punjab geographer

A DOUBLE BLIND PEER REVIEWED JOURNAL OF APG AND KSS-ISPER INDIA

VOLUME 21 ISSN: 0973–3485 OCTOBER 2025

LAND USE/LAND COVER TRANSFORMATION AND ITS DRIVERS IN BILATE WATERSHED, ETHIOPIA

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Abstract

The understanding of the extent of land use/land cover changes and their driving forces is essential for modeling future landscape dynamics and developing sustainable land resource management strategies to mitigate natural resource degradation. Therefore, this study has been aimed to assess the spatio-temporal dynamics of land use/land cover transformation and to identify the key driving factors of land use/land cover changes in the Bilate watershed, Ethiopia. In this study, a mixed-methods approach has been employed, integrating remote sensing techniques with ground-truthing of satellite data and field observations through household surveys, key informant interviews, and focus group discussions. Land use classes have been categorized with supervised classification applying maximum likelihood algorithm. The change detection has been conducted with transformation matrix. The study reveals that a significant increase has taken place in built-up area and agriculture land. In contrast, forest cover has declined sharply. Surprisingly, the expansion of wood land has been noticed which reflects a shift in land cover from dense forest to less vegetated areas. Population growth, agricultural expansion, urban settlement, charcoal production (making coal from wood chips), and firewood collection have emerged as the top five drivers of land use/land cover change, as reported by local respondents. The findings suggest that there is an urgent need for sustainable land resource management to mitigate the ongoing degradation of natural resources in the watershed.

Keywords: Bilate watershed, Drivers of land cover changes, GIS and remote sensing

Introduction

Land is an essential natural resource for human life, and modifications in land use/land cover are widely recognized as important drivers to global environmental change (Pandey et al., 2019). Land use/land cover is a widely used concept in environmental studies. Land use refers to the way humans utilize the land and its resources to meet their needs, such as for agriculture, residential settlements, industry, forestry, or recreation. It reflects human decisions and socio-economic activities that determine how land is managed and developed (Minale, 2013). In contrast, land cover describes the physical and biological features present on the surface of the earth, such as forests, grasslands, water bodies, bare soil, and built-up areas (Anderson et al., 1976;

Anteneh, et al., 2018). Land use is more about the function or purpose of the land, while land cover focuses on what is physically observable. The land use/land cover change encompasses all transformations in both land use/land cover over time, whether caused by natural processes or human intervention (Lambin et al., 2003). These changes include phenomena such as deforestation, urban expansion, agricultural intensification, or desertification, which significantly alter the land use and ecosystem services. The drivers of land use/land cover change are often categorized into proximate (direct) and underlying (indirect) factors (Geist and Lambin, 2002). Proximate drivers include immediate actions such as logging, agricultural expansion, infrastructure development, and charcoal production. In contrast, underlying drivers encompass broader structural factors such as population growth, economic development, technological innovation, land tenure systems, and institutional or policy frameworks (Lambin et al., 2003; Campbell et al., 2003; Kindu et al., 2015).

The land conversion refers to the transformation of land use types as a result of human activities and interventions (Elias et al., 2019). Although the land resources deliver critical ecosystem services that support human wellbeing; yet the integrity of these ecosystems is being compromised by escalating anthropogenic pressures (Minale, 2013). As a result, land use/land cover changes have emerged as a critical issue in contemporary environmental discourses and policy planning (Sewnet, 2015; Mariye et al., 2022).

Assessing land use/land cover changes and analyzing their temporal and spatial dynamics are critical for framing strategic land use planning and implementing sustainable natural resource management practices (Tahir et al., 2013). The analysis of land use/land cover changes, delineation and mapping of land cover types, along with the documentation of driving forces, play a crucial role in achieving sustainable natural resource management (Katana et al., 2013). Monitoring land use/land cover changes through remote sensing and GIS technologies enables quantitative analysis of land transformations; however, it does not adequately explain the underlying causes or the relationships between the driving factors and those changes (Bekele et al., 2019; Mariye et al., 2022). In the light of above, this study has been undertaken to understand the dynamics of land use/land cover transformation and its drivers in Bilate watershed, Ethiopia.

Objectives of the Study

Major objectives of the study are:

- to analyze the dynamics of land use/land cover transformation, and
- to identify the driving forces of land use/land cover transformation in Bilate watershed of Ethiopia.

Study Area

The Bilate watershed lies between 6° 0' 0" to 8° 0' 0" N latitudes and 37° 0' 0" to 38° 15' 0" E longitudes and covers an area of about 5606.7 km² (Fig. 1). It is located in the southern Ethiopian Rift Valley and partly in the Western Ethiopian Highlands. The altitude of the watershed ranges from 1124 to 3287 meters above sea level. The watershed has a tropical climate with pronounced aridity in the southern part and a warm-temperate rainy climate in the central and northern highlands. It receives about 854 to 1039 mm rainfall annually. The mean annual maximum and minimum temperatures vary between 22.8 to 30.4 °C and

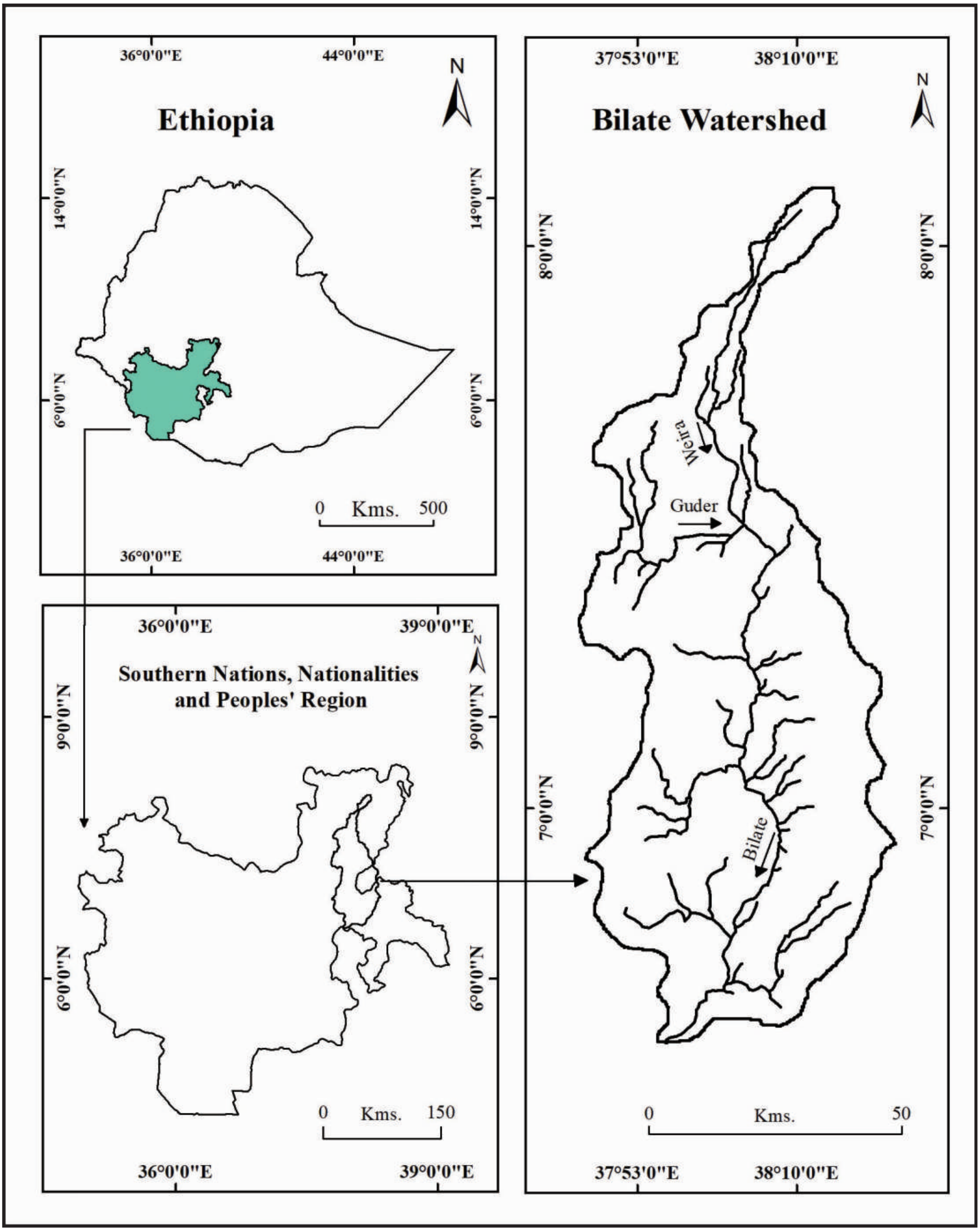
Ethiopia
36°0'0"E
44°0'0"E
14°0'0"N
6°0'0"N
N
0 Kms. 500
Southern Nations, Nationalities
and Peoples' Region
36°0'0"E
39°0'0"E
9°0'0"N
6°0'0"N
0 Kms. 150
Bilate Watershed
37°53'0"E
38°10'0"E
8°0'0"N
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Fig. 1

10.7 to 16.8 °C, respectively. The highlands and middle areas of the Bilate watershed are known for their intensive cultivation due to high population density. The land use system is dominated by rain-fed agriculture leading to a subsistence agriculture. The highlands and middle areas are known for growing different crops such as wheat (*Triticum Aestivum*), barley (*Hordeum Vulgare*), and Teff (*Eragrostis Tef*). Farmers have intensive home gardens close to their homes, where they cultivate Enset (*Ensete Ventricosum*) and coffee.

Data Base and Methodology

Time series LANDSAT images for the years 1994, 2004, 2014, and 2024 have been used to analyze land use/land cover changes. The year 1994 serves as the land mark, following significant political and economic changes in Ethiopia, including the post-Dreg regime era and the implementation of new land management policies (Abdeta et al., 2024). For land use/land cover classification, LANDSAT TM 1994, LANDSAT ETM+ 2004, LANDSAT OLI/TIRS 2014, and Sentinel-2 2024 have been utilized (Table 1). The LANDSAT images for the month of January to February have been considered to exclude the impact of cloud cover on the quality of the image.

ERDAS imagine 10.4 has been used to preprocess the imagery, to classify the land use/land cover types for accuracy assessment and for comparison matrix. Validation and accuracy assessment are critical components in evaluating the reliability of land use/land cover classification results in remote sensing. According to Congalton (1991), a minimum of 50 random points per class are required to ensure statistically sound accuracy assessment. In line with this recommendation, the stratified random sampling method has been employed to ensure adequate representation of all land use/land cover classes. Consequently, a total of 136, 106, 130, and 147 random sample points have been generated for the years 1994, 2004, 2014, and 2024, respectively, across the six identified land use/land cover classes. Furthermore, Kappa statistics have been performed to measure the extent of classification accuracy. The supervised classification method with a maximum likelihood algorithm has been used to study the land use/land cover types.

The drivers of land use/land cover change have been derived from socio-economic survey of the households spreading over three agro-climatic zones of Bilate watershed. For this, three kebele (the smallest administrative unit in Ethiopia) have been randomly selected representing each agro-climatic zone. These agro-climatic zones are (i) dega (highland or upper watershed, 2300-3200 meters above sea level), (ii) woina dega (midland or middle watershed, 1500-2300 meters above sea level), and (iii) kola (lowland or lower watershed, 500-1500 meters above sea level). Households within each kebele have been proportionally sampled, making a total of 301 surveyed households. Apart from above, focus group discussions have been conducted to explore the long-term experiences related to land use/land cover changes. Participants in the focus group discussions included farmers, development agents, members of the Kebele cabinet and community elders. For more in-depth discussions, elderly participants aged over 50 years have been purposefully chosen, as it is expected that they can provide valuable historical perspectives on land use/land cover changes over the past three decades. Ranking of the drivers of land use/land cover changes, perceived by respondents, has been computed with the principle of weighted average using

Table 1
Bilate Watershed: Sources of Remote Sensing Data

Year	Sensor Type	Spatial Resolution	Acquisition Date	Path /Row	Source
1994	LANDSAT TM	30 m	January 15/1994	169/55	USGS
2004	LANDSAT ETM+	30 m	January 22/1994	169/55	USGS
2014	OLI/TIRS	30 m	February 09/2014	169/55	USGS
2024	Sentinel -2	10 m	February 07/2024	169/55	USGS

Source: Compiled by Authors.

Table 2
Bilate Watershed: Area under Different Categories of Land Use/Land Cover

Land Use/	1994		2004		2014		2024	
Land Cover Class	Area (km²)	Percent	Area (km²)	Percent	Area (km²)	Percent	Area (km²)	Percent
Agricultural land	2546.60	45.42	3300.25	58.86	3405.67	60.74	3423.92	61.07
Barren land	123.96	2.21	264.00	4.71	251.29	4.48	110.24	1.97
Built-up area	51.58	0.92	70.77	1.26	342.42	6.11	896.42	15.99
Forest land	2710.44	48.34	1150.88	20.53	575.84	10.27	130.68	2.33
Water body	7.88	0.14	37.45	0.67	41.10	0.73	39.34	0.70
Wood land	166.27	2.97	783.35	13.97	990.24	17.66	1006.13	17.95
Total	5606.70	100.0	5606.7	100.0	5606.7	100.0	5606.70	100.0

Source: Compiled by Authors.

the ranking index (Musa et al., 2006; Solomon et al., 2017).

Results and Discussion

Pattern of Land Use/Land Cover Change

Land use/land cover dynamics refer to variations in land use/land cover and changes over a period of time largely driven by both anthropogenic factors and natural processes. The Bilate watershed has experienced significant land use/land cover changes during the study period. In this study, six major classes of land use/land cover have been identified and discussed in the following sections.

Agricultural Land

The majority of the rural inhabitants in Bilate watershed mainly rely on agriculture. In 1994, agricultural land has been the second most dominant land use/land cover category, accounting for approximately 2,546.60 km² area of the watershed (Table 2; Fig.2). Over the subsequent decades, agricultural land experienced a consistent and significant increase reaching to 3,300.25 km² in 2004, 3,405.67 km² in 2014, and 3,423.92 km² by the year 2024 (Table 2; Figs. 3, 4, and 5). Overall, agricultural land increased by 877.32 km² during the study period. The increasing trend in agricultural land is largely at the expense of forested area and barren land. This shift may be linked to the growth of small-scale farming in response to increasing population pressure.

Barren Land

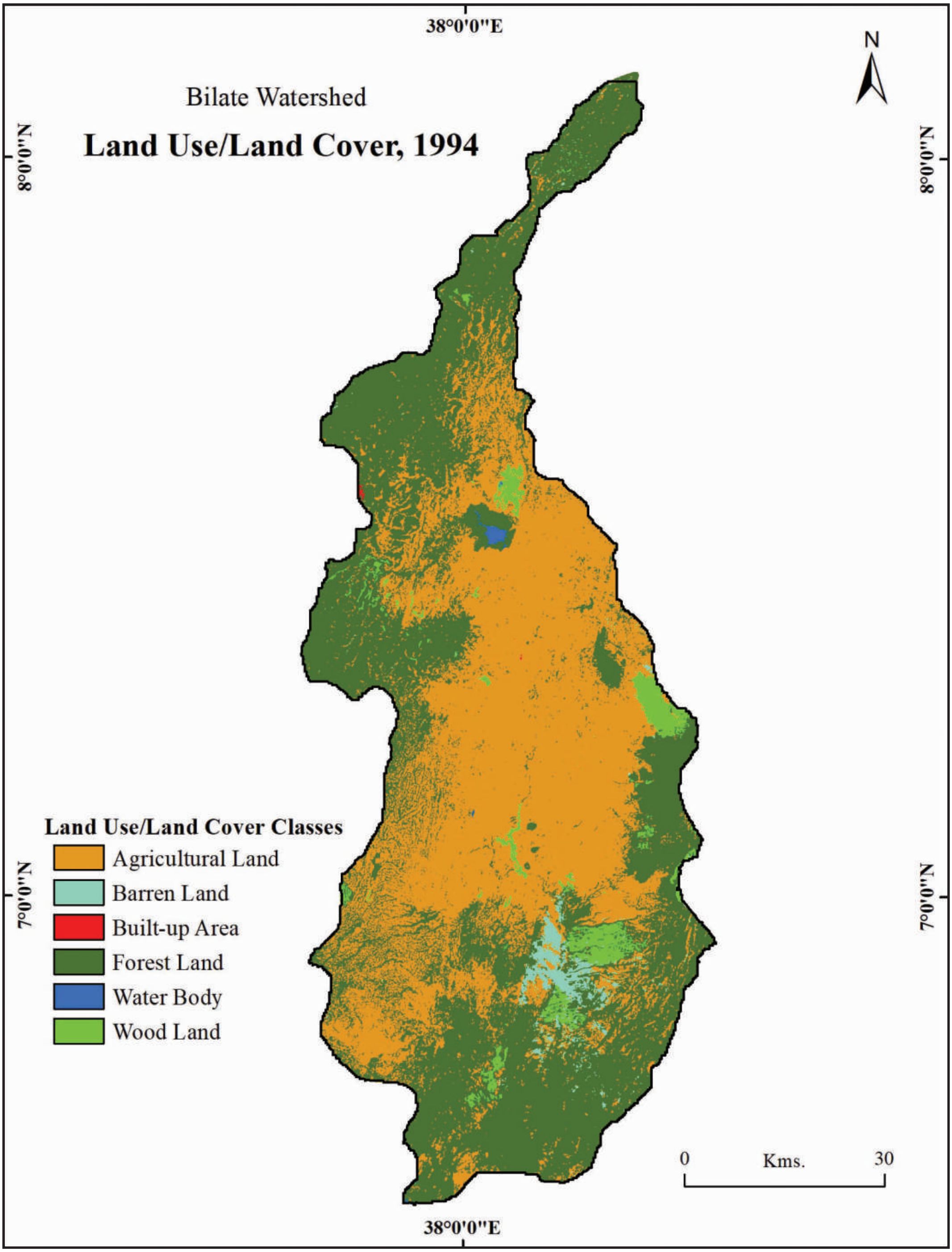
Barren land has exhibited noticeable changes. In 1994, area under barren land has been 123.96 km². This area increased significantly to 264.00 km² by 2004 (Table 2; Fig. 2 and 3). However, it experienced a substantial decline in the subsequent decades, with barren land decreasing to 251.29 km² in 2014 and further shrinking to 110.24 km² by the year 2024 (Table 2; Fig. 4 and 5). The initial increase in barren land during 1994 and 2004 may be attributed to prolonged precipitation failures in Ethiopia, which marked the start of recurrent drought events, which led to extensive degradation of natural vegetation cover and contributed to land degradation. However, decline in barren land during 2004 to 2024 can be attributed to land rehabilitation initiatives, and the implementation of sustainable natural resource management policies.

Built-up Area

The built-up area has exhibited a consistent and substantial increase. It increased from 51.58 km² in 1994 to 70.77 km² in 2004, followed by a significant increase to 342.42 km² in 2014, and ultimately reached to 896.42 km² in 2024 (Table 2, Figs. 2, 3, 4, and 5). Overall, the built-up area increased by a total of 844.84 km² during the study period. This expansion in built-up area is primarily attributed to the growth of small towns and institutions across various parts of the watershed. This trend is largely driven by rural-to-urban migration, resulting from the scarcity of arable land, low agricultural productivity, limited employment opportunities in rural areas, and inadequate infrastructure.

Forest Land

In 1994, forest land has been the dominant land use/land cover, covering approximately 2,710.44 km² of area. However, forest land underwent a sharp and consistent decline over the subsequent decades. Forest land decreased from 2710.44 km² in 1994 to 575.84 km² in 2014 and ultimately remained only 130.68 km² by the year 2024 (Table 2;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Land Use/Land Cover, 1994
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Land Use/Land Cover Classes
Agricultural Land
Barren Land
Built-up Area
Forest Land
Water Body
Wood Land
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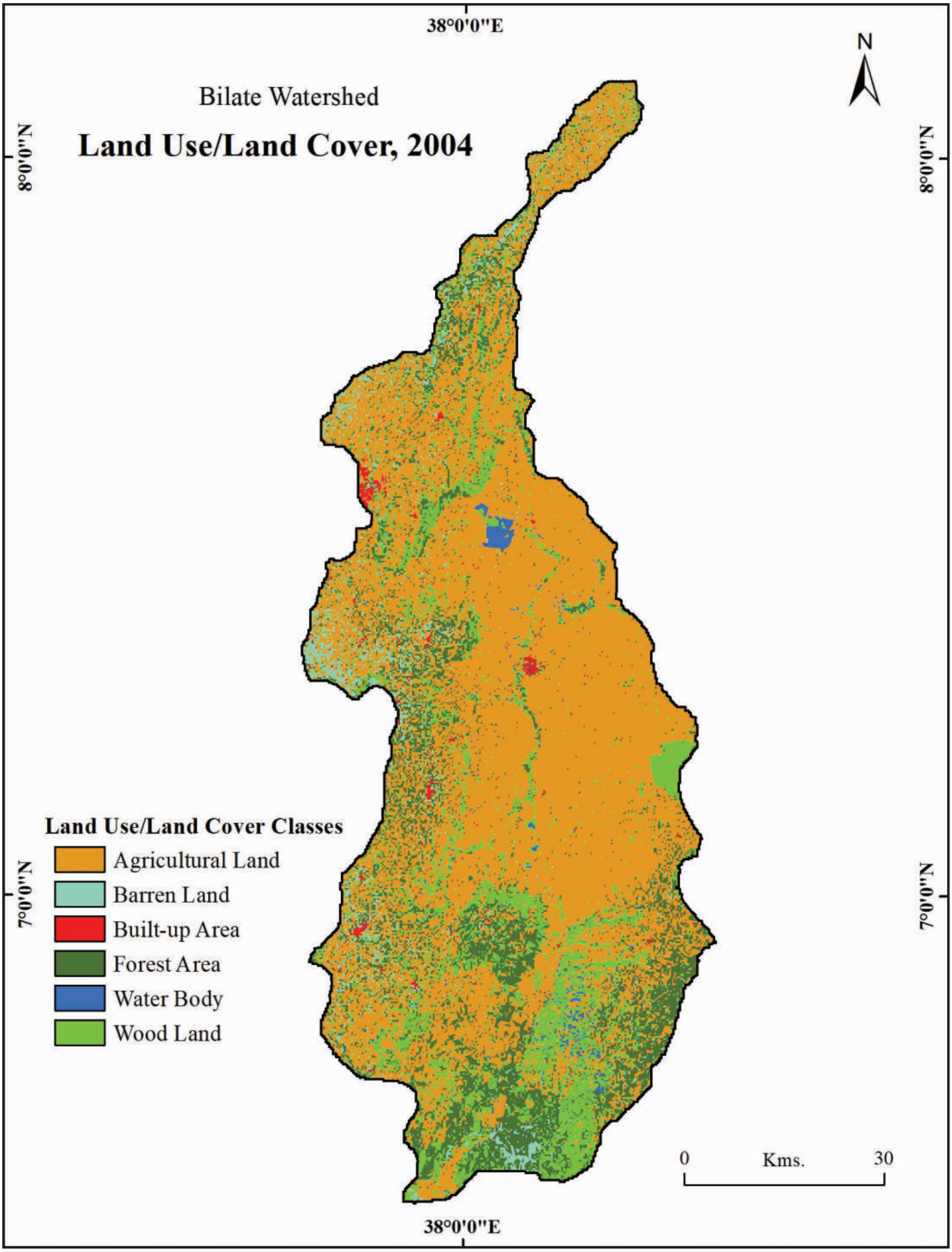
Fig. 2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Barren Land
Built-up Area
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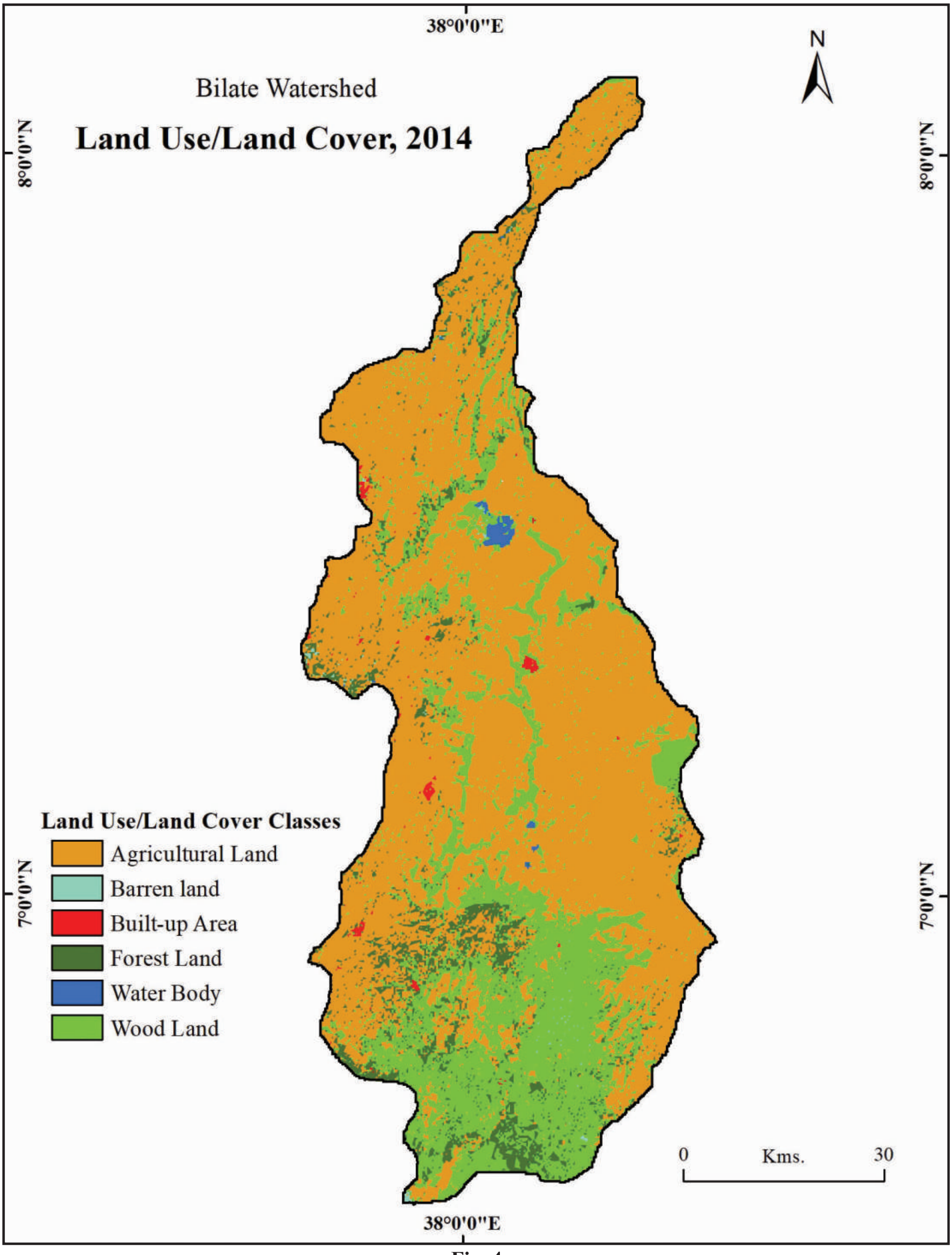
Fig. 3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Land Use/Land Cover Classes
Agricultural Land
Barren land
Built-up Area
Forest Land
Water Body
Wood Land
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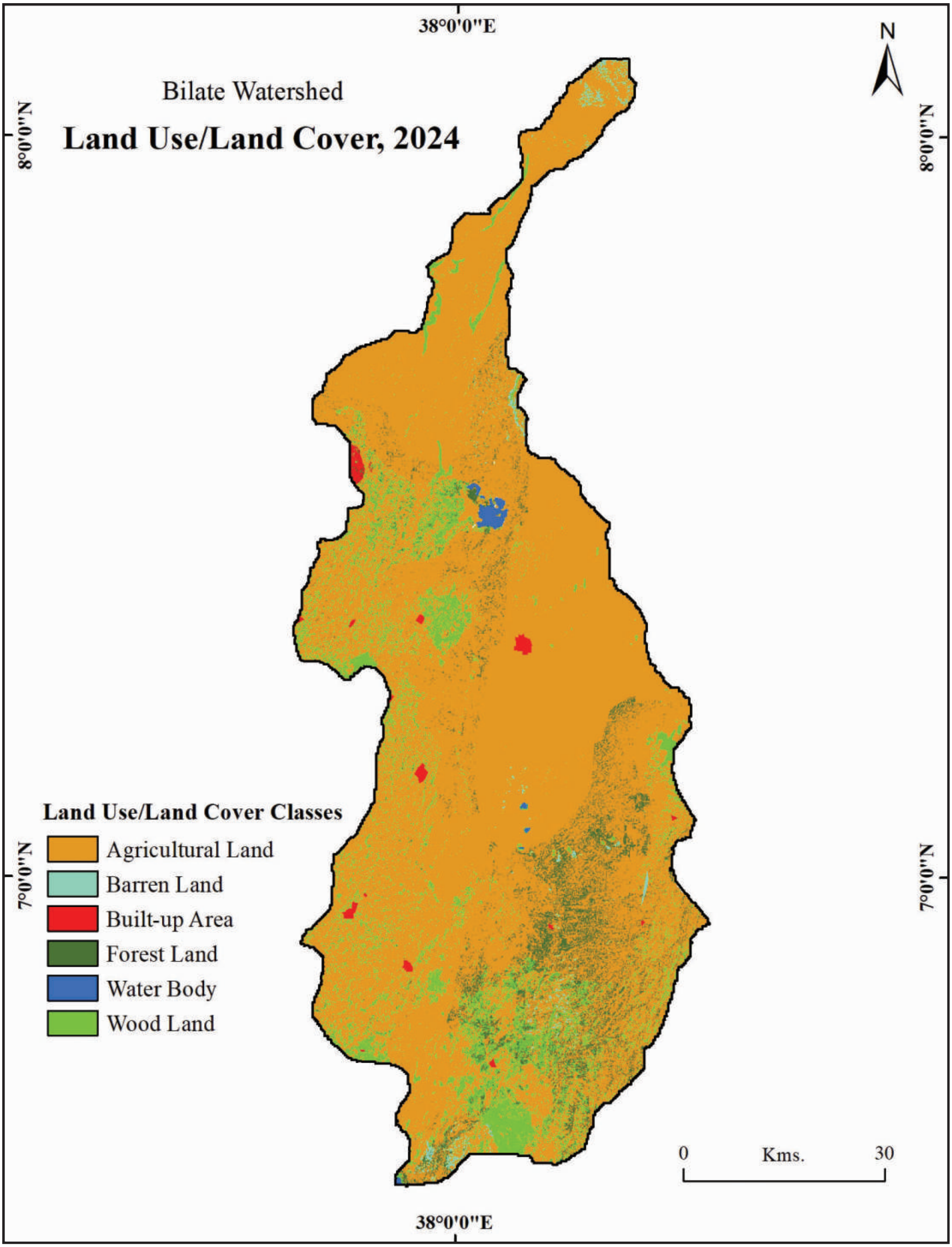
Fig. 4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Land Use/Land Cover Classes
Agricultural Land
Barren Land
Built-up Area
Forest Land
Water Body
Wood Land
7°0'0"N
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Fig. 5

Figs. 2, 3, 4, and 5). Thus, the area under forest cover decreased to 2579.76 km² during the study period. The decline in forest area is primarily attributed to widespread deforestation, largely driven by the expansion of agricultural activities. The increasing demand for cultivable land has been a consequence of rapid population growth. The conversion of dense forest areas into agriculture land has been particularly prominent in the highland and midland areas of the watershed, where population density is high. In these areas, land use has been predominantly characterized by rain-fed and subsistence agriculture.

Water Bodies

The extent of area under water bodies within the Bilate watershed exhibited an increasing trend up to the year 2014. In 1994, water bodies have covered 7.88 km² of area, which significantly increased to 37.45 km² in 2004, followed by a modest increase of 41.10 km² in 2014. However, a slight decline has been observed in 2024, with water bodies covering 39.34 km² of area (Table 2; Figs. 2, 3, 4 and 5). Despite these fluctuations, the area under water bodies remained consistently below than one per cent of the total area of the watershed. The increase in the extent of area under water bodies from 1994 to 2014 may be primarily attributed to the implementation of irrigation projects aimed at supporting the livelihoods of the growing population. These developments have significantly increased the surface water availability, particularly in the middle parts of the watershed. In lower part of the watershed, state farm irrigation schemes such as those in the Bilate and Abaya districts have contributed to this expansion. The slight decline in the extent of area under water bodies in 2024 can be attributed to reduced rainfall patterns resulting in reduced surface water visibility.

Woodland

Woodland cover has shown a consistent and substantial increase over the past three decades. It has increased from 166.27 km² in 1994 to 783.35 km² in 2004, further increasing to 990.24 km² in 2014, and 1,006.13 km² by the year 2024 (Table 2; Figs. 2, 3, 4 and 5). This consistent increase can be attributed to several factors. Major key driver has been the mass tree plantation initiatives taken under the Green Legacy Initiative, which has been actively implemented since the year 2019. Additionally, the decline in forest cover due to degradation and conversion has often led to the emergence of lower-canopy woodlands, contributing to the woodland category. Furthermore, in many districts within the watershed, farmers have planted eucalyptus trees on their farmlands as a strategy to diversify income sources and enhance livelihoods. This widespread plantation of eucalyptus is also considered a significant factor in the expansion of woodland.

Accuracy Assessment

The accuracies in land use/land cover classification for the four reference years (1994, 2004, 2014 and 2024) have been 88.2, 87.7, 89.2 and 90.5 per cent, respectively (Table 3). The accuracy assessment reveals that overall accuracy has been 85 per cent and Kappa statistics (0.85) is higher than the Anderson's standard (Anderson, 1976). The users, producers and overall accuracies have been found to be very good for almost all the land use classes. Since, the overall and per-class accuracies obtained from all types of images have been higher than 85 per cent and

Table 3

Bilate Watershed: Accuracy Assessment of Land Use/Land Cover Classification

Land Use/ Land Cover Class	1994		2004		2014		2024	
	Producer	User	Producer	User	Producer	User	Producer	User
Agricultural land	78.90	83.30	87.00	90.90	75.00	87.50	85.30	85.30
Barren land	88.20	90.90	84.20	80.00	80.00	87.00	91.30	87.50
Built-up area	92.60	86.20	82.20	82.40	76.00	86.40	87.50	90.30
Forest land	83.30	83.30	90.00	90.00	87.50	87.50	94.70	90.00
Water body	100.00	100.0	100.0	100.0	100.00	100.0	100.0	100.0
Woodland	86.90	86.90	88.00	88.20	87.50	91.30	90.90	95.20
Overall accuracy	88.20	NA	87.70	NA	89.20	NA	90.50	NA
Kappa	**0.86**	**-**	**0.85**	**-**	**0.87**	**-**	**0.88**	**-**

Source: Compiled by Authors.

minimum threshold of 70 per cent, respectively. Therefore, the accuracy assessment results of land use/land cover classification are acceptable as per the standards of Anderson, (1976) and Thomlinson et al. (1999). The overall classification accuracy of the satellite images yielded a Kappa statistics of 0.86, 0.85, 0.87 and 0.88 for the years 1994, 2004, 2014 and 2024, respectively (Table 3). The values of Kappa statistics for each of the four classified images have been greater than 0.80 (80 per cent) confirming a strong level of agreement in classification accuracy.

Land Use/Land Cover Change Transformation Matrix

The land use/land cover change matrix reveals that all the land use/land cover classes have experienced a change (Table 4). However, the extent and direction of conversion has varied significantly reflecting the impact of both human-driven pressures and environmental dynamics. Built-up area has exhibited the highest stability, with 98.64 per cent of it being categorized as unchanged, signifying the permanence of urban infrastructure once developed (Table 4). Similarly, water bodies have demonstrated a high degree of resilience, maintaining 90.35 per cent of their area, possibly due to physical constraints or conservation policies limiting their alteration. In contrast, the forest category has exhibited the most substantial change, with retaining only 7.39 per cent of its original area, marking an alarming loss of 92.61 per cent. This decline highlights a serious environmental concern, as large areas under forest land have been converted primarily to agricultural land (48.10 per cent), followed by woodland (24.01 per cent) and built-up areas (20.14 per cent). Such trends reflect, deforestation driven by the need for arable land and expansion of settlements.

Agricultural land, while remaining relatively stable compared to forest and woodland, also has underwent a notable change with loosing 22.94 per cent of its original area. The largest share of this loss has been converted into woodland (11.61 per cent) and built-up land (11.29 per cent), indicating a dual dynamic of expansion of urban areas and natural or planned vegetation recovery in the watershed. In the category of barren land, 68.02 per cent of its area has experienced a shift, primarily to agriculture (34.40 per cent) and woodland (33.62 per cent), implying reclamation efforts or natural succession of previously unproductive terrain. However, woodland itself experienced significant loss (79.8 per cent), mostly to agriculture (72.11 per cent), indicating a possible cyclic interaction where regenerated vegetative areas are reclaimed for agriculture.

Perception of Local Community on Land Use/Land Cover Change

The analysis of primary data reveals that respondents identified twelve major drivers contributing to land use/land cover change. Among these, population growth, agricultural expansion, urban-areas/ settlement, firewood collection and charcoal production have been ranked as the top five (Table 5). Majority of the respondents from the highland agro-climatic zone, identified population growth as the most pressing driver. During a focus group discussion, the common narrative of respondents has been that "with more children and families, the available farmland is no longer enough, forcing us to clear more forest and marginal lands to survive". This highlights how demographic pressures in densely populated highlands

Table 4
Bilate Watershed: Land Use/Land Cover Change Transformation Matrix (1994–2024)

Land Use/ Land Cover Class	Unit	Agriculture Land	Barren Land	Built-up Area	Forest Land	Water Body	Woodland	Total (1994)
Agricultural land	(km^2)	**1962.46**	0.04	287.54	0.56	0.34	295.66	2546.60
	Percent	77.06	0.00	11.29	0.02	0.01	11.61	100.0
Barren land	(km^2)	38.93	**38.57**	4.65	0.06	0.07	41.68	123.96
	Percent	34.40	31.12	3.75	0.05	0.06	33.62	100.0
Built-up area	(km^2)	0.09	0.50	**50.88**	0.03	0.06	0.02	51.58
	Percent	0.17	0.97	98.64	0.06	0.12	0.04	100.0
Forest land	(km^2)	1303.75	0.20	545.92	**200.10**	9.84	650.63	2710.44
	Percent	48.10	0.01	20.14	7.39	0.36	24.01	100.0
Water body	(km^2)	0.46	0.00	0.00	0.05	**7.12**	0.25	7.88
	Percent	5.84	0.00	0.00	0.63	90.35	3.17	100.0
Woodland	(km^2)	119.90	3.50	8.90	0.73	0.09	**33.15**	166.27
	Percent	72.11	2.10	5.40	0.44	0.05	20.20	100.0
Total (2024)	(km^2)	3425.59	42.81	897.89	201.53	17.52	1021.39	5606.70

Source: Compiled by Authors. The bold figures indicate the unchanged land area.

Table 5

Bilate Watershed: Perceptions of Local People about Drivers of Land Use/Land Cover

Drivers of Land Use/ Land Cover	Ranks Given by Respondents					Total	Weighted Average	Index
	1	2	3	4	5			
Population growth	165	29	37	39	31	301	1161	0.106
Urban areas/settlement	105	74	29	24	69	301	1025	0.093
Agriculture expansion	175	68	20	24	14	301	1269	0.115
Lack of law enforcement	39	94	34	37	97	301	844	0.076
Poverty	43	95	75	39	49	301	947	0.086
Fire wood collection	88	61	55	44	53	301	990	0.090
Forest fire/bush fire	2	2	11	72	214	301	409	0.037
Land related policy	15	53	73	83	77	301	749	0.068
Construction	25	78	83	85	30	301	886	0.080
Charcoal production	69	66	89	50	27	301	1003	0.091
Financial lacking	29	79	96	68	29	301	914	0.083
Timber production	40	48	57	84	72	301	803	0.073

Source: Primary Survey, 2024

intensify competition for land, leading to accelerated conversion of forests into agricultural areas and expansion of settlements.

The respondents from the midland agro-climatic zone have been of the view that agricultural expansion, intensification of farming practices and the need to increase crop yield are the driving factors for continuous land use/land cover change. The farmers during focus group interactions expressed that "we have little choice but to expand into grazing and uncultivated lands because the soil fertility of existing fields has declined and market demands are rising." This underscores how livelihood dependency on agriculture and declining soil quality are interlinked in land use change. However, the respondents from lowland agro-climatic zone have given a somewhat different perspective of land use/land cover change, particularly related to forest clearing. Due to limited livelihood resources and harsher climatic conditions, charcoal production has been cited as a critical source of income. During focus group interactions, the common narrative has been that "making charcoal is one of the few methods to earn cash, especially when farming income is low due to uncertainty of rains and crop failure". The firewood collection has been considered as essential economic activity in the lowland agro-climatic zone, as the people are selling charcoal especially during colder seasons to highland areas as there is a greater reliance on firewood for heating. Thus, the energy and economic reliance on forest products contribute substantially to forest degradation in the lowland areas.

Conclusions

This study has assessed land use/land cover changes in the Bilate watershed over the period 1994-2024 by integrating multi-temporal remote sensing approach supplemented with qualitative data collected through field survey. The study reveals a substantial increase in built-up area by 844.84 km² and agricultural land by 877.32 km² over the past 30 years. In contrast, forest cover experienced a significant decline by 2579.76 km² highlighting extensive deforestation. The expansion of woodlands also indicates degradation of dense forest cover, resulting to the emergence of sparsely vegetated areas. The respondents have identified population growth, agricultural expansion, urban development, charcoal production, and firewood collection as the top five factors that have played their role for the land use/land cover change. These factors can be considered for land use planning in the watershed to ensure long-term rural livelihood sustainability and to prepare effective land resource management strategies, that can promote sustainable land use development.

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