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Centennial Assessment of Anthropogenically-Driven Land Use/Land Cover Transformations in a Tropical River Basin, India

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ABSTRACT

This study focuses on analysing the evolving patterns of land use/land cover (LU/LC) within the Meenachil River Basin-MRB (n = 7th, L = 78 km, A = 1272 km^2), in Kerala, India, over a span of 107 years (1914–2021). The research employs remote sensing techniques to discern and characterize changes in LU/LC across four distinct periods, viz., 1914, 1967, 2007, and 2021. Data from Survey of India toposheets (1914 and 1967), Indian Remote Sensing satellite series IRS I–D (LISS; 2006–2007), and Landsat 8 OLI and TIRS imagery (2021) were processed using software such as ERDAS Imagine and Arc GIS. About seven LU/LC categories were identified under Level-I and 17 sub-categories were identified under level-II. The predominant category is agriculture, which has maintained its dominance throughout the study period. However, a significant reduction in coconut cultivation and forested land has become evident over the past century. Intriguingly, the land area allocated to rubber cultivation has exhibited a substantial increase, resulting in an observable expansion of built-up urban areas and a corresponding decline in water bodies. It is noteworthy that the ongoing trend of diminishing forested areas and water bodies contradicts established climate change mitigation policies. Urgent and concerted efforts are imperative to safeguard and conserve both forested regions and aquatic ecosystems. Moreover, proactive measures are required to address waste management issues within built-up urban locales. Additionally, considering the heightened risk of soil erosion in regions characterized by rubber cultivation, mitigative strategies should be formulated to combat this challenge effectively. This study underscores the critical need for comprehensive conservation strategies to counteract the adverse impacts of changing LU/LC patterns. By prioritizing the protection of forests, water bodies, and implementing waste management solutions, stakeholders can align with climate change mitigation objectives while fostering sustainable resource management practices. This study also identified urbanization coupled with LU/LC change, which influenced negative impact on environment.

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1. INTRODUCTION

A shift in land use/land cover (LU/LC) is prominent in the history due to human settlement patterns and various economic developments (Long et al., 2007). LU/LC is a crucial driver of global environmental change and has important implications for many national and international policy issues. The vital challenge for sustainability is to preserve natural ecosystems and their services (Ewunetu et al., 2021;

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Abebe et al., 2022). Integration of natural and social sciences as well as recognition of the increasing role of global factors, are required to meet the challenge. This challenge for developing countries confronts the force of globalization, which seeks cropland that is shrinking in availability and which triggers deforestation (Lambin and Meyfrid, 2011). Some cumulative changes in land use pattern, for instance cropland, grasslands, wetlands, or human settlements, have reached continental, even global, proportions long before the 20th century, including deforestation and the modification of grasslands. The extent of land conversion especially in croplands is also reported globally. Global expansion of croplands since 1850 has converted about 6.0 million km^2 of forests and 4.7 million km^2 of grasslands (Ramankutty and Foley, 1999).

During the period from 1980 to 2000, more than half of the new agricultural land across the tropics came at the expense of intact forests, and another 28% came from disturbed forests (Gibbs et al., 2010). Further studies have shown that the replacement of natural vegetation by modern vegetation cover leads to large changes in regional climate (Kueppers et al., 2007; Tewabe and Fentahun, 2020; Samal and Gedam, 2021; Preetha et al., 2021). Land use changes often alter the composition of plant communities of a larger area due to fragmentation of the landscape, removal and introduction of species, and alteration of nutrient and water pathways. These can further enhance greenhouse gas feedback to the climate system (Ojima et al., 1994). These changes in land use have important implications for future changes in the earth's climate and, in turn, more significant implications for subsequent LU/LC.

A plethora of publications are available on the impacts of land cover, for example, modification on the physical landscape (Skole and Tucker, 1993; Meyer and Turner II, 1992; Lambin and Geist, 2001; Li et al., 2021). A massive study of changes in land use class aimed at carbon estimates for thirteen countries in South and South–East Asia for the periods 1880, 1920, 1950, 1970 and 1980 (Richards and Flint, 1994). It summarises that, over 123 x 106 ha of land in the forested/woodland and forested wetland classes have been converted to low-biomass categories (e.g., grassland) by 1980. Studies on land use change along with carbon fluxes were carried out in different countries (Woodwell et al., 1983; Melillo et al., 1988; Tate et al., 2003; Pfeifer et al., 2013).

Intergovernmental Panel on Climate Change (IPCC) is focusing on comprehensive global land use datasets and improving the modeling strategies allowing for an extensive representation of the land use system. As a part, it is developing new advanced Earth System Models (ESMs) to assess the combined effects of human activities on the carbon-climate system and is generating land use history data together with future scenario information from multiple Integrated Assessment Models (IAMs) into a single consistent, spatially gridded set of Land use change scenarios for studies of human impacts on the past, present and future earth system (Hartman et al., 2011). Further, integrated resource analysis for CLEWs (climate, land-use, energy, and water strategies) models, incorporating Land use scenarios, were also studied (Ngondo et al., 2021; Mark, 2013). Human-induced Land use changes were also studied by simulation models (Pijanowski et al., 2002; Klein et al., 2011).

For the past two decades, remote sensing is accepted as an efficient tool for monitoring LU/LC. Remote sensing can generate cost-effective, multispectral and multi-temporal data, for understanding and monitoring land change patterns and processes, and for creating LU/LC data sets. The collection of remotely sensed data facilitates the synoptic analysis of earth-system functions, patterns and change at local, regional and global scales over time. In India, a variety of LU/LC analysis were carried out by various researchers (Menon and Bawa, 1998; Pontius and Batchu, 2003; Singh, 1989; Roy and Giriraj, 2008; Sheeja et al., 2010).

This investigation elucidates the spatio-temporal intricacies of LU/LC modifications within the Meenachil River Basin (MRB), Kerala, India. Through meticulous quantitative analyses, this endeavour stimulates a profound and resilient comprehension of LU/LC dynamics. Furthermore, it facilitates the discernment of intricate environmental challenges, thereby fostering the formulation of judicious management strategies tailored to the exigencies of the river basin. This study will help to understand major anthropogenic factors behind the LU/LC changes in Meenachil river basin.

2. STUDY AREA

The Meenachil River Basin-MRB ($n = 7$th, $L = 78$ km, $A = 1272$ km^2) holds a distinct geospatial identity with its coordinates ranging from 9°25′ to 9°55′

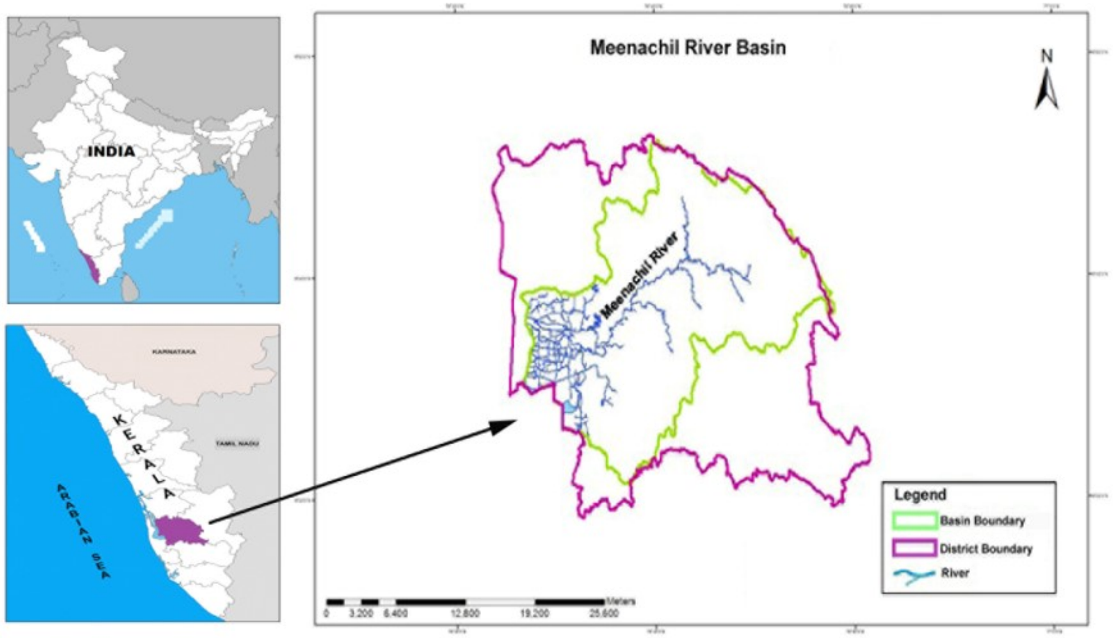

Fig. 1. Study area.

N latitudes and 76°30′ to 77°00′ E longitudes. Originating in the Western Ghats, the MRB follows an East–West trajectory, culminating in its discharge into the Vembanad Lake, situated in the lowland physiographic domain at Kavanattinkara (as depicted in Fig. 1), Kerala, India. The basin encompasses a network of 38 tributaries, collectively shaping a dendritic drainage pattern that intricately interacts with its varied physiographic domains. The river's course traverses through distinct topographical domains, constituting highlands, which account for 33% of the basin area, midlands occupying 66%, and lowlands occupying the remaining 1%. The prevailing tropical climate imparts an annual average rainfall of 3000 mm, while temperatures fluctuate between 24 and 32°C.

Predominantly characterized by Precambrian metamorphic formations, the MRB is primarily composed of quartzite, charnockite, garnetiferous biotite gneiss, and pink/grey granite. Notably, the Vagamon region, situated in the eastern basin, features amphibolite facies rocks. The geological tapestry is further embellished by the presence of quartz and pegmatite veins intricately intersecting the country rock. The major soil type prevalent in the area is well drained laterite soils (Watershed Atlas, 1998). Recent sediments, encompassing coastal sands and alluvium occupy certain areas, particularly proximate to the river's mouth, thereby framing the Vembanad lake region.

3. MATERIALS AND METHODS

The research utilized digital data from various sources to analyze Land use/Land Cover (LU/LC) changes within the Meenachil River Basin (MRB) over the period from 1914 to 2021. The data sources included Landsat 8 OLI & TIRS imagery from 2021, Indian Remote Sensing satellite series IRS I–D (LISS III) images from 2006–2007 at a scale of 1:50,000, and Survey of India (SOI) toposheets from 1914 (1:63,360 scale) and 1967 (1:50,000 scale). The collected geocoded data were merged and processed to create different layers. The study employed a supervised classification technique on the multi-temporal images using ERDAS Imagine 9.0 software for accurate LU/LC mapping and change analysis. Spatial statistical analysis was conducted using the ArcGIS 10.0 environment. The thematic map was generated through a delineation process based on image characteristics such as tone, texture, shape, association, and background. This procedure followed established visual interpretation techniques outlined in works by (Wilkie and Finn, 1996). The resulting map was classified into both Level-I and Level-II categories.

To assess the accuracy of the findings, a vector polygon was converted to a raster format, and frequency analysis was performed. This information was then used to generate a pivot table (error matrix), which provided a comprehensive evaluation of field accuracy during the assessment process.

Table 1. Area wise distribution of land classes (in km^2)

Land use Class		**1914**	**1967**	**2007**	**2021**
Level-I	**Level-II**	**Area (km^2)**	**Area (km^2)**	**Area (km^2)**	**Area (km^2)**
Agriculture	Paddy	48.19	154.87	96.22	44.51
	Pepper	0	0.12	0.27	0
	Mixed Crops	119.32	364.21	167.36	159
	Tea	0	1.08	0.61	0
	Coconut	567.19	72.4	2.64	1.80
	Rubber	0.79	545.83	749.59	787.2
	Fallow Land	7.94	57.02	10.27	0
Sub Total		**743.43**	**1195.53**	**1026.96**	**992.51**
Built-up land	Town/Cities	1.85	15.68	130.18	178.64
Forest	Forest	202.66	11.74	10.96	8.2
Grassland	Grassland	33.46	5.76	2.81	0
Wasteland	Land with scrub	26.99	15.69	77.84	78.59
	Land without scrub	51.6	1.95	0	0
	Sandy Area	0.71	0.34	0	0
	Mining/industrial waste	0	0.07	0	0
	Barren land	28.62	2.12	0.43	2.98
Sub Total		**107.92**	**20.17**	**78.27**	**81.57**
Waterbodies	River/waterbodies	119.69	23.99	16.83	9.28
Wetland		0	0.06	6.86	2.69
Total		**1208.99**	**1272.89**	**1272.89**	**1272.89**

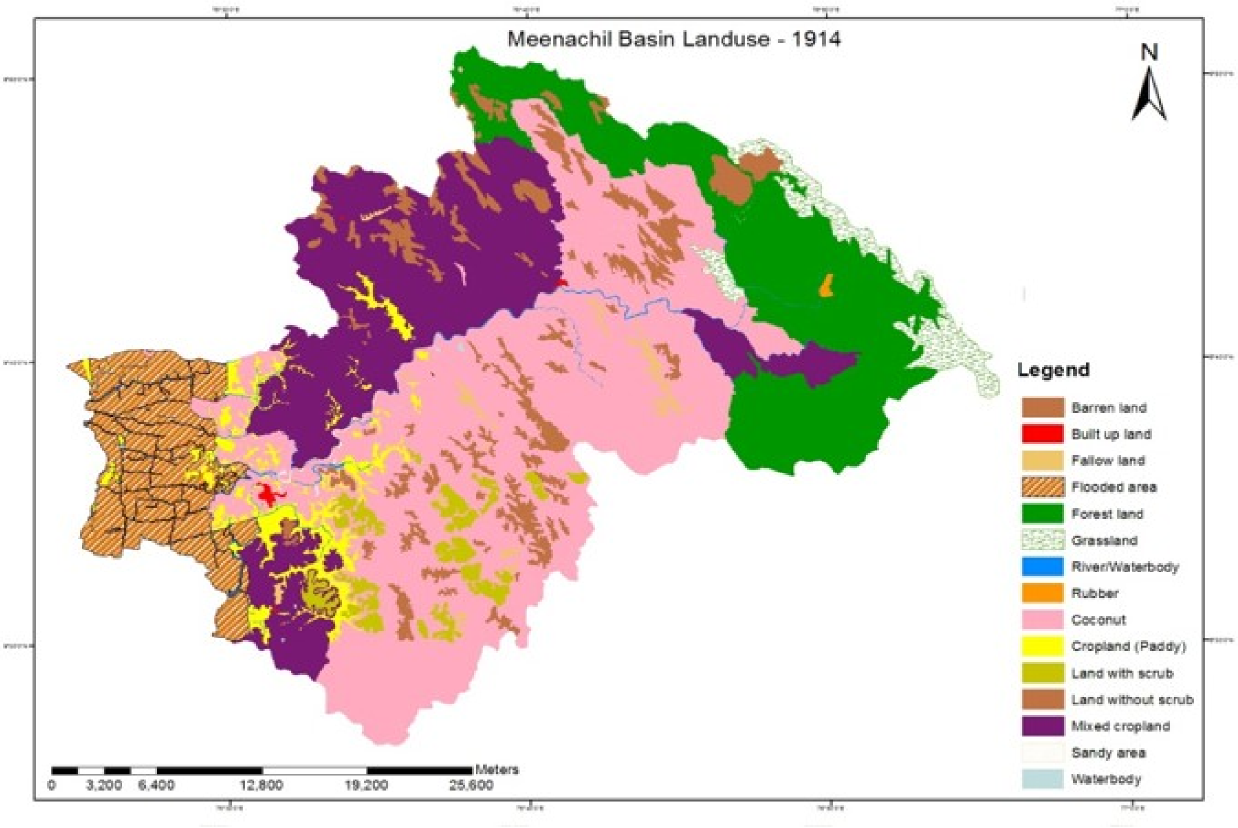

Fig. 2. LULC Change of MRB, 1914.

4. RESULTS AND DISCUSSION

Table 1 and Fig. 2–6 present the spatial distribution of Land Use/Land Cover (LU/LC) classes within the Meenachil River Basin (MRB) at both Level-I and Level-II for the years 1914, 1967, 2007, and 2021. Additionally, Table 2 provides a comprehensive overview of the percentage-wise abundance of these categories, while Table 3 and 4, along with Fig. 7 and 8, elucidate the dynamic changes observed between the four time periods for Level-I and Level-II classifications. During the analysis, an error matrix was generated in the ArcGIS platform by integrating 72 ground truth

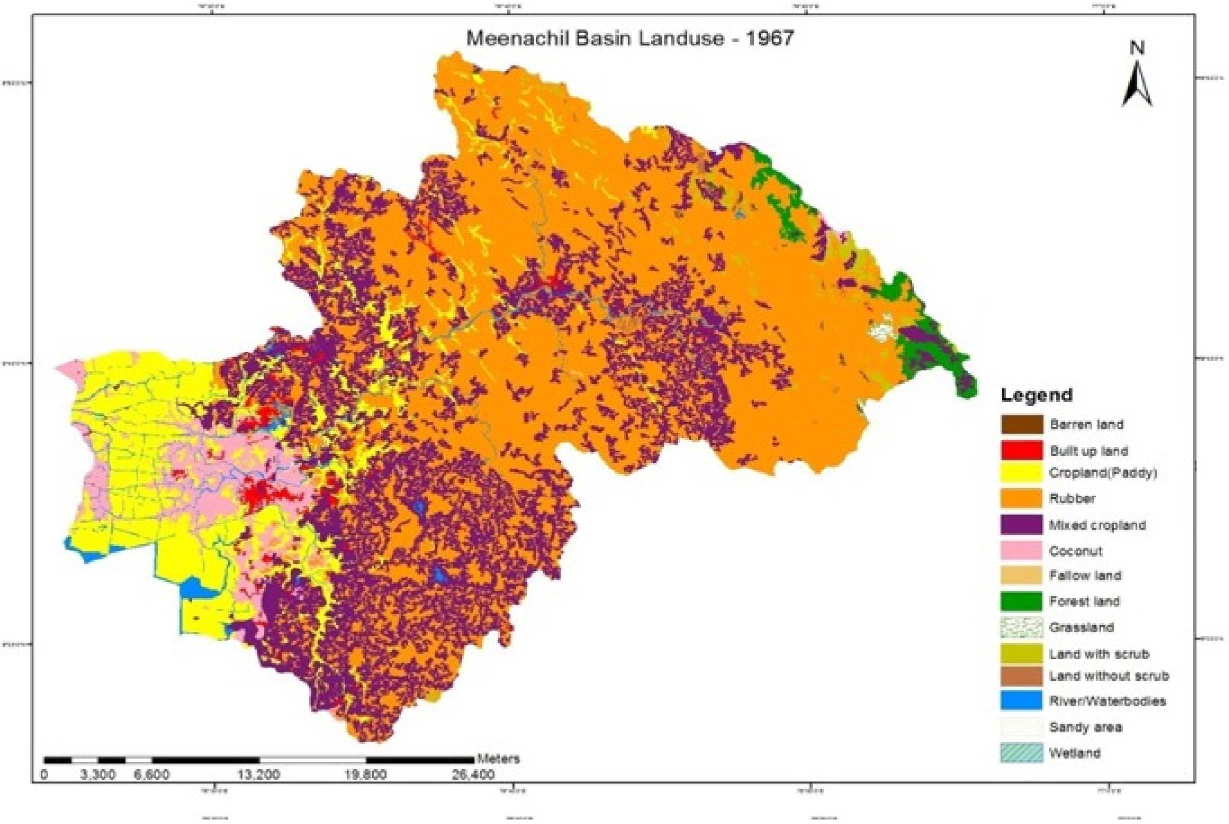

Fig. 3. LULC Change of MRB, 1967.

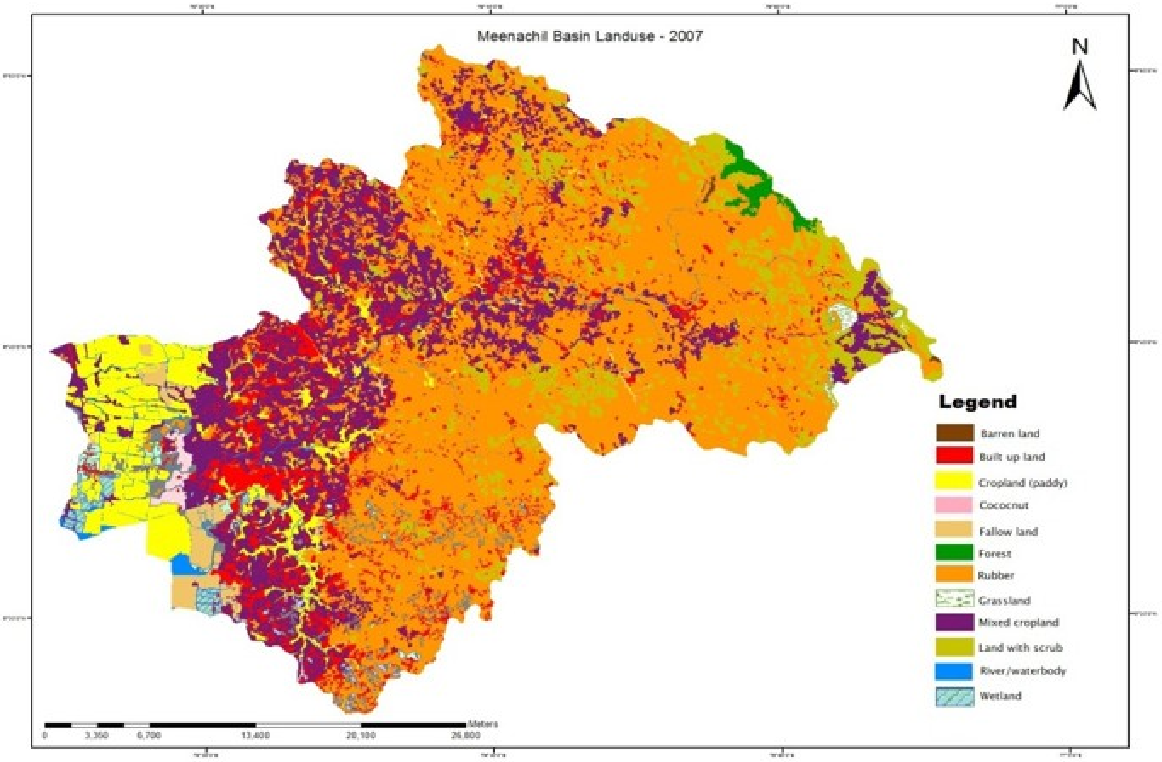

Fig. 4. LULC Change of MRB, 2007.

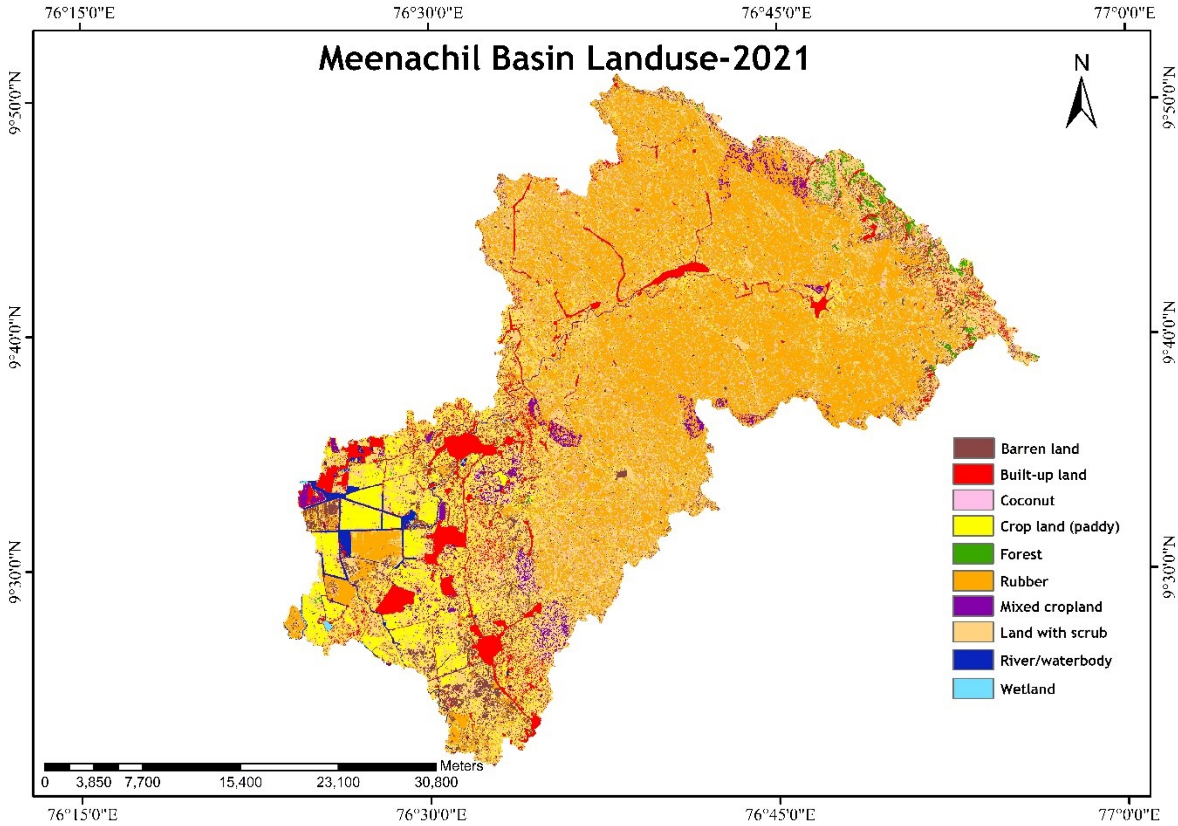

Fig. 5. LULC Change of MRB, 2021.

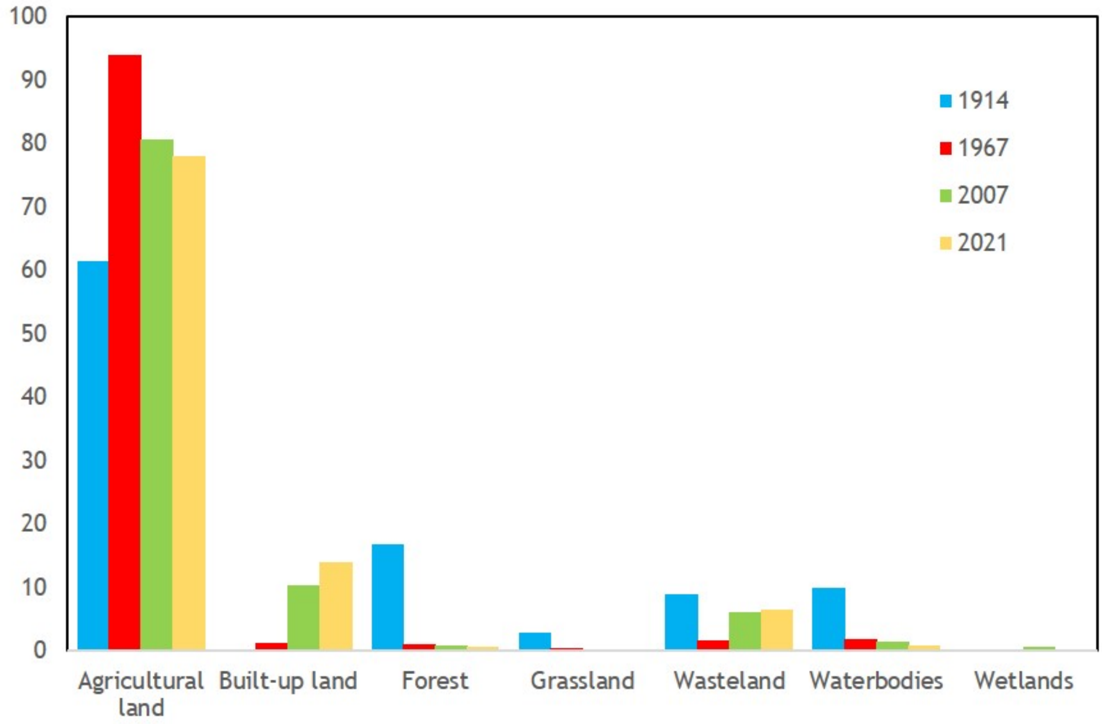

Fig. 6. Area wise distribution of land classes (in %).

Table 2. Land use class (Level-I) for 1914, 1967 and 2007 (in area %).

Land use Level-I	**1914 Area (%)**	**1967 Area (%)**	**2007 Area (%)**	**2021 Area (%)**
Agricultural land	61.49	93.92	80.68	77.97
Built-up land	0.15	1.23	10.23	14.03
Forest	16.76	0.92	0.86	0.64
Grassland	2.77	0.45	0.22	0
Wasteland	8.93	1.58	6.15	6.4
Waterbodies	9.90	1.88	1.32	0.73
Wetlands	0.00	0.00	0.54	0.23

Table 3. Change in area (%) for different periods of Land use class (Level-I).

Land use Level-I	**1914–1967 Area change (%)**	**1967–2007 Area change (%)**	**1914–2007 Area change (%)**	**2007–2021 Area change (%)**	**1914–2021 Area change (%)**
Agricultural land	+32.43	-13.24	+19.19	-2.71	16.48
Built up land	+1.08	+9.00	+10.07	3.8	13.88
Forest	-15.84	-0.06	-15.90	-0.22	-16.12
Grassland	-2.32	-0.23	-2.55	-0.22	-2.77
Wasteland	-7.34	+4.57	-2.78	0.25	-2.53
Waterbodies	-8.02	-0.56	-8.58	-0.59	-9.17
Wetlands	0.00	+0.54	+0.54	-0.31	0.23

Table 4. Land use class (Level-II) for years 1914, 1967, 2007 and 2021.

No.	**Land use Level-II**	**1914 Area (%)**	**1967 Area (%)**	**2007 Area (%)**	**2021 Area (%)**
1	Paddy	3.99	12.17	7.56	3.49
2	Pepper	0	0.01	0.02	0
3	Mixed crop	9.87	28.61	13.15	12.49
4	Tea	0	0.08	0.05	0
5	Coconut	46.91	5.69	0.21	0.14
6	Rubber	0.07	42.88	58.89	61.85
7	Fallow land	0.66	4.48	0.81	0
8	Built up land	0.15	1.23	10.23	14.03
9	Forest	16.76	0.92	0.86	0.65
10	Grassland	2.77	0.45	0.22	0
11	Land with scrub	2.23	1.23	6.12	6.18
12	Land without scrub	4.27	0.15	0	0
13	Sandy area	0.06	0.03	0	0
14	Mining/industrial waste	0	0.01	0	0
15	Barren land	2.37	0.17	0.03	0.23
16	River/waterbodies	9.9	1.88	1.32	0.73
17	Wetlands	0	0	0.54	0.21

No.	**Land use Level-II**	**1914 Area (%)**	**1967 Area (%)**	**2007 Area (%)**	**2021 Area (%)**
1	Paddy	3.99	12.17	7.56	3.49
2	Pepper	0	0.01	0.02	0
3	Mixed crop	9.87	28.61	13.15	12.49
4	Tea	0	0.08	0.05	0
5	Coconut	46.91	5.69	0.21	0.14
6	Rubber	0.07	42.88	58.89	61.85
7	Fallow land	0.66	4.48	0.81	0
8	Built up land	0.15	1.23	10.23	14.03
9	Forest	16.76	0.92	0.86	0.65
10	Grassland	2.77	0.45	0.22	0
11	Land with scrub	2.23	1.23	6.12	6.18
12	Land without scrub	4.27	0.15	0	0
13	Sandy area	0.06	0.03	0	0
14	Mining/industrial waste	0	0.01	0	0
15	Barren land	2.37	0.17	0.03	0.23
16	River/waterbodies	9.9	1.88	1.32	0.73
17	Wetlands	0	0	0.54	0.21

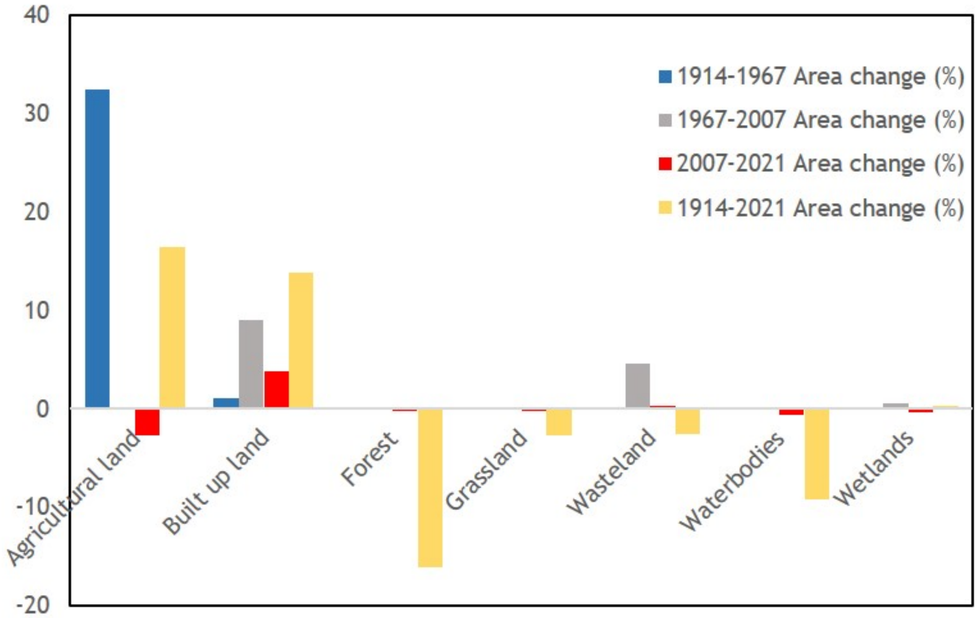

Fig. 7. Change in area (%) for different periods of Land use class (Level-I).

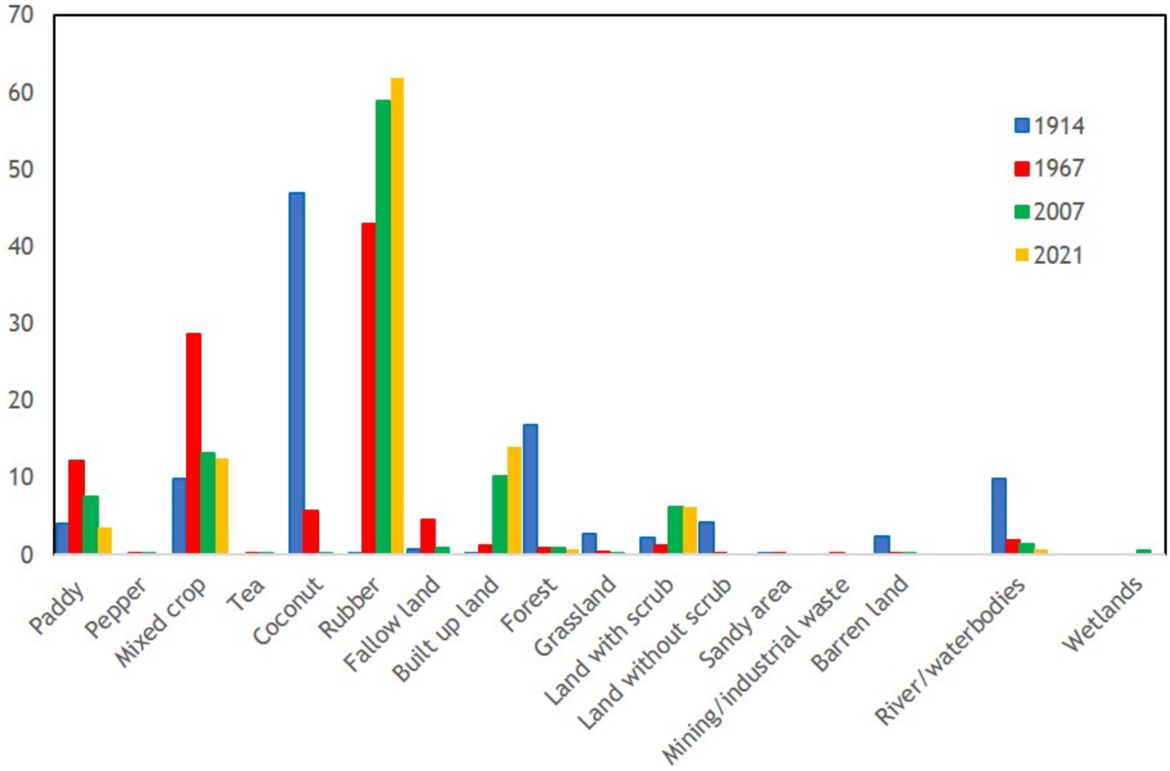

Fig. 8. LULC class (Level-II) for years 1914, 1967, 2007 and 2021.

points (GCP) from diverse land use classes, ensuring a rigorous validation of accuracy.

This study identified and categorized seven principal land use classes at Level-I, viz., agricultural land, built-up land, forest, grassland, wasteland, water bodies, and wetland. Subsequently, Level-II classification further delineated these into 17 distinct sub-categories. An assessment of the spatial distribution revealed the dominance of the agriculture category across the entire study duration, while the remaining categories exhibited varying and often fluctuating trends. For instance, in 1914, agricultural land held the highest abundance, followed by forest, water bodies, wasteland, grassland, and built-up land in a descending order. However, by 1967, the hierarchy shifted to agricultural land > water bodies > built-up land > forest > grassland. Notably, 2007 saw a significant alteration in this sequence, with agriculture land > built-up land > wasteland > water bodies > forest > grassland becoming the new order. By 2021, the order had evolved once again to prioritize agricultural land > built-up land > wasteland > water bodies > forest > wetland > grassland. The description of various categories under level I and II are as follows:

4.1. Land Use Changes

4.1.1. Agricultural lands

Agricultural lands play a pivotal role within the Meenachil River Basin (MRB), serving as the foundation for food, fiber, and the cultivation of commercial and horticultural crops. Leveraging satellite data, a meticulous and detailed classification of these agricultural zones has been achieved, extending even to the Level-II categorization. In the year 1914, the agricultural stretch covered a total area of 743 km^2 (61%). This encompassed a diverse range of crops including paddy, mixed crops, coconut, rubber, and fallow land. This footprint expanded significantly by 1967, covering 1195 km^2 (94%). However, a minor reduction was noted between 2007 and 2021, with the area shrinking from 1026 km^2 (80.6%) to 992.51 km^2 (77.97%). These shifts can be primarily attributed to the conversion of waterlogged areas and ambitious land reclamation efforts in the Vembanad lake region, particularly on the western fringes of the MRB.

Taking a more nuanced perspective, the Level-II classification of the agricultural sector (as depicted in Table 4 and Fig. 8) reveals intriguing patterns. In 1914, coconut cultivation held prominence in the agricultural landscape, followed by mixed crops. In contrast, by 1967, 2007, and 2021, rubber cultivation emerged as the dominant activity, surpassing mixed crops. A closer examination of crop-specific changes across the study periods presents compelling dynamics. The area dedicated to paddy cultivation witnessed a remarkable surge from 3.99% in 1914 to 12.17% in 1967, driven by extensive land reclamation activities in the Vembanad lake regions during that period. However, this trajectory witnessed a subsequent decline, receding to 7.56% in 2007 and further to 3.49% in 2021. The dip in paddy cultivation during the 1967–2021 period can be attributed to a convergence of factors including crop failures, labour shortages, heightened input costs, encompassing labour expenses, and the absence of a robust marketing infrastructure.

Conversely, the cultivated area of coconut witnessed a substantial decline, plummeting from 46.91% in 1914 to a mere 0.14% by 2021. This decline can be attributed primarily to reductions in toddy tapping and coir processing activities. In contrast, rubber plantations experienced rapid expansion, escalating from a mere 0.07% in 1914 to 42.8% in 1967, further surging to 58.89% in 2007, and culminating at 61.85% in 2021. Notably, reports indicate a staggering 627% expansion of rubber plantation area in the Kerala State from 1955 to 2000, with Kottayam district occupying a leading position in this trajectory (Kumar, 2005). The surge in rubber cultivation was propelled by burgeoning market demand, compelling individuals to transform traditionally cultivated lands into rubber plantations. The transformation of scrubland saw a notable intensification, expanding from 2.23% in 1914 to 6.18% in 2021. This shift was primarily attributed to the abandonment of agricultural land. Meanwhile, barren land underwent a decline, dwindling from 2.37% in 1914 to a mere 0.23% by 2021.

Overall, when considering both Level-I and Level-II classifications, the period between 1914 and 1967 witnessed an increase in the areas dedicated to paddy, mixed crops, rubber, built-up land, and fallow land. In contrast, coconut, forest, water bodies, and grassland experienced substantial declines. The surge in agricultural areas, particularly rubber and paddy, came largely at the expense of forest and fallow land.

However, during the 1967–2021 period, a decline was observed in paddy cultivation, mixed crops, coconut cultivation, and fallow land. In contrast, built-

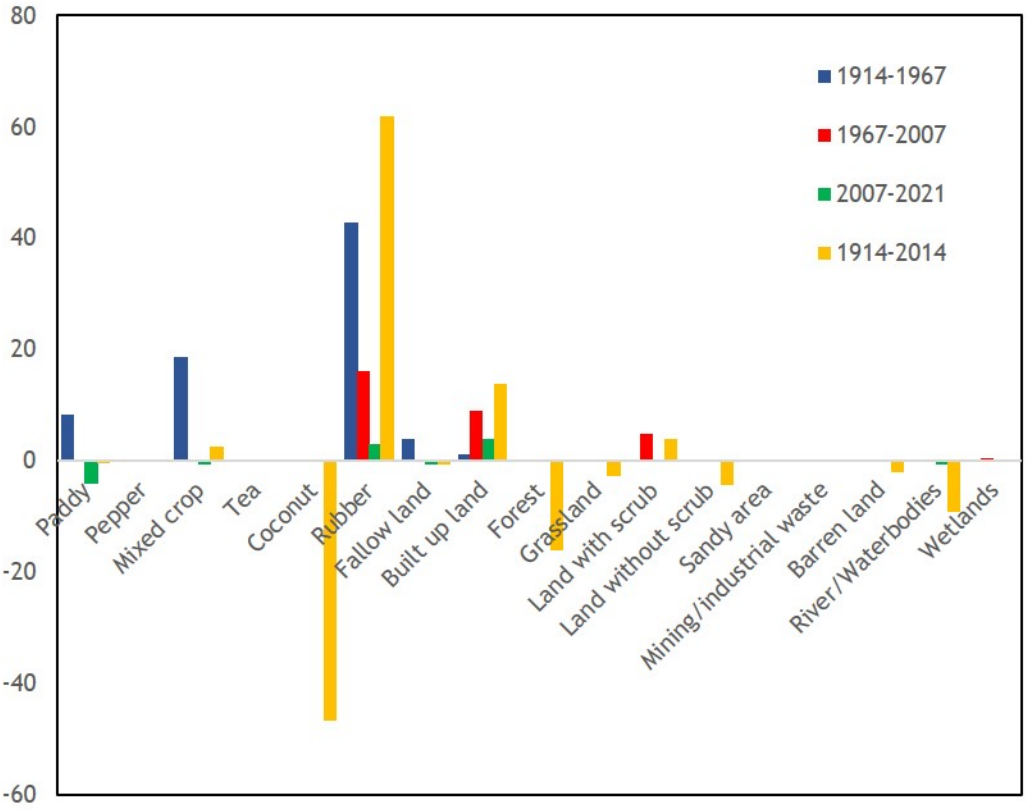

Fig. 9. Change in area (%) for different periods of LULC class (Level-II).

up land, rubber plantations, and shrubland experienced rapid expansion. The growth in built-up land was primarily at the cost of mixed crops and coconut cultivation, while the increase in rubber plantations predominantly replaced mixed crops. In 1914, coconut (46%) and forest (16.7%) were the dominant land use classes, but by 1967 and 2007, rubber had assumed prominence with proportions of 42% and 58%, respectively. Throughout the study period from 1914 to 2021, a pronounced decline in coconut cultivation, forested areas, and water bodies was observed, while rubber cultivation and built-up areas underwent intensification. Similar conclusions based on the studies in Neyyar river basin, Kerala (Sheeja et al., 2010).

4.1.2. Built-up land

Built-up lands encompass areas of human habitation that have been developed for non-agricultural purposes, such as construction, transportation, communication, and utility infrastructure. These zones emerge either in vacant spaces or through the conversion of water bodies and vegetated lands. They are distinguishable on satellite images by their distinctive dark bluish-green core and a bluish tone along the periphery. Notably, they exhibit a characteristic coarse and mottled texture, often interwoven with the network of canals, roads, and railway lines.

Built-up land being a minor fraction of 1.85 km^2 (0.15%) in 1914, increased to 15.6 km^2 (1.2%) in 1967, 130.2 km^2 (10.2%) in 2007, and 178.64 km^2 (14.03%) in 2021. Major construction activities which took place at Kottayam, Pala, and Erattupetta township regions during these periods were responsible for this. The primary cause of increased built-up area is largely attributed rapid urbanization. The study aligns with previous research findings (Abraham and Kundapura, 2022).

4.1.3. Forest

Forests within the Meenachil River Basin (MRB) are characterized by dense canopies of towering trees, predominantly maintaining their verdant hue throughout the year. Distinguished by their red-to-dark red tonality and varied sizes, these areas exhibit irregular shapes and smooth textures. The forest cover encompasses diverse types including evergreen, semi-evergreen, and deciduous forests, as well as degraded forests, forest blanks—defined as openings within forests devoid of tree cover—and forest plantations consisting of trees of significant forestry value, cultivated on officially designated forest lands.

Within the context of the MRB, the forested stretch has witnessed a gradual decline, contracting from 202.6 km^2 (16.76% of total area) in 1914 to 11.7 km^2 (0.92%) in 1967, further diminishing to 10.9 km^2 (0.86%) in 2007, and finally reaching 8.2 km^2 (0.64%) by 2021. This decline can be attributed to deforestation practices and the conversion of these areas into rubber plantations, which have emerged as a primary catalyst for this transformation. Four distinct phases of deforestation within Kerala, including (1) the extensive conversion of forestlands to plantations following a Royal Proclamation in the late 19th century, (2) the "Grow More Food" campaign during the mid-1940s, which led to the clearing of substantial forested areas for food crop cultivation, (3) the colonization wave of the 1950s and 60s, marked by the establishment of new settlements within deforested regions, and (4) the post-independence era's infrastructure development, during which forestlands became host to projects in the power, irrigation, and transportation sectors (George and Chattopadhyay, 2001).

4.1.4. Grassland

The grassland area, constituting 2.77% of the region in 1914, has also exhibited a persistent declining trend, dwindling to 0.22% by 2007. Similarly, the wasteland area, accounting for 8.93% in 1914, experienced a substantial decline to 1.58% in 1967. This decline was primarily attributed to the conversion of waterlogged areas into agricultural lands.

4.1.5. Wasteland

There was a notable intensification of scrubland, which shifted from 8.93% in 1914 to 6.4% by 2021. This transformation was predominantly a consequence of abandoned agricultural land areas. Conversely, barren land experienced a decline from 2.37% in 1914 to a mere 0.23% in 2021. Similarly, sandy areas decreased from 0.06% in 1914 to nearly zero by 2021. This doomed decline may be attributed to illegal sand mining and channel encroachment, emerging as the primary factors contributing to this distressing situation.

4.1.6. Water Bodies

Water bodies, comprising 9.95% of the landscape in 1914, underwent a rapid reduction to 1.88% in 1967, 1.32% in 2007, and further declined to 0.73% by 2021. This swift decline can be attributed to several factors, including the conversion of waterlogged areas within the lowlands for agricultural activities, land reclamation initiatives along river banks and channels, and a shift in traditional water use practices. Notably, this shift encompasses the abandonment of inland water transport facilitated by ferry boats and the exacerbating issue of eutrophication, primarily due to the proliferation of water hyacinth. These combined factors have played a pivotal role in shaping this downward trend in water body coverage. Global phenomena like LU/LC changes cause significant challenges to resource management, including the management of water resources [43]. These changes particularly concerning given the increasing uncertainties and stresses associated with resource management. Several numbers of studies have been conducted worldwide revealing that decline in natural resources, which is resulting in the reduction of ecosystem services; specifically, services related to support, regulation and provisioning of the services.

4.1.7. Wetland

Until 1967, wetland areas were nearly absent; however, they subsequently expanded to 0.5%. This notable change was primarily attributed to wetland conservation activities concentrated along Kumarakom and other coastal regions within the basin (Fig. 2).

In light of the results depicting percent area changes for Level-I (as presented in Table 3 and Fig. 7), a discernible pattern emerges. The period between 1914 and 1967 witnessed the expansion of agricultural land (+32.43%) and built-up land (+1.08%), while forest (-15.84%), grassland (-2.32%), wasteland (-7.34%), and water bodies (-8.02%) experienced a decline in their coverage. A closer examination based on Level-II changes (as detailed in Table 5 and Fig. 6) unveils a clearer perspective. During this same period, there was intensification observed in paddy cultivation (+8.18%), mixed crop cultivation (+18.74%), rubber plantations (+42.82%), fallow land (+3.77%), and built-up areas (+1.08%). In contrast, coconut cultivation (-42.15%), forest (-15.84%), and barren land (-2.20%) exhibited substantial declines.

However, the period spanning 1967 to 2007 witnessed a drastic shift in this landscape. Agricultural lands (-13.24%), forest (-0.06%), grassland (-0.23%), and water bodies (-0.56%) all experienced reductions,

Table 5. Change in area (%) for different periods of Land use class (Level-II).

No.	Land use Level-II	1914–1967 Area change (%)	1967–2007 Area change (%)	1914–2007 Area change (%)	2007–2021 Area change (%)	1914–2021 Area change (%)
1	Paddy	+8.18	-4.61	+3.57	-4.07	-0.5
2	Pepper	+0.01	+0.01	+0.02	-0.02	0
3	Mixed crop	+18.74	-15.47	+3.27	-0.66	2.62
4	Tea	+0.08	-0.04	+0.05	-0.05	0
5	Coconut	-41.23	-5.48	-46.71	-0.07	-46.77
6	Rubber	+42.82	+16.01	+58.82	2.96	61.78
7	Fallow land	+3.82	-3.67	+0.15	-0.81	-0.66
8	Built up land	+1.08	+9.00	+10.07	3.8	13.88
9	Forest	-15.84	-0.06	-15.90	-0.21	-16.11
10	Grassland	-2.32	-0.23	-2.55	-0.22	-2.77
11	Land with scrub	-1.00	+4.88	+3.88	0.06	3.95
12	Land without scrub	-4.11	-0.15	-4.27	0	-4.27
13	Sandy area	-0.03	-0.03	-0.06	0	-0.06
14	Mining/industrial waste	+0.01	-0.01	0.00	0	0
15	Barren land	-2.20	-0.13	-2.33	0.2	-2.14
16	River/Waterbodies	-8.02	-0.56	-8.58	-0.59	-9.17
17	Wetlands	0.00	+0.53	+0.54	-0.33	0.21

while a corresponding growth occurred in built-up land (+9.00%), wasteland (+4.57%), and wetland areas (+0.54%). A similar trend emerged in Level-II classifications, where paddy cultivation (-4.61%), mixed crop cultivation (-15.47%), and coconut cultivation (-5.48%) declined, while intensification was notable in rubber plantations (+16.01%), scrubland (+4.88%), and built-up areas (+9.00%). In essence, these shifts underscore the dynamic nature of land use and cover within the MRB, shaped by multifaceted interactions between human activities, conservation efforts, and ecological factors. The similar results are also made Vincy et al. (2012). The transition from rural to urban living, particularly in central Kerala, has led to significant alterations in LU/LC patterns. These transformations, primarily the rise in urban development and deterioration of wetlands, played a pivotal role in intensifying the floods witnessed by the region in the years 2018, 2019 and 2021 (Sonu and Bhagyanathan, 2022). Greater flood peaks could occur as a result of growing urbanisation (Chandu et al., 2022). Land conversions and rapid urbanization could have an impact on both the ecosystem and the presence of diverse inhabitants. If there is inadequate planning during infrastructure development, there is a possibility that an ecologically significant area could be turned into an ecologically insignificant region (Raj and Azeez, 2010).

4.2. Comparison of land use trend with the current policies

A comparison has been made with the current land use with the current policies for climate change and sustainable development. The present land use trend in the basin is totally against the policies. A drastic reduction in the forest can be observed in the basin, which is against the present climate change policy for the intensification efforts to protect forests. The high rise in built-up area may cause a rise in the discharge of waste water into the river, soil erosion etc. The current policy on sustainable development is to be strictly adhered to. The facility for the treatment of wastewater shall be in place. The considerable reduction in our water bodies is to be considered seriously, and provision for the conservation of water resources is to be made.

4.3. Suggested Land use policy for MRB

1. The deforestation and degradation of existing forests shall be stopped. Reforestation and afforestation shall be encouraged. Forest is to be protected from the forest fire, mining and natural calamities. The existing forests are to be developed as national park for its protection. Survey of the forest is to be conducted and its inventory shall be prepared. The laws for the protection of forest are to be implemented in an effective manner.
2. Appropriate soil erosion control measures shall be adopted, especially in the steep sloping area having rubber plantations. Steps are to be taken to identify such areas for soil erosion control measures. Water recharge measures are to be adopted in plantation areas.
3. The conservation of water bodies is to be given prime importance in consideration of climate

change and the rise in population. Rivers, wetlands, and springs are to be protected, especially from reclamation and encroachment. The summer flows in rivers shall be enhanced by watershed conservation measures. The area in which the depletion of water resources occurred shall be studied, and steps for restoring water bodies are to be taken.

4. The paddy fields, wetlands shall be preserved for the percolation of rain water. Artificial ground water recharge shall be promoted. The recharge of wells shall be improved. The percolation of ground water shall be promoted storm water drainages shall be rejuvenated, especially in rubber plantation areas.
5. Mixed crop cultivation, paddy cultivation, and coconut cultivation shall be encouraged. The use of bio fertilizers and bio pesticides shall be promoted for agricultural activities.
6. Adequate treatment facilities shall be provided in the built-up area for the sewage, sullage, and garbage generated in the basin. Green public transportation, green energy access, green housing, and building are to be adopted, especially in the built-up areas for developing sustainable cities. The reuse and recycling of water shall be encouraged.

5. CONCLUSION

The Land Use/Land Cover (LU/LC) study conducted in the Meenachil River Basin (MRB), India, spanning over 107 years—encompassing the years 1914, 1967, 2007, and 2021—has meticulously identified seven categories under Level-I and delved into 17 sub-categories under Level-II. The findings of this study illuminate profound and dramatic shifts in land use patterns during the observed period, with agriculture consistently dominating the landscape. However, the trends within other categories have been notably erratic.

In 1914, the hierarchy of land abundance was led by agricultural land, trailed by forest, water bodies, wasteland, grassland, and built-up areas. This landscape configuration underwent significant transformations by 2007, with agricultural land surging to the forefront, followed by built-up areas, wasteland, water bodies, forest, and grassland. This pronounced shift underscores the drastic decline in forested areas and the rapid expansion of built-up spaces.

Analyzing the period from 1914 to 1967, considering both Level-I and Level-II classifications, reveals an expansion in areas dedicated to paddy cultivation, mixed crops, rubber plantations, built-up development, and fallow land. Simultaneously, significant decreases are observed in coconut cultivation, forest cover, water bodies, and grassland. The upswing in agricultural land is largely at the expense of forested areas. However, within the agricultural domain, the rise of rubber plantations is chiefly at the cost of forest, coconut cultivation, and mixed crops. Conversely, from 2007 to 2021, a decline is noted in paddy cultivation, mixed crops, coconut cultivation, and fallow land. This period saw substantial growth in built-up areas, rubber plantations, and scrubland. The expansion of built-up areas primarily encroached upon mixed crop and coconut cultivation spaces, while rubber plantations saw growth at the expense of mixed crops.

A striking transformation emerges in the realm of rubber cultivation, which witnessed an exponential rise of 816.94%, contrasted by a sharp decline of 624.2% in coconut cultivation. A noteworthy reduction of 214.26% in forested areas is evident, indicating a significant impact of rubber cultivation on both coconut plantations and forests. Across the entire observation span (1914–2021), a stark decrease in coconut cultivation, forest cover, and water bodies is evident, juxtaposed with the intensification of rubber cultivation and the expansion of built-up areas. The surge in built-up areas poses a considerable threat to water conservation efforts, as it leads to a decline in water resources. This concerning trajectory must be addressed with utmost urgency, as the increasing demand for water due to population growth will exacerbate the already dwindling water resources. Thus, prioritizing water resource conservation becomes paramount.

Furthermore, the current land use change is not in lieu of the climate change policy, and mitigatory measures are urgently needed for the sustainable management of MRB, safeguarding its ecological integrity and the well-being of its inhabitants.

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