# AN EXPLORATIVE ANALYSIS OF LAND USE LAND COVER CHANGES AND HYDROMETEOROLOGY OF THE VAIGAI RIVER BASIN, INDIA

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(Received 4th Aug 2022; accepted 19th Jul 2023)

**Abstract.** The impact of land use and land cover changes (LULCC) is one of the major contributors to increasing greenhouse gas emissions to the atmosphere. At the terrestrial surface, the impact of LULCC is realized in altered hydrology. Conversion of cultivable lands into fallow lands severely affects crop production in agriculturally dominant basins such as the Vaigai River Basin (VRB) in Tamil Nadu, India. Considered as a granary of South Tamil Nadu, any LULCC in VRB results in uncertainty in food production. Therefore, in this study, Landsat images were used to evaluate changes in land use and MODIS NDVI images to estimate changes in browning and greening in VRB during 2001-2020. We also analyzed the rainfall and river discharge in the basin to understand the variations from 2001 to 2019 concerning LULCC. The results showed an increase of seventy-seven percent in fallow lands between 2010 and 2020 and a forty-one to fifty-nine percent increase in urban settlements between 2001 and 2020 in the basin. The impacts of LULCC were realized in monsoon rainfall with no change in river discharge in the lower Vaigai Basin. The study results will aid regulated land use planning and encourage further research on feedback between terrestrial and atmospheric water fluxes for ensuring food security.
**Keywords:** *agricultural basin, Landsat, change maps, MODIS-NDVI, seasonal rainfall, river discharge*

## Introduction

Semi-arid or arid climatic zones are vulnerable to water scarcity due to their hot climate, higher evapotranspiration, and dependency on rainfall. Dependency on rain forced humans to migrate near the water resources to cultivate food grains. The advent of technologies to extract water from faraway sources, such as reservoirs in headwater regions and groundwater, led to intense land use and land cover changes (LULCC). These LULCCs cause unregulated use of water resources and deplete them. For instance, an increase in a built-up area leads to the withdrawal of groundwater to meet domestic and industrial demands, resulting in its overexploitation. The impact of such changes is realized on the entire ecosystem and the socio-economic growth of lives that depend on it (Martellozzo et al., 2018; Srivastava and Chinnasamy, 2021). Land degradation can be mitigated by improvised agricultural methods, but the consequences on the water regime are irreversible. Furthermore, the effects of climate change intensify the water scarcity in basins (Awotwi et al., 2017; Mahadevan and Ramaswamy, 2020). This natural and human-induced water scarcity threatens food productivity in agriculturally dominated basins.

On a global level, an increase in carbon dioxide in the atmosphere and emission of other greenhouse gases are the major impacts of land use and land cover changes (Cheruto et al., 2016). Differences in photosynthetic rates and water use of native and invaded plant species cause changes in greenhouse gas emissions and terrestrial water cycles (del Rosario Uribe and Dukes, 2021). LULCC, particularly urbanization, leads to the loss of cultivable areas and increased fallow lands, resulting in food insecurity (Truong et al., 2018). When food crops are replaced by transpiring or non-transpiring landcover, water distribution is altered. The cycle continues with anomalies in rainfall patterns due to terrestrial water storage (Duerinck et al., 2016). This results from a reduction in evapotranspiration to the atmosphere and reduces the cumulative available potential energy (Pielke et al., 2007; Paul et al., 2016). Changes in cumulative available potential energy, which are associated with fluctuations in surface temperature sensible heat fluxes, cause extreme rainfall conditions (Kar and Liou, 2019; Boyaj et al., 2020).

The feedback loop eventually raises uncertainty in rainfall patterns and extremes, the regularity of which is essential in agriculturally dominated areas, particularly in semi-arid catchments. The Vaigai River Basin (VRB) is one of these basins, spanning 7153 $km^2$ over five districts in Tamil Nadu, India. The Vaigai river is located in the state of Tamil Nadu, India. The non-perennial Vaigai river flows for about 295.11 km towards Palk Strait before twisting south-east and passing through Madurai before draining into Palk Strait in Ramanathapuram district of Tamil Nadu.

Cash crops such as tea, coffee, and sugarcane are also grown due to the mixed hilly and plain terrain characteristics, with the highest elevation of 2600 m in the upper Vaigai region. As the granary of South Tamil Nadu (Arumugam and Charles, 2016), any loss of land cover leads to food insecurity in the region if proper land-use planning is not enforced. The rainfall pattern in the basin is highly variable, with higher rainfall in the upper catchment areas. As per DoE (2015), the VRB has a mean annual rainfall of 970 mm (48% during the north-east monsoon, 33% during the south-west monsoon, 14% in the summer, and 5% in the winter) and over the ten years from 1995-1996 to 2005-2006, the contribution of rainfall from the north-east monsoon grew from 34% to 63%, whereas rainfall from the south-west monsoon declined from 48% to 24%. This short-term decadal change is worth evaluating with respect to the change in catchment land use landcover, particularly for the intensification of agricultural practices that increased the crop yield by 50%. In comparison, the net sown area of the basin declined by 14% from pre-liberalization 1975 to post-liberalization 2006 (Palanisami et al., 2011). It has been evidenced from the literature that the change in land use from forest to agricultural land increases carbon emissions into the atmosphere (Lamb et al., 2021; Tubiello et al., 2021). The increase in carbon emissions subsequently increases the land


http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2105_46154632

surface temperature. It amplifies climate change, as Silvério et al. (2015) concluded based on a ten-year study from 2000 to 2010 in the Xingu region of southeast Amazonia. A similar study by Thomas et al. (2015), who analyzed daily maximum rainfall in Narmada Basin, India, found an increased number of days of rainfall and areas receiving high-intensity rainstorms in the 20 years from 1989-2008. Therefore, land use land cover and climate change studies focusing on decadal or less than 30 years of data and its driving forces are noteworthy to understand the impact of recent changes in the physiohydrology of catchments.

To implement optimal land, soil, and water resource management in the basin, it is necessary to understand the chronological changes in the land use and land cover and its effects on water distribution. The physiography of the VRB is particularly unusual, with 1497 tanks (*Fig. 1*), 35% of which are system tanks in the lower section of the basin area. As a result, the catchment hydrology is quite active, with 55,726 ha of system tankfed farmland and 14,619 ha of non-system tankfed cultivation. The flow accumulation occurs at different locations, such as tanks in the basin, as shown by the multimodal wetness index calculated from topography (*Fig. 1*). As a result, analyzing LULCC in terms of physio-hydrographic characteristics such as a change in flow accumulation area could aid in the creation of management methods to sustain agricultural productivity in the basin.

Hence, the impact of land-use change in rainfall and river discharge in the basin was studied using land use and hydrometeorological time series. From understanding the changes in hydrometeorology concerning land-use change, the results of this study will be beneficial in the effective use of land in the basin to sustain its water distribution and productivity. The study will also provide a comprehensive understanding of the weather anomalies concerning land use in a basin.

The objectives of the study are, therefore,

- Studying the land use and land cover change from 2001-2020
- Evaluating conversion of land using greening and browning indices
- Evaluation of impacts of land-use change on characteristics of rainfall and river discharge in the basin.

## Materials and methods

### *Data used*

The USGS Earth Explorer was used to gather data from the Landsat 4-5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) for the study years 2001, 2010, and 2020. The captured scenes have been level-1 terrain-corrected (i.e., relief displacements have been rectified using ground control points and a digital elevation model), making them ideal for pixel-level time-series analyses. The cubic convolution method was used to resample the Landsat data to 30 m resolution using the Universal Transverse Mercator (UTM)-World Geodetic System (WGS) 84 projection. *Table 1* shows the date of satellite data capture as well as sensor specifications.

16-day continuous MODIS derived Normalized Difference Vegetation Index (NDVI) product MYD13Q1-V6 with 250 m spatial resolution was downloaded from National Aeronautics and Space Administration (NASA) and used to examine the vegetation dynamics (browning and greening) in the study area for the period from 01-01-2001 to 31-12-2020 (*Table 1*).


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***Table 1.*** *Details of the satellite data used in this study*

| Satellite-sensor | Path/row | Pixel size in meters | Date of acquisition |
|---|---|---|---|
| Landsat TM | 142-144/53-54 | 30 | 14-12-2001 |
| Landsat TM | 142-144/53-54 | 30 | 17-01-2010 |
| Landsat OLI | 142-144/53-54 | 30 | 12-12-2020, 14-12-2020 |
| MODIS NDVI (MOD13Q1 V6) | h25/v07-08 | 250 | 01-01-2001 to 31-12-2020/ 16-day interval |

Daily rainfall data from 2001-2019 at 10 rain gauge locations and daily river discharge data from 2001 to 2015 were obtained from the State Surface and Ground Water Data Center, Tamil Nadu State water resources division of Public Works Department (PWD) (*Fig. 1*). The change in rainfall pattern and variations in hydrometeorology in the basin were studied using monthly rainfall and monthly discharge data.

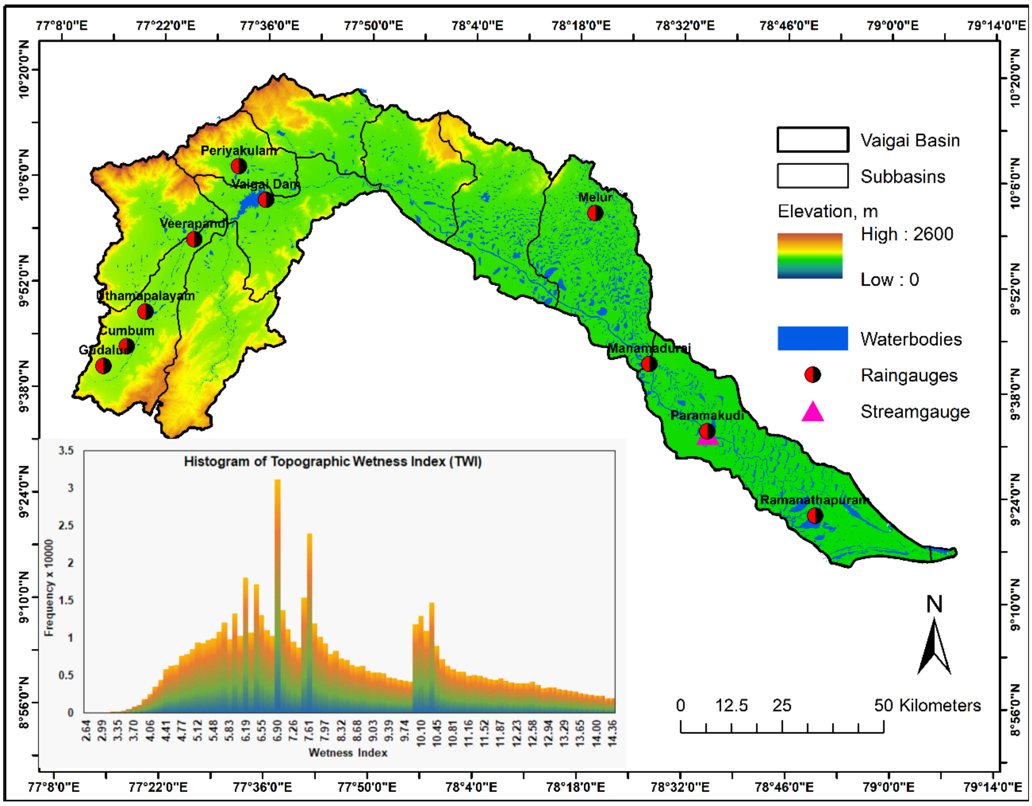


***Figure 1.*** *Vaigai River Basin shown with the waterbodies. The Inset shows the distribution of flow accumulation (topographic wetness index) in the basin due to reservoirs and tanks*

## *Image classification*

Using decision tree (DT) classification (Yang et al., 2017) in Q-GIS software, supervised image classification was performed using training samples obtained from


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false colour composite (FCC) of Landsat satellite imagery as shown in the LULC classes and their descriptions (*Table 2*). 80% and 20% pixels were used in training and testing respectively. In the year 2019-2020, from region of interest polygons, total pixels were 12,018. Through stratified random sampling, the testing pixels of 2,562 (21%) were segregated and the remaining pixels were used in training the supervised classification model. Very high-resolution images from Google Earth Pro were used to identify the testing pixels for the years from 2001 to 2020. The Landsat series satellites have almost similar wavelength bands and spectral characteristics that make sample collection easy. The change maps were derived from actual classified LULC maps for the year 2001, 2010 and 2020 in QGIS software as given by Spruce et al. (2020).

***Table 2.*** *Categories and descriptions of the LULC classes*

| S. No | Class name | Description |
|---|---|---|
| 1. | Cropland | Currently cultivated land and with presence of crop |
| 2. | Fallow land | The land using for farming but that is left with no crops |
| 3. | Built-up | Residential, commercial, industrial, transportation, roads, mixed urban |
| 4. | Barren land | Land surface devoid of vegetation |
| 5. | Open scrub | The land dominated by shrubs, grasses, and small trees |
| 6. | Forest | Trees forming open to closed canopies mainly dry deciduous |
| 7. | Water body | River, open water, lakes, ponds and reservoirs |

### *Vegetation greening/browning*

Using time-series of MODIS NDVI data, the vegetation greening and browning patterns (de Jong et al., 2011) were investigated. On the MODIS NDVI 16-day product data (2001–2020), a “Theil-Sen trend” analysis (Theil, 1992) was carried out to find positive and negative significant trends in the vegetative cover. At a significance of 5%, the “Mann-Kendall” test was performed to evaluate trend for statistical significance using “ZYP” package (Bronaugh and Werner, 2013) in “R” software. The class transitions and rate of change were calculated using the post-classification comparison technique (Peiman, 2011).

### *Accuracy assessment*

The confusion error matrix was used to assess the accuracy of actual classified LULC maps (Congalton, 1991). The confusion error matrix (*Table 3*) was used to determine overall accuracy (NRSA, 1995), user and producer accuracies (UA and PA), and consistency of the actual LULC maps. The accuracy of interpretation of land use categories using remote sensing data should be at least 85% (Manandhar et al., 2009). The number of training pixels assigned to each individual class influences the UA, whereas the PA was exclusively based on the training pixels assigned to that specific class as suggested by NRSA (1995).

***Table 3.*** *Confusion matrix to describe the accuracy of classification of land cover class*

| Classes | Accuracy | | |
|---|---|---|---|
| | **2001** | **2010** | **2020** |
| Barren land | 82.38 | 86.39 | 84.09 |
| Built-up | 86.06 | 89.52 | 91.62 |
| Cropland | 83.65 | 85.53 | 85.71 |
| Fallow land | 83.29 | 81.68 | 80.40 |
| Forest | 90.91 | 90.18 | 91.49 |
| Open Scrub | 72.20 | 81.18 | 76.36 |
| Water body | 99.21 | 97.94 | 96.99 |

### *Hydrometeorological analysis*

Trends in monthly rainfall data from 2001-2019 and river discharge data from 2001-2015 were also identified using Theil-Sen trend analysis as mentioned earlier. The distribution of monthly rainfall across the basin was analyzed using boxplots and the river discharge data were evaluated with reference to rainfall on a monthly time scale to study the influence of rainfall and catchment properties.

## Results

### *Land use and land cover change*

*Figures 2, 3,* and *4* show actual LULC maps derived using Landsat images for the year 2001, 2010 and 2020, respectively. *Table 4* shows the % change in percentage between the study periods. Between 2001 and 2010, there was a 59% increase in built-up area and a slight reduction in aquatic bodies (1%). In this decade, fallow land has increased by 30% since 2001, while crop land has increased by 15% as the open scrub, barren and fallow land were converted into crop land. The reduction of 34% in barren land from 2001 to 2010 can be explained by the increase in crop land which is shown by the change map (*Figs. 5a, b* and *6a, b*). It is also to be noted that except forested lands, other land uses had been converted to crops lands.

***Table 4.*** *LULC changes between 2001-2010 and 2010-2020*

| LULC class | Area in km$^2$ | | | | |
|---|---|---|---|---|---|
| | **2001** | **2010** | **2001-2010 percent change, %** | **2020** | **2010-2020 percent change, %** |
| Barren land | 1344 | 883 | −34 | 937 | 6 |
| Built-up | 106 | 169 | 59 | 238 | 41 |
| Cropland | 1510 | 1736 | 15 | 1113 | −36 |
| Fallow land | 580 | 752 | 30 | 1330 | 77 |
| Forest | 1342 | 1284 | −4 | 1525 | 19 |
| Open scrub | 2110 | 2170 | 3 | 1770 | −18 |
| Water body | 171 | 168 | −1 | 249 | 48 |


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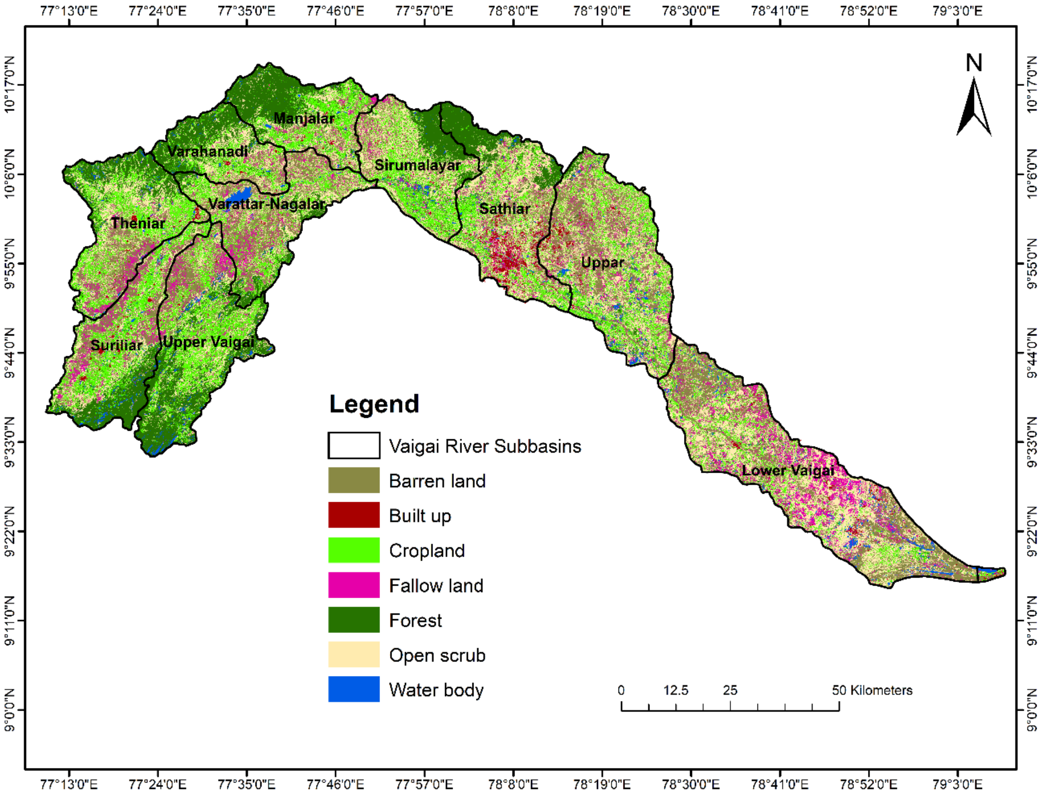


***Figure 2.** Landuse Landcover in Vaigai River Basin in the year 2001*

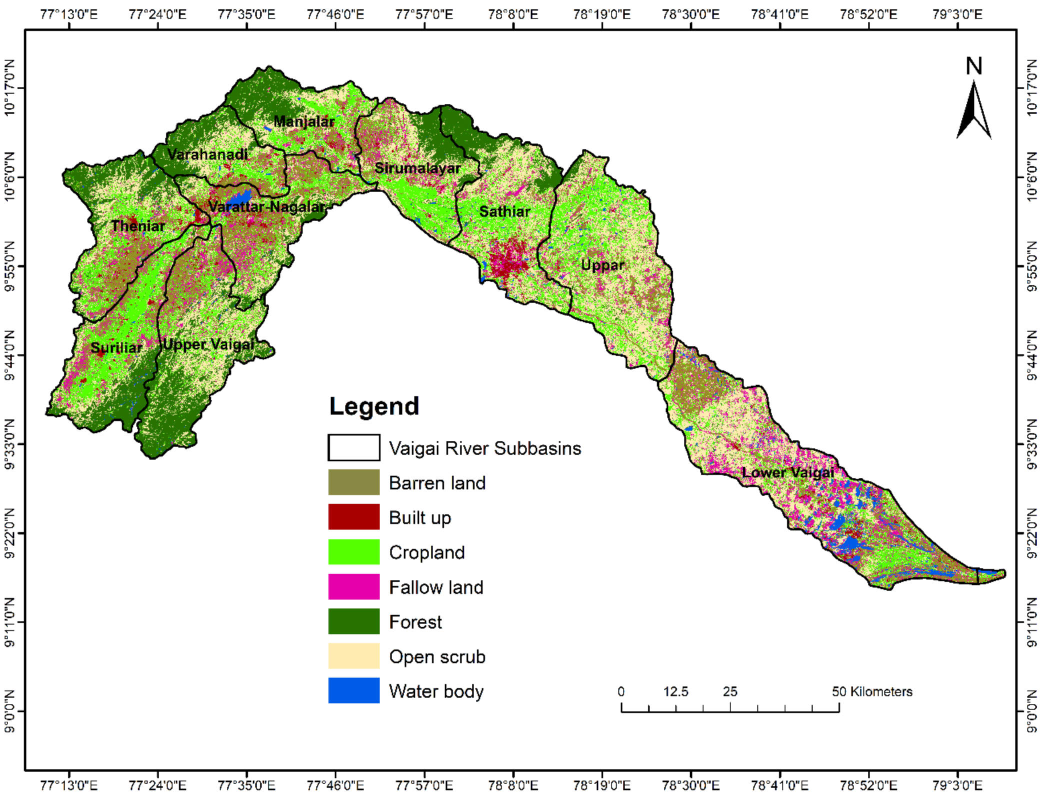


***Figure 3.** Landuse Landcover in Vaigai River Basin in the year 2010*

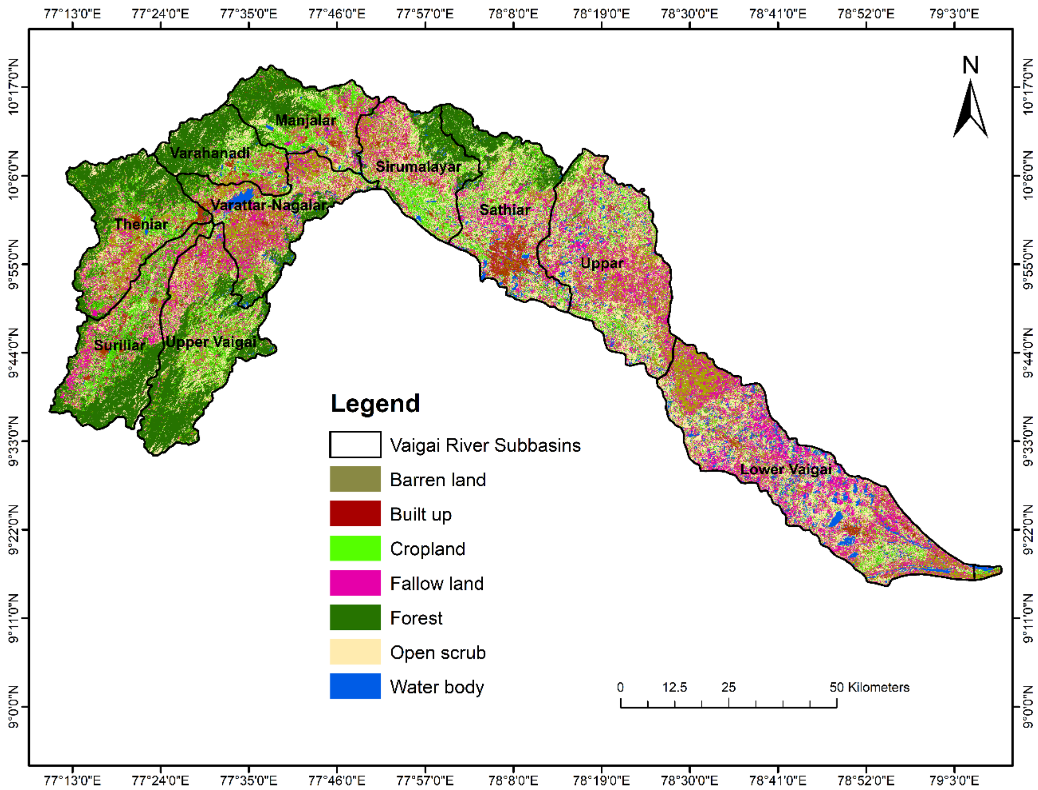


***Figure 4.*** *Landuse Landcover in Vaigai River Basin in the year 2020*

There was greater reduction of 36% in crop land from 2010 to 2020 as can be seen from the change maps (*Table 4*). 31% of the crop lands were converted into open scrub and 27% were converted into fallow lands. Cumulatively, the fallow land has seen the greatest increase of 77 percent, followed by water bodies (48%), and built-up areas (41%) from 2010-2020. The forested areas showed no change or minimal change over the study years when compared to other land uses. Water bodies were identified as open scrub, forests, and fallow lands, which might be due to the presence of aquatic plant water hyacinth growing in post-monsoon season, and the dried-up boundaries of the water bodies.

Greening and browning map derived using MODIS NDVI data (*Fig. 7*) depicts greening of lower and upper Vaigai area, with green color representing increasing trend and brown color indicating declining tendency in LULC. The pixels that were browning was compared against the change maps, which showed that the browning was the resultant of vegetated land use converted into built-up areas, open scrub and fallow land. The invasive plant species *Prosopis juliflora*, a scrub plant, which is actively colonizing village water tanks and agricultural fallow lands in the region, is the source of vegetation greening in the lower Vaigai basin.

### *Hydrometeorology and LULC change*

The basin's hydro-climatology showed an increase in the number of wet days and a shift in seasonal rainfall (*Fig. 8*). The increase in trend in rainfall was most noticeable after the year 2010 during south-west monsoon from June to September with increase in number of rainy days during the monsoon months. However, during the north-east monsoon, the number of rainy days all reduced post- 2010. During 2001-2019, the years 2002-2004, 2006-2007, 2012 and 2016 have been low-rainfall years whereas 2009-2010, and 2015 have been above-average rainfall years.

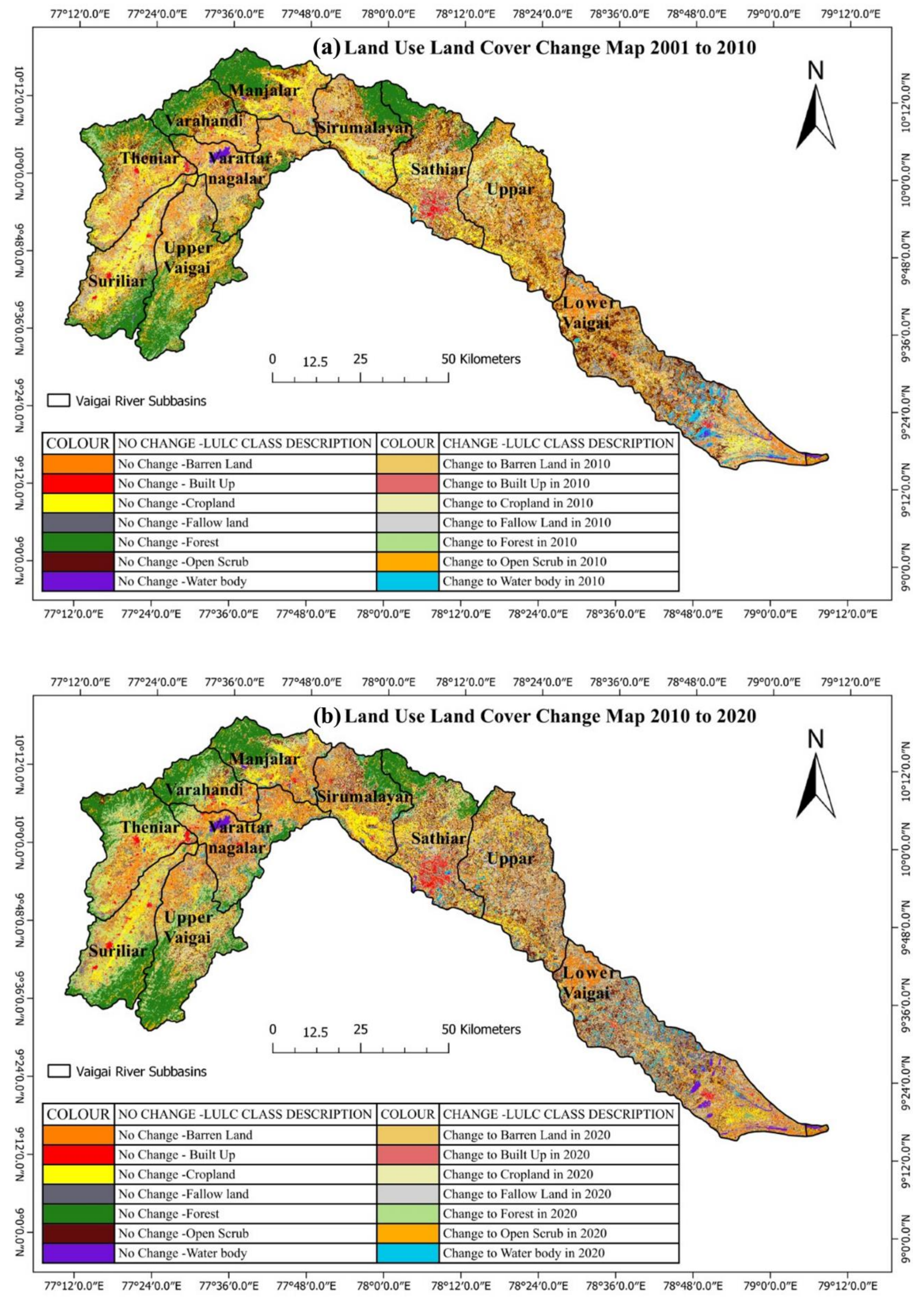


***Figure 5.** Land use land cover change map. (a) 2001-2010 and (b) 2010-2020*


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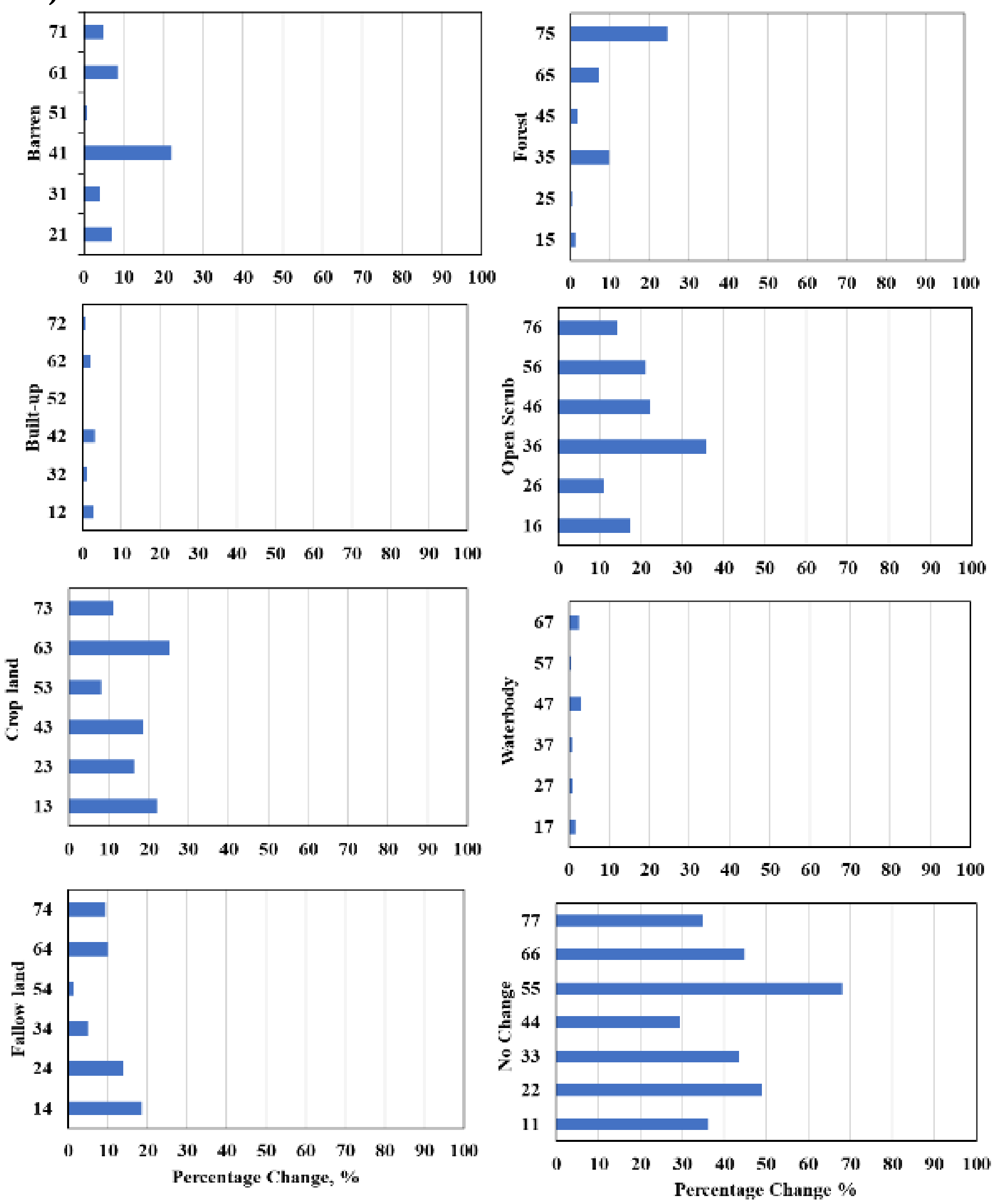
Long term average (LTA) annual rainfall in the basin is 819.17 mm from 2001-2019; and the low rainfall years, 2012 and 2016 received 38% and 50% lower rainfall respectively, as compared to the LTA. The above-average rainfall year 2005 recorded 45% more rainfall than LTA followed by 2008, 2010, and 2018 receiving 28%, 19%, and 22% more annual rainfall than LTA. The average rainfall during north-east monsoon season was 138.7 mm; during south-west monsoon season was 46 mm and during non-monsoon season was 32.2 mm. Deviation from seasonal rainfall during deficit year 2016 was highest (−61%) during north-east monsoon, −33% during south-west monsoon and −46% during the non-monsoon months from January-May. The above-average rainfall years 2005 and 2008 showed largest positive deviation of +60% and +42% from LTA during the north-east monsoon season. Also, 81% increase in non-monsoon rainfall was observed in the surplus year 2005. Trend analysis of rainfall showed increasing rainfall at all the stations, however the overall trend was not significant at 5% confidence interval except during July, August and December.

**a)**





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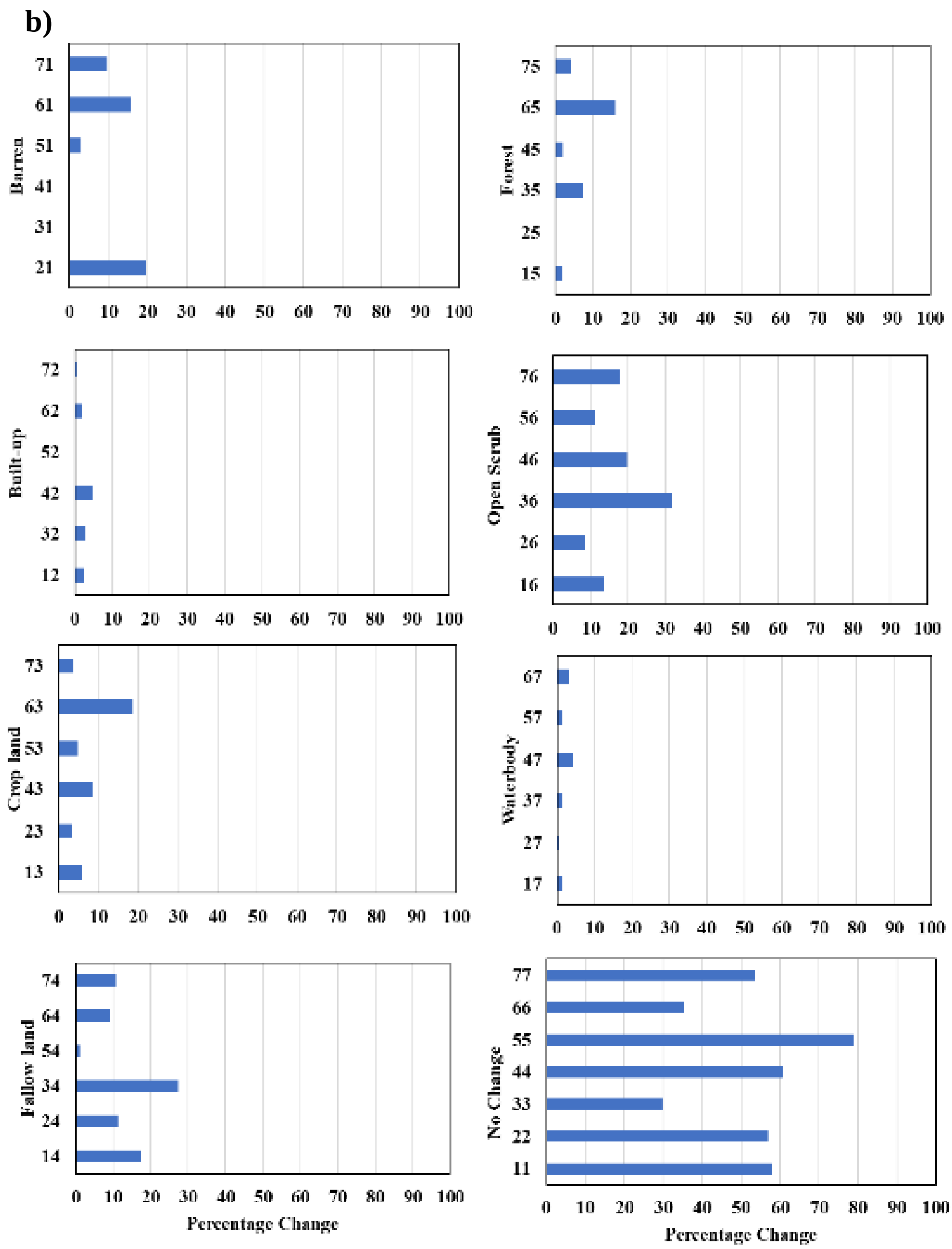


***Figure 6.*** *Contribution of each land use to other land use and land cover (a) 2001-2010 and (b) 2010-2020*

River discharge data collected in Paramakudi, in the lower Vaigai region, shows flow in response to rainfall events (*Fig. 9*). Trend analysis of river flow showed that there is an insignificant (p value at 5%) increase in river flow from 2001-2015. However, the flow that occurred during the north-east monsoon from November to December was higher compared to other months, as the basin receives maximum rainfall in these months. The flow during November and December was higher in surplus years 2005 and 2010 and no flow was observed during deficit years 2012-2013. Discharge during the south-west monsoon increased until 2008, after which there was no flow. The monthly average discharge showed surplus years 2005 and 2008 receiving higher flow in the river as compared to other months. Similarly, non-monsoon months from January to May also


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showed increasing flows in the river during surplus years and no flows during deficit years.

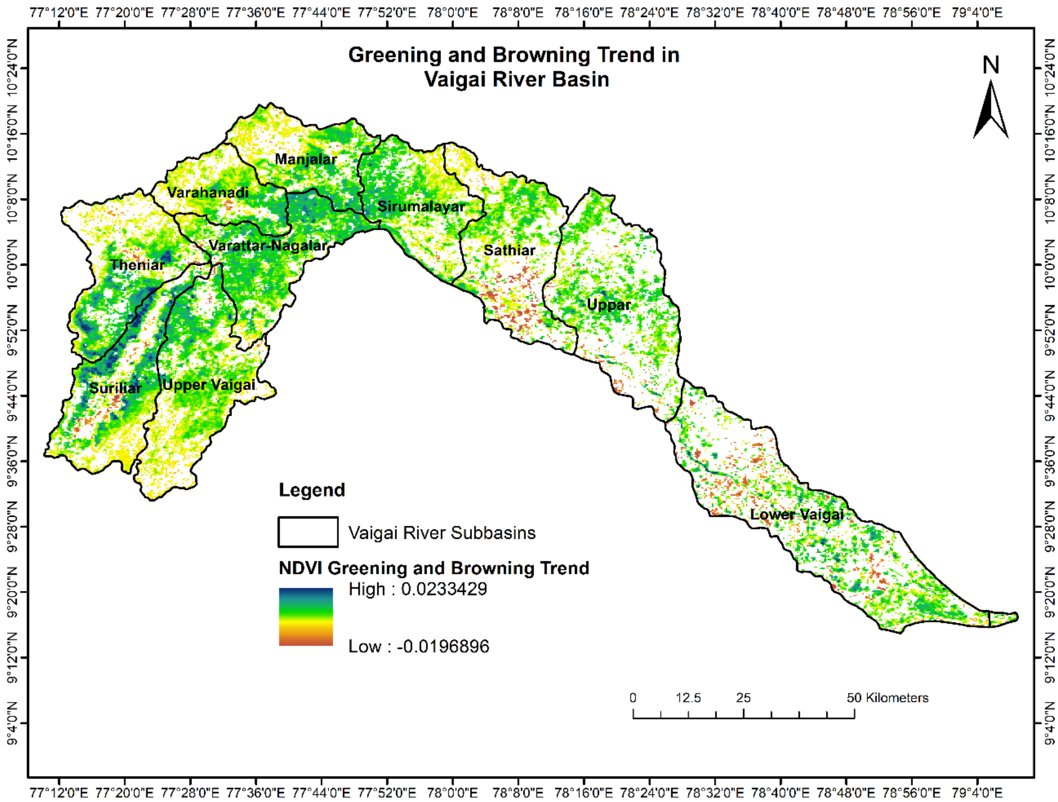


***Figure 7.*** *Greening and Browning in Vaigai River Basin from 2001 to 2020*

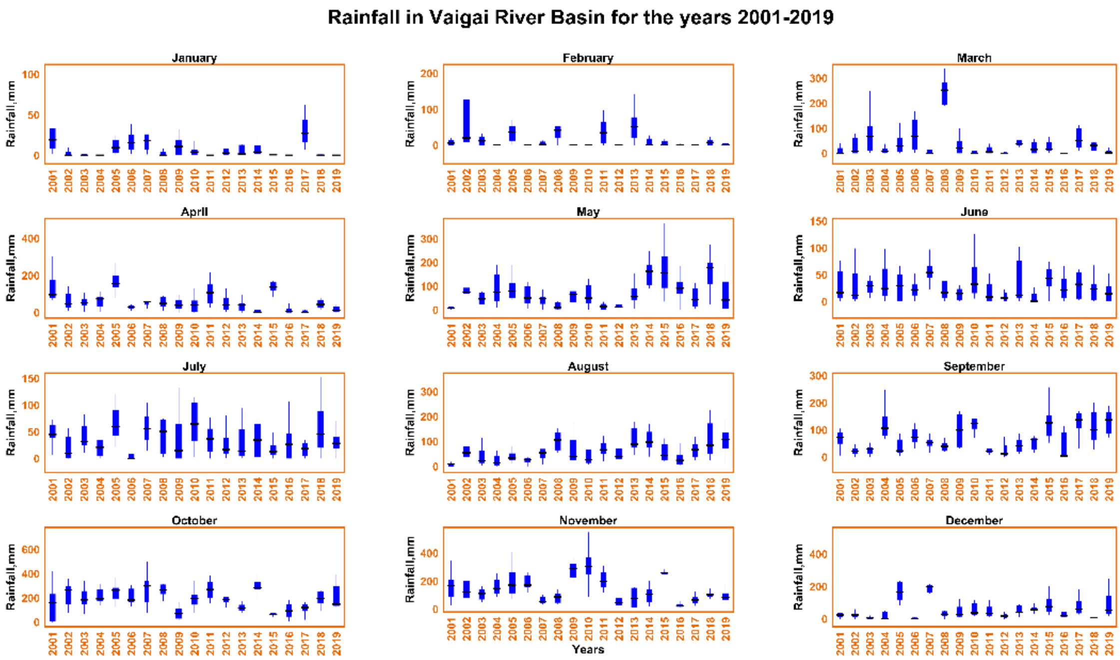


***Figure 8.*** *Monthly distribution of rainfall in Vaigai River basin (Default Y-axis values are retained to show distinct variations in rainfall)*


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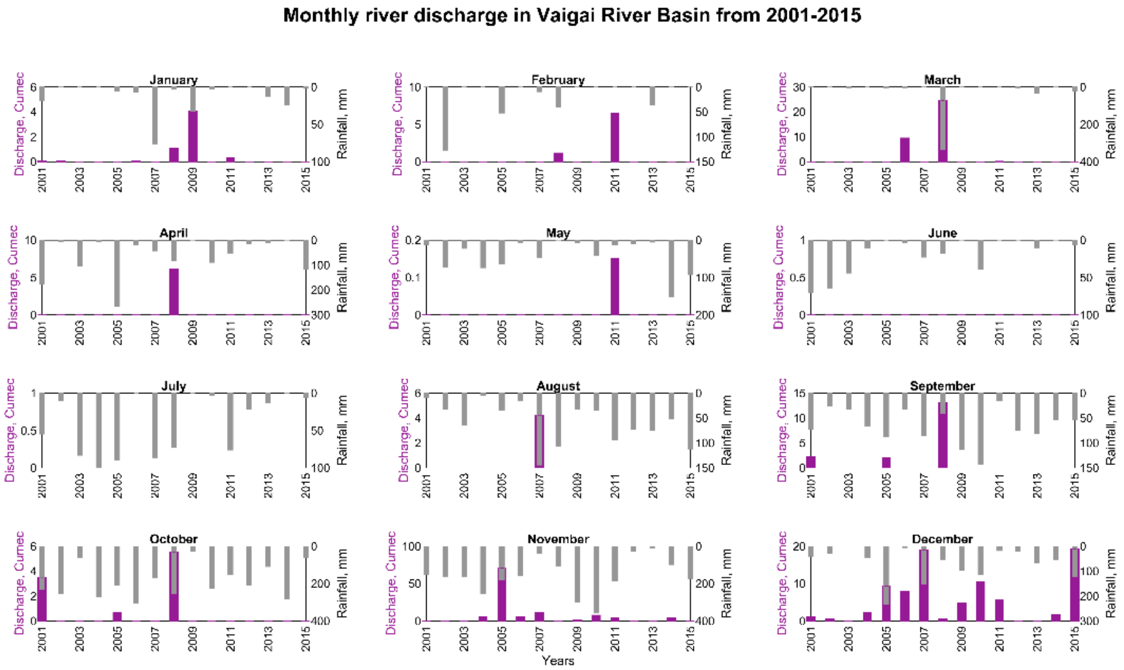


***Figure 9.*** *Rainfall and river discharge in Vaigai River (default Y-axes values are retained to show distinct variations in rainfall and discharge)*

## Discussion

Land use and land cover change maps derived using Landsat images (*Fig. 5a, b*) showed increase in built-up, crop and fallow lands from 2001-2010 whereas from 2010-2020 the crop lands had decreased up to 36% with consistently increasing in fallow and built-up areas. Decrease in croplands and increase in urban areas and fallow lands have also been reported for the years 2000-2017 in Tamil Nadu (Boyaj et al., 2020). 48% expansion in water bodies was observed since 2000 in VRB, which was also pinpointed by Boyaj et al. (2020) in Tamil Nadu.

The land use change map and relative contribution of each land use to others (*Fig. 6a, b*) showed forest lands remained intact compared to other land uses which were impacted by LULC change. Built-up areas increased followed by crop lands and open scrub. During 2001-2010, maximum conversion occurred in open scrub from barren, built-up, crop, fallow and forested areas. Conversion of crops lands from other land use categories was prominent in 2010 followed by fallow lands. Primary contributor to change in crop lands was open scrub (25%) followed by barren lands (22%), which is the cause of increase in crop lands in the basin (Srinivasan and Sathik, 2015). 18% of barren lands have been converted into fallow lands during 2001 to 2010. Conversely, 22% of the fallow lands were converted to barren lands in the basin.

From the year 2010 to 2020, 57% of agricultural lands were converted into fallow, open scrub, and built-up areas, which explains the basin-wide reduction in crop lands. As a result, the open scrub areas and fallow lands increased significantly in the basin. The greening, which was derived using MODIS NDVI data, as identified from *Figure 5a, b* is the resultant of increase in open scrub, *Prosopis juliflora* as noted by Vidhya et al. (2017), both in lower and upper Vaigai basins. It can also be noted that the LULC change to urbanized areas in parts of Suruliyar, Sathiyar and Lower Vaigai sub-


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basins shown by change maps (*Fig. 5a, b*) reflected as browning areas in *Figure 7*. Similarly, about 16% of the open scrub was shown to be classified as forest areas because the forest type present in the basin is dry deciduous and the hilly terrain is covered with plantations, shrubs and scrub species and account for 532 $km^2$ (NWM, 2017). The spectral separability of open scrub land and scrub forest is low and therefore possible misclassification may be mainly due to spectrally nearest classes. The misclassified single pixels were removed by a post-classification refinement process where a $3 \times 3$ majority filter window was applied. 21% and 11% conversion shown from forest to open scrub lands in 2010 and 2020, respectively, could also have resulted from this misclassification.

In concurrence with the LULC change, the seasonal increase in rainfall particularly in July and August was observed between the years 2001 and 2010 (*Fig. 8*) (Gumma et al., 2015; Sathyamoorthy et al., 2018; Nagalapalli et al., 2019; Mahadevan and Ramaswamy, 2020). The built-up area increased by about 59% in the basin (*Table 4*), which could be a contributing factor to the shift in rainfall pattern. This results from reduction in evapotranspiration to the atmosphere which eventually leads to decreased cumulative available potential energy (Pielke et al., 2007; Paul et al., 2016). Such changes in moisture sources reduce its distribution to atmosphere hence reducing precipitation. However, changes in cumulative available potential energy are associated with fluctuations in surface temperature sensible heat fluxes, which results in extreme rainfall conditions (Kar and Liou, 2019; Boyaj et al., 2020). Shastri et al. (2014) also identified increasing trend of rainfall extremities as a result of urbanization in Southern India.

Palanichamy et al. (2020) also reported rising rainfall in the VRB in the month of January at Gudalore_M, Periyakulam, Uthamapalaym, Vaigai dam, and Veerapandi raingauge stations. The raingauge at Veerapandi, Theni district, in particular, indicates a substantial rising trend in March, April, and August. The monthly mean rainfall from 12 raingauge stations in Manjalar sub-basin of the VRB also showed that it experiences mild droughts quite frequently, with least frequency of extreme droughts. The basin experienced severe drought in 1985, 2004, and 2006 (Janapriya et al., 2016). More research into the moisture flow between surface and atmosphere in the basin is essential since changes in land use land cover have a key influence on monsoon rainfall patterns (Shastri et al., 2014; Quesada et al., 2017; Duraisamy et al., 2018; Martellozzo et al., 2018). As Quesada et al. (2017) stated biophysical effects resulting due to changes in land use and land cover causes reduction in monsoon rainfall and suggested incorporating LULC changes in climate change studies for rainfall forecasting.

The river flow in VRB remained unchanged from the year 2001 to 2015 despite the changes in monsoon rainfall at significance level of 5% (*Fig. 9*). During the north-east monsoon season, Vaigai river recorded maximum discharge in November and December at Paramakudi gauging site, which is located in the lower part of the basin. No-flow conditions persisted during rest of the year in the river (Chellasamy, 1996) except during surplus rainfall years 2005, 2007-2008 making it an ephemeral river. However, the gauging site at Theni located upstream of Paramakudi gauging site recorded discharge, but there is a very low (almost nil) discharge at Paramakudi (Personnel Communication). This shows that hydrologic flow of the basin is explicitly divided between upstream and downstream, the influence of which could be applied for effective implementation of land use planning and management strategies in the basin.


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DOI: http://dx.doi.org/10.15666/aeer/2105_46154632

## Conclusions

Land use and land cover changes in the Vaigai River Basin have been assessed using Landsat satellite images between 2001 and 2020, and the impact on the basin's hydrometeorology and hydrology was investigated. For the same research period, MODIS NDVI images were used to examine the basin's greening and browning trends. The following conclusions have been drawn based on the comprehensive research:

- The land use change was dominated by increase in built-up areas, crop lands, fallow lands and open scrub during 2001-2020. In 2020, the increase in fallow land and barren land was the result of suspension of farming activities due to water scarcity.
- Land use and land cover change map analysis showed reduction in agricultural lands, and increase in fallow and barren lands.
- Change in rainfall pattern was not significant although there was an increase in monsoon rainfall from 2001 to 2020, which was attributed to increase in built-up areas. The results from this study showed the influence of land use change on monsoon rainfall.
- Consequently, the discharge in the basin, in particular, lower Vaigai occurred during November and December months only with rest of the year receiving low flow or no discharge. No significant trends have been observed in the river flow at Paramakudi from 2001 to 2015.

In concluding remarks, in VRB, agricultural activities were shown to be reducing from 2001 to 2020. There was no significant trend shown in rainfall in the basin except during the monsoon seasons. Therefore, although the land use changes are evident from the analysis in the basin, its impact was only evident in the extreme rainfall during monsoon season. The river discharge measured at the basin's downstream gauging site showed no change in flow during 2001-2015 and therefore change in land use and land cover does not indicate any influence the flow pattern in the Vaigai river. The results of the study thus prove beneficial for efficient land use planning to minimize the potential impacts of meteorological extremes.

**Acknowledgements.** We highly respect the critical reviews from anonymous reviewers, which helped to improve the quality of this paper.

**Conflict of interests.** Authors of this manuscript do not have any conflict of interests.

## REFERENCES

[1] Arumugam, S., Charles, P. M. (2016): Distribution and seasonal availability of freshwater prawn (Macrobrachium sps.) in Vaigai river basin, Tamil Nadu, India. – Acta Velit 3(2): 86-93.

[2] Awotwi, A., Anornu, G. K., Quaye-Ballard, J., Annor, T., Forkuo, E. K. (2017): Analysis of climate and anthropogenic impacts on runoff in the Lower Pra River basin of Ghana. – Heliyon 3(12): e00477.

[3] Boyaj, A., Dasari, H. P., Hoteit, I., Ashok, K. (2020): Increasing heavy rainfall events in south India due to changing land use and land cover. – Quarterly Journal of the Royal Meteorological Society 146(732): 3064-3085.


http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2105_46154632

[4] Bronaugh, D., Werner, A. (2013). Zhang + Yue-Pilon trends package. – R CRAN, 2013, ftp://cran.r-project.org/pub/R/web/packages/zyp/zyp.pdf (accessed June 27, 2018).
[5] Chellasamy, R., Balasubramanian, A. (1991): Hydrogeological Studies in the Vaigai River Basin, Tamil Nadu. – In: Durga Prasad, M. K., Pitchaiah, S. (eds.) Inland Water Resources. Discovery Publishing House, Delhi.
[6] Cheruto, M. C., Kauti, M. K., Kisangau, D. P., Kariuki, P. C. (2016): Assessment of land use and land cover change using GIS and remote sensing techniques: a case study of Makueni County, Kenya. – Journal of Remote Sensing & GIS 5(4): 175. DOI: 10.4175/2469-4134.1000175.
[7] Congalton, R. G. (1991): A review of assessing the accuracy of classifications of remotely sensed data. – Remote Sensing of Environment 37(1): 35-46. https://doi.org/10.1016/0034-4257(91)90048-B.
[8] De Jong, R., de Bruin, S., de Wit, A., Schaepman, M. E., Dent, D. L. (2011): Analysis of monotonic greening and browning trends from global NDVI time-series. – Remote Sensing of Environment 115(2): 692-702. https://doi.org/10.1016/j.rse.2010.10.011.
[9] del Rosario Uribe, M., Dukes, J. S. (2021): Land cover change alters seasonal photosynthetic activity and transpiration of Amazon Forest and Cerrado. – Environmental Research Letters 16(5): 054013.
[10] DoE (2015): Department of Environment, Government of Tamil Nadu, Final Draft on State Action Plan for Climate Change, Chapter 6 - Water Resources. – www.environment.tn. nic.in/sapcc.html (accessed in March 2015).
[11] Duerinck, H. M., van der Ent, R. J., van de Giesen, N. C., Schoups, G., Babovic, V., Yeh, P. J. F. (2016): Observed soil moisture-precipitation feedback in Illinois: a systematic analysis over different scales. – Journal of Hydrometeorology 17(6): 1645-1660. https://doi.org/10.1175 /JHM-D-15-0032.1.
[12] Duraisamy, V., Bendapudi, R., Jadhav, A. (2018): Identifying hotspots in land use land cover change and the drivers in a semi-arid region of India. – Environmental Monitoring and Assessment 190(1): 535. https://doi.org/10.1007/s10661-018-6919-5.
[13] Gumma, M. K., Kajisa, K., Mohammed, I. A., Whitbread, A. M., Nelson, A., Rala, A., Palanisamy, K. (2015): Temporal change in land use by irrigation source in Tamil Nadu and management implications. – Environmental Monitoring and Assessment 187(1): 4155. https://doi:10.1007/s10661-014-4155-1.
[14] Janapriya, S., Santhana Bosu, S., Balaji Kannan, Kokilavani, S. (2016): Spatial and temporal analysis of drought in Manjalar sub-basin of Vaigai in Tamil Nadu using standardized precipitation index. – Journal of Applied and Natural Science 8(2): 609-615.
[15] Kar, S. K., Liou, Y. A. (2019): Influence of land use and land cover change on the formation of local lightning. – Remote Sensing 11(4): 407. https://doi.org/10.3390/rs11040407.
[16] Lamb, W. F., Wiedmann, T., Pongratz, J., Andrew, R., Crippa, M., Olivier, J. G., Wiedenhofer, D., Mattioli, G., Al Khourdajie, A., House, J., Pachauri, S. (2021): A review of trends and drivers of greenhouse gas emissions by sector from 1990 to 2018. – Environmental Research Letters 16(7): 073005.
[17] Mahadevan, P., Ramaswamy, S. N. (2020): Statistical studies on planning for water resource management on Vaigai reservoir catchment on Vaigai river, Tamil Nadu State, India. – Indian Journal of Geo Marine Sciences 49(4): 665-677.
[18] Manandhar, R., Odeh, I. O., Ancev, T. (2009): Improving the accuracy of land use and land cover classification of Landsat data using post-classification enhancement. – Remote Sensing 1(3): 330-344. https://doi.org/10.3390/rs1030330.
[19] Martellozzo, F., Amato, F., Murgante, B., Clarke, K. C. (2018): Modelling the impact of urban growth on agriculture and natural land in Italy to 2030. – Applied Geography 91: 156-167. https://doi.org/10.1016/j.apgeog.2017.12.004.
[20] Nagalapalli, S., Kundu, A., Mall, R. K., Thattai, D., Rangarajan, S. (2019): An appraisal of flood events using IMD, CRU, and CCSM4-derived meteorological data sets over the

Vaigai river basin, Tamil Nadu (India). – Sustainable Water Resources Management 5(4): 1731-1744. https://doi.org/10.1007/s40899-019-00325-2.
[21] NRSA (1995): National Remote Sensing Agency. – All India Report on Area Statistics of Land Use/Land Cover Generated Using Remote Sensing Techniques, Hyderabad, pp 1-71.
[22] NWM (2017): National Water Mission, Ministry of Jal Shakthi, Department of Water Resources, Government of India. – E-resource: http://nwm.gov.in/sites/default/files/ Vaigai Basin -17.07.17.pdf (accessed on March 3, 2022).
[23] Palanichamy, M., Sankaralingam, R., Narayanasamy, N. (2020): Statistical studies on rainfall and time-based deviations in precipitation trends in Vaigai River basin, TN State, India. – Indian Journal of Geo Marine Sciences 49(01): 15-23.
[24] Palanisami, K., Ranganathan, C. R., Vidyavathi, A., Rajkumar, M., Ajjan, N. (2011): Performance of agriculture in river basins of Tamil Nadu in the last three decades - a total factor productivity approach. – A Project sponsored by Planning Commission, Government of India. Centre for Agricultural and Rural Development Studies, Tamil Nadu Agricultural University.
[25] Paul, S., Ghosh, S., Oglesby, R., Pathak, A., Chandrasekharan, A., Ramsankaran, R. A. A. J. (2016): Weakening of Indian summer monsoon rainfall due to changes in land use land cover. – Scientific Reports 6(1): 32177.
[26] Peiman, R. (2011): Pre-classification and post-classification change-detection techniques to monitor land-cover and land-use change using multi-temporal Landsat imagery: a case study on Pisa Province in Italy. – International Journal of Remote Sensing 32(15): 4365-4381. https://doi.org/10.1080/01431161.2010.486806.
[27] Pielke Sr, R. A., Adegoke, J., BeltraáN-Przekurat, A., Hiemstra, C. A., Lin, J., Nair, U. S., Niyogi, D., Nobis, T. E. (2007): An overview of regional land-use and land-cover impacts on rainfall. – Tellus B: Chemical and Physical Meteorology 59(3): 587-601.
[28] Quesada, B., Devaraju, N., Noblet-Ducoudre, N., Arneth, A. (2017): Reduction of monsoon rainfall in response to past and future land use and land cover changes. – Geophysical Research Letters 44(2): 1041-1050. https://doi.org/10.1002/2016GL070663.
[29] Sathyamoorthy, N. K., Ramaraj, A. P., Senthilraja, K., Swaminathan, C., Jagannathan, R. (2018): Exploring rainfall scenario of Periyar Vaigai command area for crop planning. – Indian Journal of Ecology 45(1): 11-18.
[30] Shastri, H., Paul, S., Ghosh, S., Karmakar, S. (2015): Impacts of urbanization on Indian summer monsoon rainfall extremes. – Journal of Geophysical Research: Atmospheres 120(2): 495-516. https://doi.org/10.1002 /2014JD022061.
[31] Silvério, D. V., Brando, P. M., Macedo, M. N., Beck, P. S., Bustamante, M., Coe, M. T. (2015): Agricultural expansion dominates climate changes in southeastern Amazonia: the overlooked non-GHG forcing. – Environmental Research Letters 10(10): 104015.
[32] Spruce, J., Bolten, J., Mohammed, I. N., Srinivasan, R., Lakshmi, V. (2020): Mapping land use land cover change in the Lower Mekong Basin from 1997 to 2010. – Frontiers in Environmental Science 8. https://doi.org/10.3389/fenvs.2020.00021.
[33] Srinivasan, R., Sathik, M. M. (2015): Integrated technology of data remote sensing and GIS techniques assess the land use and land cover changes of Madurai city between the year 2003-2013. – Journal of Advance Research in Computer Science & Engineering 2(11): 01-07.
[34] Srivastava, A., Chinnasamy, P. (2021): Water management using traditional tank cascade systems: a case study of semi-arid region of Southern India. – SN Applied Sciences 3(3): 281.
[35] Theil, H. (1992): A rank-invariant method of linear and polynomial regression analysis. – Proceedings of the Koninklijke Nederlandse Academie van Wetenschappen 53: 345-381. https://doi.org/10.1007/978-94-011-2546-8_20.
[36] Thomas, T., Gunthe, S. S., Ghosh, N. C., Sudheer, K. P. (2015). Analysis of monsoon rainfall variability over Narmada basin in central India: implication of climate change. – Journal of Water and Climate Change 6(3): 615-627.


http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2105_46154632

[37] Truong, N. C. Q., Nguyen, H. Q., Kondoh, A. (2018): Land use and land cover changes and their effect on the flow regime in the upstream Dong Nai River basin, Vietnam. – Water 10(9): 1206. https://doi.org/10.3390 /w10091206.
[38] Tubiello, F. N., Rosenzweig, C., Conchedda, G., Karl, K., Gütschow, J., Xueyao, P., Obli-Laryea, G., Wanner, N., Qiu, S. Y., De Barros, J., Flammini, A. (2021): Greenhouse gas emissions from food systems: building the evidence base. – Environmental Research Letters 16(6): 065007.
[39] Vidhya, R., Vijayasekaran, D., Ramakrishnan, S. S. (2017): Mapping invasive plant *Prosopis juliflora* in arid land using high resolution remote sensing data and biophysical parameters. – Indian Journal of Geo-marine Sciences 46(6): 1135-1144.
[40] Yang, C., Wu, G., Ding, K., Shi, T., Li, Q., Wang, J. (2017): Improving land use/land cover classification by integrating pixel unmixing and decision tree methods. – Remote Sensing 9(12): 1222. https://doi.org/ 10.3390/rs9121222.