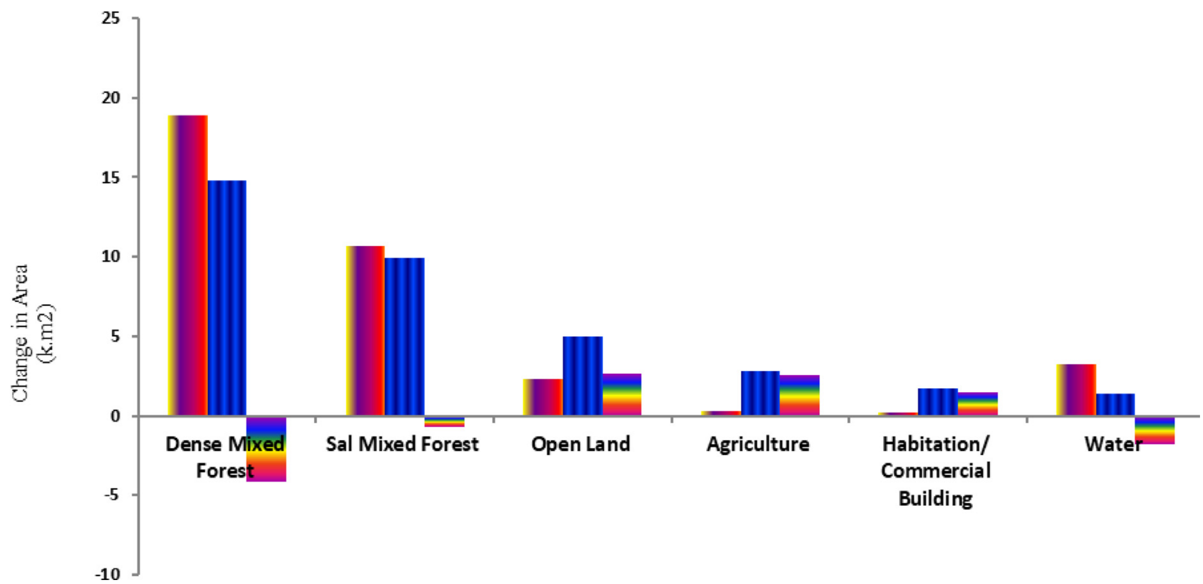

Fig. 7. Change Detection pattern of various LC classes during assessment period 2018 Vs 1980 (km^2)

Table 4
Pattern of LULC changes in the upper catchment area of Narmada river between 1980 and 2018.

Change From	Changed to	Percentage Change			
		1980–1988	1988–1998	1998–2008	2008–2018
Dense Mixed Forest	Sal Mixed Forest	2.8	0.99	1.5	0.1
	Open Land	0.25	0.69	1.3	0
	Agriculture	0	0.14	0.98	0.41
	Habitation/Commercial Building	0.5	0	1.47	0.56
	Water	0	0	0.29	0.74
Sal Mixed Forest	Dense Mixed Forest	0	0	0	0
	Open Land	0.75	0	1.86	0
	Agriculture	0	0	1	0
	Habitation/Commercial Building	0	0	1.50	0
	Water	0	0	0.29	0
Open Land	Dense Mixed Forest	0	0	0	0
	Sal Mixed Forest	0	0	0.45	0.58
	Agriculture	0	0	0	0.71
	Habitation/Commercial Building	0	0	0	0.15
	Water	0	0	0.36	0.48
Agriculture	Dense Mixed Forest	0	0	0	0
	Sal Mixed Forest	00	0	0	0
	Open Land	0	0	0.11	0.19
	Habitation/Commercial Building	0	0	0	0
	Water	0	0	0	1.10
Habitation/Commercial Building	Dense Mixed Forest	0	0	0	0
	Sal Mixed Forest	0	0	0	0
	Open Land	0	0	1.5	1.98
	Agriculture	0	0	0	0
	Water	0	0	0.47	0.45
Water	Dense Mixed Forest	0	0	0	0
	Sal Mixed Forest	0	0	0	0
	Open Land	0	0	0	0
	Agriculture	0	0	0.25	0.38
	Habitation/Commercial Building	0	0.58	0.98	1.25

4. Conclusion

The study infers that satellite based remote sensing and GIS techniques are indeed the most reliable tools for the characterization of land use along the river basin of the concerned study area. One of the most important features of Narmada and its tributaries such as Gayatri, Savitri, Kapila, Baitarini, Arandi emerging from Amarkantak region is that all of them are fed by rain water. Ample rainfall is therefore positively correlated to the existence of these rivers which develops the core idea of sustenance in the region. These rivers originate from Maikal mountain range are under threat due to natural as well as anthropogenic causes as listed above. Holistic development guided by eco-restoration strategies is the need of the hour. Lack of monitoring and scientific approaches can bring a death blow to these rivers. The upper zone of the Narmada is very important from ecological viewpoint and needs urgent attention. The entire riparian ecosystem is dependent on good forest cover for sustainability. Vegetation mapping using NDVI reveals shrinking forest cover and degradation in forest health over the years. The anthropogenic stress factors such as increase in commercial zones, utilization of river water for irrigation purposes, agricultural run-off, industrial effluents, domestic

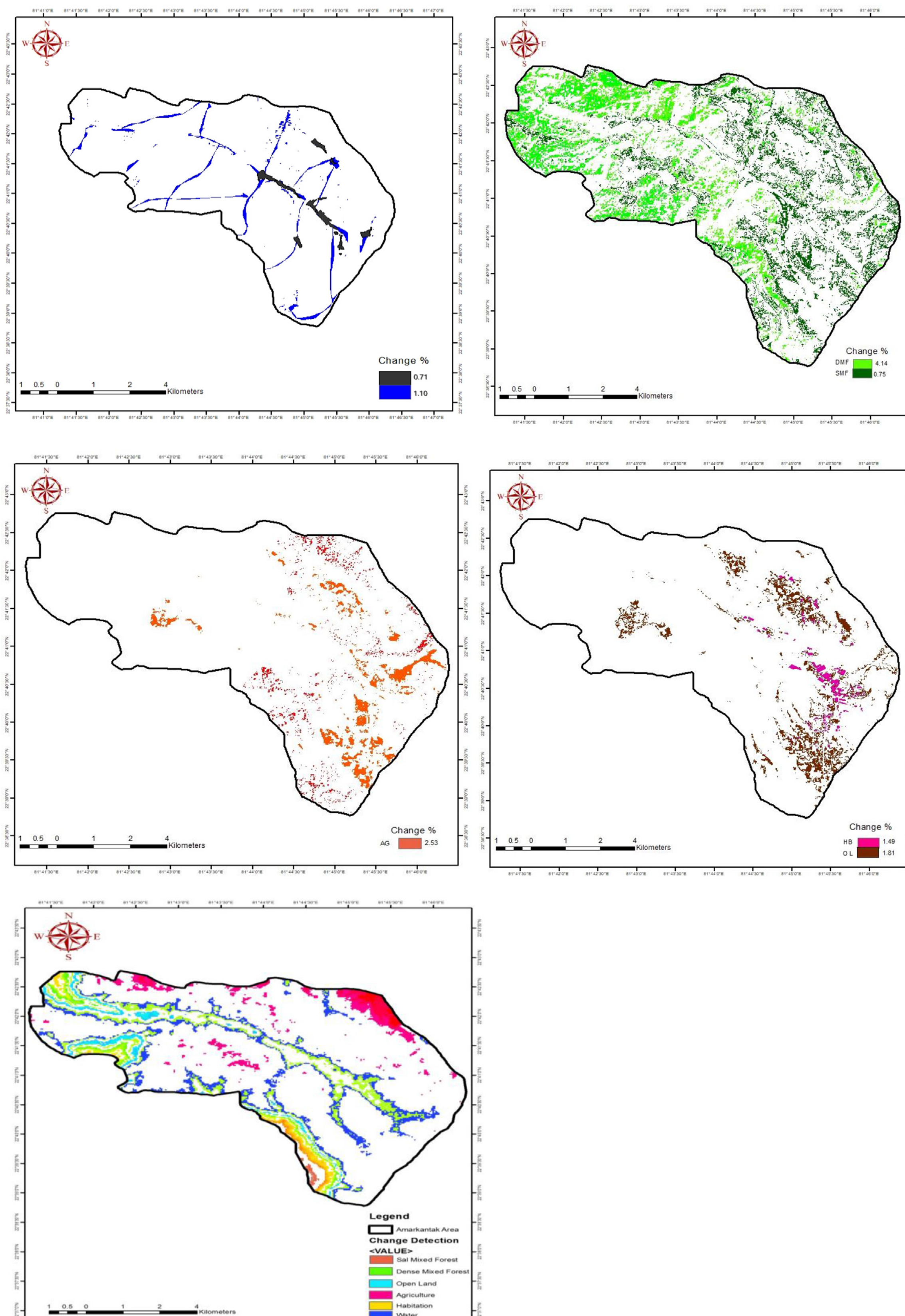

Fig. 8. Spatial distribution of land use land cover changes at upper catchment area of Narmada River between 1980 and 2018; (A) Waterbodies, (B) Forest type, (C) Agriculture, (D) Rural areas, (E) All LULC classes. Unchanged areas are shown in white.

Table 5
Summary of Accuracy assessment

Maps	1980	1988	1998	2008	2018
Overall accuracy (%)	85.95	87.06	91.86	93	97
Kappa	0.85	0.87	0.83	0.92	0.97

Table 6
Change matrices calculation of upper catchment area of Narmada river during 1980–2018

2018								
		Water bodies	Sal mixed forest	Dense mixed forest	Open Land	Agriculture	Habitation	Total
1980	Water bodies	0	4	4	0	0	0	8
	Sal mixed forest	1054	634	9634	102	49	4	11,477
	Dense mixed forest	0	59	59	523	47	47	735
	Open Land	1521	523	7723	489	0	0	10,256
	Agriculture	244	9392	1492	924	130	113	12,295
	Habitation	247	0	0	302	3	53	605
	Total area (histogram Value)	3066	10,612	18,912	2340	229	217	35,376
	Total area (km^2)	3.2	10.65	18.92	2.34	0.29	0.21	35.61

Fig. 9. Images from Study Area: Deterioration of health of Narmada River.

exploitation of water resources, municipal sewage and sludge mixing with flowing water are the major factors behind the degradation of forest health which is causing negative impact on the entire environment. LULC analysis also supports these findings.

The study also reveals that Digital Elevation Model (DEM) is very useful in studying the topography within a GIS environment. Geomorphic analysis of an area is based on the systematic study of present-day landforms which can be related to their origin, nature, development, geologic changes and their relationship with other underlying structures. The technology has been effectively and economically used in the analysis and inventory of basin area development and management. The scientific investigation proves the vulnerability of Narmada and her tributaries. Relief ratio, ruggedness number and visual interpretation of the DEM of the study area indicate moderate to high relief, low run off and high infiltrations with the early mature stage of erosion.

The identification of rare, endangered and threatened species is essential for prioritization of conservation in the upper catchment area of Narmada. Application of geospatial techniques will be exploited for the expansion of spatial data sets that is quite necessary for the conservation of the forest ecosystem with sustainable approach. Further, the field surveys in selected villages help in gathering information on ground realities of socio-economic status and also traditional methods, and uses of forests produces. Finally, the study documented a total of 157 species potentially exploited and utilized by aboriginal communities of

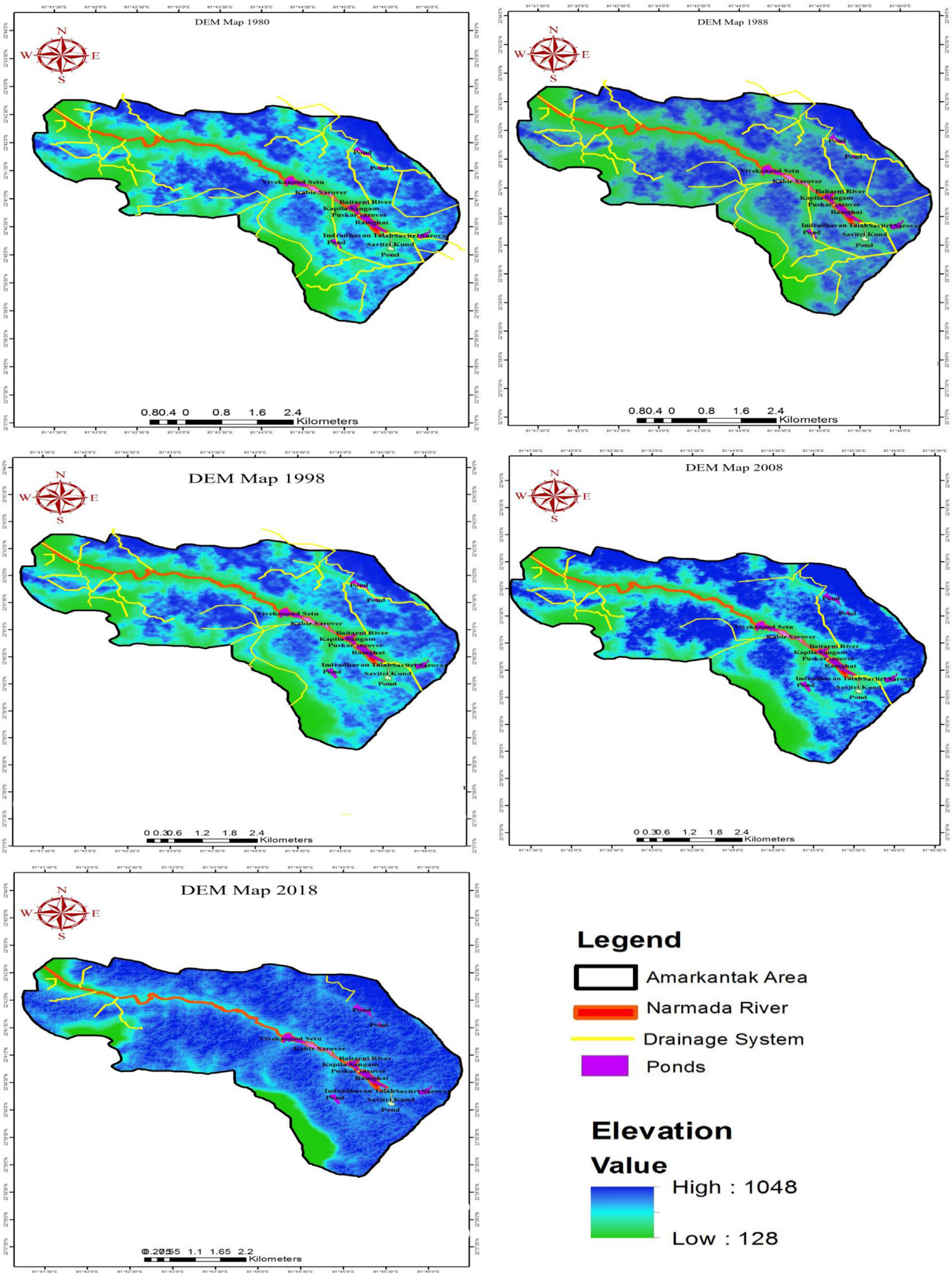

Fig. 10. Digital elevation models of the upper catchment area of Narmada River during 1980–2018.

upper catchment area of Narmada in Central India. Study highlighted the unsustainable and overexploitation of resources leading to forest degradation as well. Therefore, appropriate management interventions were suggested to conserve the susceptible species as well as associated rivers of Narmada by involving the indigenous communities.

Table 7
List of the overstorey, understorey and groundstorey vegetation of upper catchment area of Narmada River with their uses

S. No.	Common name	Scientific name	Family	Parts used	Uses
1.	Bel	*Aegle marmelos*	*Rutaceae*	Fruit Leaf	Edible, Medicinal, Religious
2.	Dhabda	*Anogeissus latifolia*	*Combretaceae*	Stem Resin	House construction, Fuel wood, Agriculture implement
3.	Mohline	*Bauhinia purpurea*	*Caesalpiniaceae*	Leaf Flower	Cup and plate making, Medicinal
4.	Semel	*Bombax ceiba*	*Malvaceae*	Fruit Flower	Medicine, Edible
5.	Salei	*Boswellia serrata* Roxb.	*Burseraceae*	Resin	Medicine
6.	Chironji	*Buchanania lanzan*	*Anacardiaceae*	Fruit seed	Edible
7.	Khakra	*Butea monosperma*	*Fabaceae*	Leaf	Cup and plate making
8.	Kumbhi	*Careya arborea*	*Lecythidaceae*	Bark	Fish poisoning
9.	Amaltash	*Casia fistula*	*caesalpinaceae*	Fruit	Medicinal
10.	Mahalimb	*Cedrela toona* Roxb.	*Meliaceae*	Stem	Furniture
11.	Ghiriha	*Chloroxylon swietenia*	*Rutaceae*	Stem Bark	House Construction, Agricultural implements, Fuel wood, Fish
12.	Karra	*Cleistanthus collinus*	*Euphorbiaceae*	Stem	Furniture
13.	Sita phal	*Custard apple*	*Annonaceae*	Fruit Stem	Edible House Construction Agricultural implements, Fuel wood
14.	Shisham	*Dalbergia sisoo*	*Leguminosae*	Stem Leaf	House Construction, Agricultural Implements, Fuel Wood, Medicinal
15.	Gulmohar	*Delonix regia*	*Leguminosae*	Stem	Fuel wood
16.	Dhoben	*Dillenia pentagyna* Roxb.	*Dilleniaceae*	Root	Medicinal
17.	Tendu	*Diospyros melanoxylon* Roxb.	*Ebenaceae*	Fruit Leaf	Edible (When ripe) Selling
18.	Bargad	*Ficus benghalensis*	*Moraceae*	Fruit	Edible
19.	Peepal	*Ficus religiosa*	*Moraceae*	Whole tree Fruit Leaf	Religious Edible Fodder
20.	Kekad	*Garuga pinnata* Roxb.	*Burseraceae*	Stem	Agricultural implements
21.	Lendia	*Lagerstroemia parviflora* Roxb.	*Lythraceae*	Stem	Firewood Boundary wall making
22.	Maida	*Litsea sebifera*	*Lauraceae*	Bark	Medicinal
23.	Mahua/Guli	*Madhuca indica*	*Sapotaceae*	Flower Fruit Leaf	Edible after cooking Liquor preparation Oil Religious
24.	Aam	*Mangifera indica*	*Anacardiaaceae*	Fruit Seed	Edible Edible, medicinal
25.	Munga	*Moringa pterygosperma* Gaertn.	*Moringaceae*	Leaf Fruit	Edible Edible
26.	Amla	*Phyllanthus emblica*	*Euphorbiaceae*	Fruit Leaf	Edible and medicinal Cultural and medicinal
27.	Kanji	*Pongamia pinnata*	*Fabaceae*	Fruit	Oil extraction
28.	Bija	*Pterocarpus marsupium* Roxb.	*Faabaceae*	Stem	House construction Furniture
29.	Kusum	*Schleichera trijuga* Willd.	*Sapindaceae*	Fruit	Edible
30.	Bhelwa	*Semicarpus anacardium*	*Anacardiaceae*	Fruit	Edible, Medicinal
31.	Sarai	*Shorea robusta* Gaertn.	*Dipterocarpaceae*	Stem	House construction, Furniture, Fuel wood, Tooth brush, oil
32.	Gulhar/kullu	*Sterculia urens*	*Sterculiaceae*	Resin Bark	Medicinal
32.	Jamun	*Syzygium cumini*	*Myrtaceae*	Stem Fruit Leaf	Cultural, Edible, medicinal
34.	Emli	*Tamarindus indica*	*Caesalpiniaceae*	Fruit	Edible, Pickle preparation, Medicinal, Selling
35.	Sagaun	*Tectona grandis*	*Lamiaceae*	Stem Leaf	House construction, Furniture Furniture, Dona making
36.	Arjun	*Terminalia arjuna*	*Combretaceae*	Stem	Firewood, House construction
37.	Beheda	*Terminalia bellirica*	*Combretaceae*	Fruit	Medicinal (Digestive)
38.	Harra	*Terminalia chebula*	*Combretaceae*	Fruit	Medicinal (Digestive)
39.	Saja	*Terminalia tomentosa*	*Combretaceae*	Stem	House construction, Fuel wood, Used during marriage
40.	Kala Umbar	*Ficus hispida* L.f.	Moraceae	Fruits	Fruits, vegetable
41.	Alu Bukhara	*Flacourtia indica (Burm.f.) Merr.*	Salicaceae	Fruit	Fruit - raw or cooked
42.	Phalsa	*Grewia asiatica L*	Malvaceae	Fruit	The fruit can be eaten raw,
43.	Jungli sami, Khejri	*Prosopis cineraria*	Fabaceae	Fruit	Leaves and fruit eaten
44.	Kadam	*Anthocephalous kadamba*	Rubiaceae	Fruits	Ripe fruits eaten
45.	Kaji, Kinu	*Bridelia retusa* (L.) A.Juss	*Phyllanthaceae*	Fruit, Bark, Flowers	Ripe fruit pulp
46.	Wild kajur	*Phoenix sylvestris* (L.) Roxb.	Arecaceae	Fruit	Ripe fruits eaten
47.	Neem	*Azadirachta indica* A.Juss.	Meliaceae	Fruit	Pulp of ripe fruits eaten
48.	Ghughch	*Abrus precatorius*	*Fabaceae*	Leaves	Mouth freshener
49.	Bans	*Bambusa* bamboo	*Poaceae*	Seeds	mix into flour
50.	Chakor	*Cassia tora*	*Caesalpiniaceae*	Pod and seed	Vegetable
51.	Ratan jot	*Jathropa curcus*	*Euphorbiaceae*	Seed, Whole plant	Biofuel, Substitute of candle Bio-fencing
52.	Lantana	*Lantana camara*	*Verbenaceae*	Ripen fruits Whole plant	Edible Bio-fencing
53.	Khajuri	*Phoenix sylvestris*	*Arecaceae*	Ripen fruits	Edible.
54.	Mainhar	*Randia dumetorum*	Rubiaceae	Leaf Root	Vegetable Medicinal
55.	Arandi	*Ricinis communis*	*Euphorbiaceae*	Seed	Oil
56.	Nirgundi	*Vitex nigundo*	*Verbenaceae*	Leaf	Medicinal
57.	Ber	*Zizipus zilopyrus*	*Rhamnaceae*	Fruit	Edible
58.	Aak	*Calotropis gagentia*	Musaceae	Leaf & flower	Offer to god
59.	Banana	*Musa paradisca*	Lythraceae	Whole tree	Religious use
60.	Mehandi	*Lawsonia irnemis*	family	Leaf	Dye
61.	Sitaphal	*Annona squamosa* L.	Annonaceae	Fruit	Ripe fruits eaten
62.	Karonda	*Carissa carandas L.*	Apocynaceae	Fruit	Ripe fruits eaten & pickled

Table 7 (*continued*)

S. No.	Common name	Scientific name	Family	Parts used	Uses
63.	Chota ber	*Zizyphus martuiana Lam*	Rhamnaceae	Fruit	Ripe fruits eaten
64.	Dhavai	*Woodfordia floribunda* (L.). Kurz.	Lytharaceae	Flowers	Flowers are eaten as food
65.	Raimuniya	*Lantana camara L.*	Verbenaceae	Fruit	Ripe fruits eaten
66.	Makora	*Ziziphus oenophylla Lam.*	Rhamnaceae	Fruits	Eaten by children
67.	Kathber, Baraber	*Ziziphus xylopyrus* (Retz.) Willd.	Rhamnaceae	Fruits	Eaten and used as drug
68.	Bilangada	*Flacourtia indica* (Burm.f.) Merr.	Salicaceae	Fruits	Raw eaten or cooked
69.	Kiraman	*Grewia rothii DC.*	Malvaceae	Bark	Medicinal
70.	Beli	*Limonia crenulata (Roxb.) Roem*	Rutaceae	Fruit	Eaten
71.	Munya	*Meyna spinosa Roxb.*	Rubiaceae	Fruit	Raw eaten
72.	Gajar ghas	*Parthenium hysterophorus* L.	*Asteraceae*	Seeds	Medicinal
73.	Kubbi	*Ageratum conyzoide* L.	*Asteraceae*	Leaves	Medicinal
74.	Kurie	*Bidens pilosa* L.	*Asteraceae*	Leaves	Medicinal
75.	Safed munga	*Celosia argentea* L.	*Amaranthaceae*	Leaves, Fruit	Medicinal & Vegetable
76.	Bhrangraj	*Eclipta alba*) Hassk. L)	*Asteraceae*	Oil	Medicinal
77.	Kutki	*Panicum antidotale* Retz.	*Poaceae*	Leaves	Food
78.	Grass lily	*Iphigenia indica*.L) A. Gray ex Kunth)	*Poaceae*	Leaves	Fodder
79.	Meethi buti	*Scoparia dulcis* L.	*Plantaginaceae*	Leaves, Seeds	Medicinal
80.	Naichi bhaji	*Smithia conferta* Sm.	*Fabaceae*	Leaves	Vegetable
81.	Kanghi	*Blainvillea acmella* (L.) Philipson	*Asteraceae*	Leaves	Medicinal
82.	Soli	*Aeschynomene americana* L.	*Leguminosae*	Seeds/grains	Grain edible
83.	Dudhali	*Sopubia delphinifolia* G.	*Scrophulariaceae*	Leaves, Seeds	Medicinal
84.	Akarkara	*Spilanthes paniculata* Wall. ex DC.	*Asteraceae*	Inflorescences	Medicinal
85.	Bhui amla	*Phyllanthus niruri* L.	*Euphorbiaceae*	Whole plants	Medicinal
86.	Doodhi	*Euphorbia heterophylla* Des F.	*Euphorbiaceae*	Leaves	Medicinal
87.	Pulpuli grass	*Arthraxon hispidus* (T. Makino)	*Poaceae*	Leaves	Fodder
88.	Satawar	*Asparagus racemosus* Willd.	*Liliaceae*	Roots/Tubers	Medicinal
89.	Haddi mushli	*Chlorophytum borivilianum* Santapau & R. R. Fern.	*Asparangaceae*	Tubers	Medicinal
90.	Ghughunia	*Crotalaria retusa* L.	*Leguminosae*	Leaves	Food
91.	Pihri chara	*Mecardonia procumbens* Mil Small	*Scrophulariaceae*	Leaves	Fodder
92.	Satparni	*Desmodium gangeticum* L.	*Fabaceae*	Leaves	Medicinal
93.	Kharatti	*Sida acuta* Burm. f.	*Malvaceae*	Leaves	Medicinal
94.	Sitab	*Ruta graveolens* L.	*Rutaceae*	Leaves	Medicinal
95.	Mameera	*Thalictrum foliolosum* DC.	*Rananculaceae*	Leaves	Medicinal
96.	Bathua bhaaji	*Chenopodium album* L.	*Chenopodiaceae*	Leaves	Vegetable
97.	Patthar choor	*Plectranthus mollis (A)* Spreng.	*Lamiaceae*	Roots/Tubers	Medicinal
98.	Bariyari	*Sida cordata* (Burm. f.) Borss. Waalk.	*Malvaceae*	Leaves	Medicinal
99.	Hirankhuri	*Emilia sonchifolia* (L.) DC. ex DC.	*Asteraceae*	Fruits	Medicinal
100.	Badranj boya	*Nepeta cataria* L.	*Lamiaceae*	Seeds	Medicinal
101.	Kevkand	*Dioscorea bulbifera* L.	*Dioscoreaceae*	Suckers/Tuber	Medicinal
102.	Kali mushli	*Curculigo orchioides* Gaertn	*Agavaceae*	Suckers/Roots	Medicinal
103.	Tinpaniya	*Oxalis corniculata* L.	*Oxalidaceae*	Leaves	Medicinal & Vegetable
104.	Maskani	*Evolvulus nummularius* L	*Convolvulaceae*	Leaves	Medicinal
105.	Chanchu	*Corchorus fascicularis* Lam.	*Tiliaceae*	Leaves	Food
106.	Kena	*Commelina diffusa* Burm. f.	*Commelinaceae*	Roots/tubers	Medicinal
107.	Kharmor	*Rungia pectinata* L.	*Acanthaceae*	Leaves/shoots	Medicinal
108.	Ghueen	*Fimbristylis littoralis* Gaudich.	*Cyperceae*	Roots/leaves	Medicinal
109.	Nagar motha	*Cyperus gracilis* R. Br.	*Poaceae*	Leaves, roots	Fodder and Commercial products
110.	Bufalo grass	*Paspalum conjugatum* P. J. Bergius	*Poaceae*	Leaves	Fodder
111.	Baiga sikiyab	*Digitaria divaricatissima* R. B) Hughes)	*Poaceae*	Leaves	Fodder
112.	Jangli marua	*Eleusine indica*) Gaert).	*Poaceae*	Leaves	Fodder
113.	Dokar bel	*Vitis carnosa* Lam Wall.	*Vitaceae*	Leaves/Fruits	Medicinal
114.	Chhuimui	*Mimosa pudica* L.	*Fabaceae*	Leaves	Medicinal
115.	Nuniya bhaji	*Portulaca oleracea* L.	*Portulaceae*	Leaves	Vegetable
116.	Kanthkari	*Solanum xanthocarpum* Schrad. & H. Wendl.	*Solanaceae*	Leaves	Medicinal
117.	Jungli sama	*Echinochloa colona* Link	*Poaceae*	Seeds grains	Grain edible
118.	Amti	*Solanum nodiflorum* Jacq.	*Solanaceae*	Fruits	Vegetable
119.	Chirchita	*Achyranthes aspera* L.	*Amaranthaceae*	Seeds, leaves	Medicinal
120.	Ghooma	*Leucas aspera* Willd	*Lamiaceae*	Leaves	Vegetable
121.	Kaniya kanda	*Dioscorea oppositifolia* L.	*Dioscoreaceae*	Tubers	Medicinal
122.	Chench	*Corchorus trilocularis* L.	*Tiliaceae*	Leaves	Vegetable
123.	Chanahur	*Marsdenia tenacissima* Roxb.	*Asclepiadaceae*	Leaves	Vegetable
124.	Van rai	*Blumeopsis flava* D Gagnep.	*Asteraceae*	Seeds, Leaves	Medicinal, vegetable
125.	Tikhur	*Curcuma angustifolia* Roxb.	*Zingiberaceae*	Tuber	Medicinal
126.	Mandukparni	*Centella asiatica* L.	*Apiaceae*	Leaves	Medicinal
127.	Ghuia	*Colocasia esculenta* L Schott.	*Araceae*	Leaves, Rhizomes	Vegetable
128.	Kev kand	*Costus specios* J. Koen Sm.	*Zingiberaceae*	Tuber	Medicinal
129.	Amahaldi	*Curcuma amada* Roxb.	*Zingiberaceae*	Tuber	Medicinal
130.	Jungli dhania	*Eryngium foetidum* L.	*Apiaceae*	Leaves, Seeds	Vegetable
131.	Bisakhpara	*Boerhavia procumbens* Banks ex Roxb.	*Nyctaginaceae*	Leaves	Vegetable
132.	Badi dudhi	*Euphorbia hirta* L.	*Euphorbiaceae*	Leaves	Medicinal

(*continued on next page*)

Table 7 (*continued*)

S. No.	Common name	Scientific name	Family	Parts used	Uses
133.	Chhoti dudhi	*Euphorbia macrophylla* Pax	*Euphorbiaceae*	Leaves	Medicinal
134.	Bara	*Flemingia chappar* Benth.	*Fabaceae*	Shoots	Lac
135.	Bedarikand	*Coccinia grandis* Voigt	*Cucurbitaceae*	Climber	Edible
136.	Kalihari	*Gloriosa superba* L.	*Colchicaceae*	Climbers, Flower	Medicinal
137.	Kheksa	*Momordica dioica Roxb*	*Cucurbitaceae*	Climber	Vegetable
138.	Karmata	*Ipomoea aquatica* Forssk.	*Convalvulaceae*	Leaves	Vegetable
139.	Jungle kevanch	*Mucuna pruriens L.*	*Papilionaceae*	Seeds	Medicinal
140.	Jangli pyaj	*Urginea indica* Roxb	*Liliaceae*	Tuber	Medicinal
141.	Chirula	*Aerva lanata* L.	*Amaranthaceae*	Leaves	Medicinal
142.	Chirinya	*Peristrophe roxburghiana* Roem & Schult	*Acanthacea*	Leaves	Medicinal
143.	Garundi	*Alternanthera sessilis L.*	*Amaranthaceae*	Leaves	Medicinal
144.	Jungli rye	*Sisymbrium nigrum* Prantl	*Cruciferae*	Seeds	Vegetable
145.	Jangli Tulsi	*Ocimum gratissimum* L.	*Lamiaceae*	Seeds, Leaves, Inflorescences	Medicinal
146.	Chirpoti	*Physalis minima* L.	*Solanaceae*	Fruits	Fruit edible
147.	Sarpgandha	*Rauvolfia serpentine* L Benth. ex Kurz	*Apocynaceae*	Seeds	Medicinal
148.	Sadabahar	*Catharanthus roseus* L G. Don	*Apocynaceae*	Flowers	Medicinal
149.	Brahmi	*Bacopa monnieri* L Wettst.	*Plantaginaceae*	Whole plants	Medicinal
150.	Tulsi	*Ocimum sanctum* L.	*Lamiaceae*	Seeds, Leaves, Inflorescences	Medicinal, Religious use
151.	Chirayta	*Swertia alba* T. N. Ho & S. W. Liu	*Gentianaceae*	Whole plants	Medicinal
152	Aswagandha	*Withania somnifera* Dunal	*Solanaceae*	Suckers, leaves	Medicinal
153.	Chand kal	*Macaranga peltata* Roxb Müll. Arg.	*Euphorbiaceae*	Leaves	Medicinal
154.	Chaulai	*Amaranthus spinosus* L.	*Amaranthaceae*	Leaves	Vegetable
155.	Tiger lily	*Belamcanda chinensis* L. DC.	*Iridaceae*	Tubers	Medicinal
156.	Buch	*Acorus calamus* L.	*Acoraceae*	Rhizomes, Oil	Medicinal
157.	Mandukparni	*Centella asiatica* L.	*Plantaginaceae*	Whole plants	Medicinal

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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