



RESEARCH ARTICLE

Urbanisation and agricultural land use dynamics in Karnataka: Implications for sustainable land management

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Received: 07 February 2025; Accepted: 21 April 2026; Available online: Version 1.0: 03 June 2026

Cite this article: Radhika C, Mahesh E, Rajib S. Urbanisation and agricultural land use dynamics in Karnataka: Implications for sustainable land management. Plant Science Today. 2026; 13(sp2): 1-15. <https://doi.org/10.14719/pst.14027>

Abstract

Rapid urbanization has significantly influenced land use transformation and district-level land transitions in Karnataka. This study examines land use dynamics and the role of socio-economic and biophysical factors across districts during 2001–02 to 2020–21 using GIS-based spatial analysis and panel regression. The results indicate substantial shifts in land use patterns driven by urban expansion and economic development. Urbanization significantly reduces the share of land under gross cropped area while increasing fallow land, indicating the diversion of agricultural land to non-agricultural uses. District GDP shows a significant positive effect only on culturable wasteland, suggesting category-specific impacts. Average landholding size is positively associated with fallow land and negatively associated with other land use types. Climatic variables were not statistically significant in the model. The findings highlight the need for region-specific land use policies to balance agricultural sustainability with urban growth.

Keywords: agricultural sustainability; district-level analysis; land use change; panel data regression; urbanisation

Introduction

In Karnataka, rapid urbanisation is increasingly transforming agricultural landscapes, leading to decreasing gross-cropped areas and rising fallow and non-agricultural lands. Districts with higher population densities witness the displacement of cropland by residential, industrial and barren uses. This trend aligns with past research showing continuous diversion of cultivable land, including fallows, pastures and culturable wastelands to non-agricultural purposes (1, 2), while economic shifts during the post-liberalisation era have driven migration of agricultural labourers (3, 4), further exacerbating land use change. Our district-level analysis in Karnataka suggests that urbanisation and farm size play a significant role in shaping land use dynamics, while per capita GDP and road infrastructure exhibit more limited, category-specific effects. Larger farm sizes and improved infrastructure are associated with increased fallow land and reduced wasteland, whereas higher GDP is linked to an expansion of cultivable wasteland.

These findings highlight a complex interplay between urban pressures and structural determinants, calling for region-specific strategies to balance agricultural resilience with urban development. Urban expansion increases land demand for infrastructure and housing, labour migration reduces agricultural workforce availability and land speculation encourages temporary fallowing and delayed cultivation. This study contributes to the existing literature by providing a longitudinal district-level analysis of land use transitions in Karnataka using an integrated framework combining spatial analysis and panel econometrics. Unlike previous studies that rely on aggregate or cross-sectional data, this study captures spatial

heterogeneity and temporal dynamics across districts. It further contributes by examining category-specific land use responses to socio-economic and infrastructural factors.

Indian context

India is the second most populous country in the world, with a population of 1.43 billion, accounting for 17.88 % of the total global population (5). It occupies 2.4 % of the world's land area, covering 328.72 M ha, making it the seventh-largest country globally (6). India also leads the world in livestock population, with 512 million animals (7). The country features diverse land uses, land covers and climates, including evergreen forests, barren lands, cold and hot deserts, highly productive agricultural areas, glaciers and dunes. Rainfall and temperature vary widely across the nation (8). A significant majority of India's population relies on agriculture for their livelihood and India is the second-largest food producer in the world (9). The per capita availability of agricultural land in India is 0.12 ha, compared to 0.29 ha globally (10). With the second-largest arable land area, India faces significant pressure on its land resources due to its high population, agricultural productivity and diverse agro-climatic conditions (11).

Consequently, optimising land use is critical for achieving sustainable ecosystem objectives, given the finite resources available (12). Understanding the effects of regional and district-specific factors—such as population, GDP, policies, technology adoption, markets and infrastructure, climatic conditions and socio-economic characteristics—is essential for comprehending land use changes (13, 14).

Urbanisation and population growth significantly contribute to the demand for non-agricultural land, converting fallow land, pastures and cultivable wastelands to accommodate such needs. In contrast, positive opportunities in agriculture can motivate individuals to maintain or initiate farming practices, thereby preserving land for agricultural use. At the district level, land use preferences are shaped by economic, policy and biophysical elements, including climate conditions and soil characteristics. The interplay of economic development and job creation in the non-farm sector and ongoing urbanisation drives demand for converting land to non-agricultural uses (2). This study addresses critical questions surrounding the changes in land category shares across various districts and the diverse factors contributing to these changes. We analyse the spatial distribution of land use and the factors influencing its distribution at the district level. Our research revolves around three main aspects.

First, we compare land use changes at the district level across six types, including gross cropped area, non-agricultural area, culturable wasteland, total fallow land, permanent pasture and non-cultivable area (which encompasses barren and non-agricultural zones) for two distinct periods, 2001–02 and 2020–21, utilising GIS mapping. Second, we quantify the spatial distribution of these land use types across the districts using a location coefficient for the two periods mentioned, facilitating a comparison of changes in the distribution of major land use types throughout Karnataka. Third, we employ a panel data regression approach to determine the key factors influencing significant land use outcomes at the district administrative level for Karnataka state's principal land use types.

Materials and Methods

Data

We gathered secondary data from 27 districts of Karnataka for five time periods: 2001–02, 2006–07, 2011–12, 2016–17 and 2020–21. These data includes land use information such as total area, non-agricultural land, barren land and total arable land. We also examined the demographic details like population density per square kilometre and socio-economic factors, including the district's GDP. Our data sources are the National Accounts Statistics from the Government of India, Crop Production and the Quinquennial Agricultural Census from the Directorate of Economics and Statistics in Karnataka and Land Use Statistics from the Department of Agriculture and Co-operation Network in India. Land use data were obtained from the Directorate of Economics and Statistics, Government of Karnataka and Land Use Statistics from the DAC&FW. Socio-economic data were sourced from the National Accounts Statistics and Agricultural Census.

Numerous determinants have been reported in the past for land use change at different levels, such as the individual level, parcel level and administrative region levels (Village, district, etc.) (13, 15). For our analysis at the district administrative level, we selected potential explanatory variables based on a thorough literature review. Key variables included urban population share, district-level GDP, credit institutions, road density, climatic variables such as rainfall and temperature, area under irrigation, small and marginal land share and average land size (average operational holding size in hectares at the district level). This approach enables a comprehensive assessment of the diverse factors affecting land use outcomes in the region. The analysis uses 27 districts of Karnataka as

per the administrative boundaries before district reorganisation. Data were harmonised to ensure consistency across time periods.

Study area

Fig. 1 and 2 show Karnataka's district map and the land use land cover map. Karnataka was selected for this study due to its significant trend in land use changes, particularly the approximately 10% increase in net sown area over the last twenty years, driven by a marked shift towards high-value crops (16). Additionally, the state has emerged as a notable reformer in agricultural marketing, enhancing the engagement of private entities in the high-value crop value chain (17). The corresponding rise in non-agricultural land, alongside the expansion of the net sown area, necessitates a detailed exploration of their causative factors and quantifying their contributions.

Spatial distribution analysis of land use classes

Location coefficient (Equation 1) quantifies the spatial distribution of a land category across districts; this is calculated using the following equation:

$$\text{Location coefficient } b = \frac{N_{ij}/N_i}{N_j/N_s} \quad (\text{Eqn. 1})$$

Where, N_{ij} is the area of the j^{th} land use category in the i^{th} district, N_i is the sum of the area of all land use types in district i , N_j is the area of the j^{th} land category at the state level and N_s is the sum of all land use types at the state level. A higher value of b implies a higher regional concentration of a particular category of land use or vice versa (1).

Econometric model: Determinants of land use under different land use types

We used a panel regression with fixed effects to understand the determinants of land using five major land use types as dependent variables, namely, gross cropped area; land not available for cultivation (includes non-agricultural area and barren and unculturable wasteland); fallow land, including both current fallow and long fallow land; land under culturable wasteland; and land under permanent pasture at the district level. We used five time periods, namely, 2001–02, 2006–07, 2011–12, 2016–17 and 2020–21, with nine independent variables, which we chose based on their proven significance reported from past studies on land use change determinants. This method identifies regional factors and their significant role in determining land use outcomes across the region, as some factors behave differently at the regional level compared to the national level or other scales (12). The disturbances in panel data models are cross-sectionally independent for short panels with larger cross-sectional dimension (N) than the time dimension (T) (18). One of the assumptions of the fixed effects model is that the unobservable entity (district) effects are correlated with the observed independent variables, i.e., covariance (X_i, α_i) is a non-zero value.

We apply the following empirical model (Equation 2) to test the hypotheses. The fixed effects regression model for unit i and period t is specified as follows, where X_i is the regressor variables and α_i is the unobservable individual effects.

$$Y_{it} = \alpha_i + X_{it}\beta + v_t + \epsilon_{it} \quad (\text{Eqn. 2})$$

Y_{it} = response variable where $i=1, 2, 3, \dots, n$ and $t=1, 2, 3, \dots, t$, X_{it} = regressor variables for $i=1, 2, 3, \dots, n$ and $t=1, 2, 3, \dots, t$, β = coefficients



Fig. 1. District map of Karnataka.

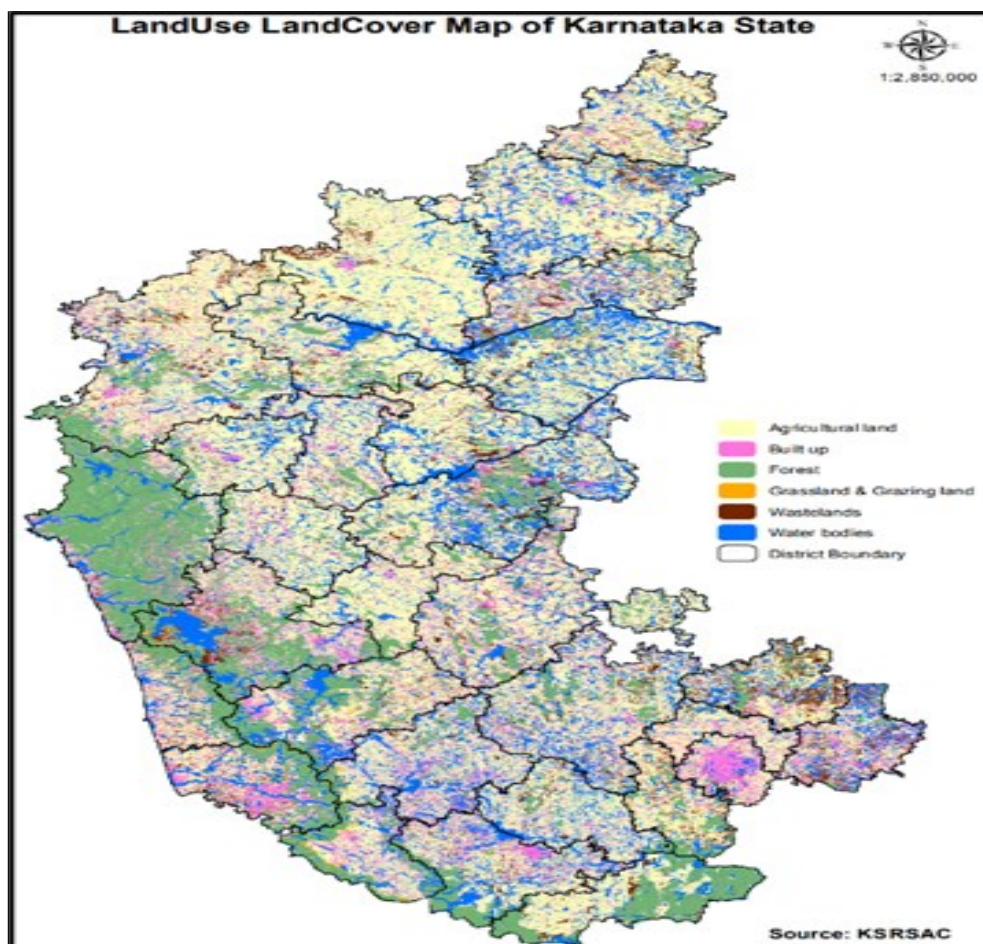


Fig.2. LULC map of Karnataka state

for the k regressor variables in X_i , ϵ_{it} = idiosyncratic error term with zero mean and constant variance where $i=1, 2, 3, \dots, n$ and $t=1, 2, 3, \dots, T$, v_i = group-specific error term (omitted variables constant over time for every i also known as fixed effects to induce unobserved heterogeneity in the model) where $i=1, 2, 3, \dots, n$. The fixed-effects estimator (within estimator) was used to estimate the coefficients using ordinary least squares. This approach controls for unobserved time-invariant heterogeneity across districts. However, as the model conditions on the sample, the unit-specific effects are treated as fixed, which may limit out-of-sample generalisation.

Empirical model

Specification of the regression model with share under individual land use (Five land use types) as the dependent variable

$$\text{Share (Land use)}_{it} = X_{k,it}\beta_k + \delta_t + v_i + \epsilon_{it} \quad (\text{Eqn. 3})$$

We use five dependent variables as discussed above and nine regressor variables namely, per capita GDP at the district level; road density; average annual rainfall (cm); average annual temperature (Degree Celsius); irrigated area share; urban population share; average land size (Average land size refers to the average operational holding size (hectares) at the district level); Credit Institutions; share of land holdings belonging to Scheduled Caste (SC) and Scheduled Tribe (ST) social groups (percentage). In this case, the l is 27, t is 5 and k is 9.

Robustness of the model

To evaluate the robustness of the results, the following tests were conducted. The choice of the preferred model from the panel regression to estimate the unbiased coefficients was based on the diagnostic tests, namely, the robust Hausman test (19). The Hausman test supported the use of fixed effects over random effects. The Modified Wald test indicated the presence of heteroskedasticity; therefore, robust standard errors were used in estimation. We tested the model for heteroscedasticity error in the model after estimating the panel regression (fixed effects) model using the Modified Wald test for group-wise heteroscedasticity. The clustered or robust standard errors account for correcting heteroscedasticity and autocorrelation. We generated robust standard errors using robust techniques applied to the fixed effects regression model to obtain heteroscedasticity-robust standard errors instead of default standard errors to correct the problem of heteroscedasticity in the model (20). The regression function includes the complete set of year dummies, also referred to as fixed time effects, to control general trends in predictor variables and cross-individual correlation. Data analysis was carried out using Stata version 12.0.

Results and Discussion

Land use trends in Karnataka during the study period

The ongoing transformation of land use in Karnataka is characterised by an increasing allocation of land for non-agricultural purposes alongside a decline in culturable wasteland and total fallow land over time. This trend warrants closer examination to understand the extent to which arable land is being diverted toward non-agricultural uses. While the net sown area has remained largely stable at the national level, Karnataka has witnessed a notable increase, rising from 54.65 % in 2000–01 to 64.49 % in 2020–21 (Table 1). All percentage values in Table 1 are expressed as a share of the total reporting area. During the same period, the proportion of several other land use types declined, including permanent pasture and grazing land, barren and uncultivable land, culturable wasteland, total fallow land and land under miscellaneous tree crops and groves. In contrast, land allocated for non-agricultural purposes increased from 6.89 % in 2000–01 to 7.96 % in 2020–21, while the forest area remained relatively unchanged throughout the study period. These patterns collectively indicate a gradual restructuring of land use in the state, shaped by both agricultural intensification and increasing developmental pressures. The expansion in net sown area appears to have been primarily driven by the conversion of fallow land into cultivated land. This transition likely reflects improvements in irrigation infrastructure, the adoption of modern agricultural technologies and enhanced access to inputs, which have enabled farmers to bring previously underutilised or rainfed lands under cultivation.

District-wise land use distribution in Karnataka

The district-wise distribution of major land use types in Karnataka for 2001 and 2020 is presented in Fig. 3-8. These include culturable wasteland, total fallow land, permanent pasture and grazing land, barren and non-cultivable land, land under non-agricultural use and gross cropped area, illustrating the spatial variation across districts during the study period (Fig. 3-8). The legend scales differ across time periods in the map-based figures; therefore, visual comparisons should be interpreted with caution. A uniform classification scheme will be adopted in future work to improve temporal comparability.

Trends in per capita arable land use across the agro-climatic zones of Karnataka

Table 2 outlines the districts classified under the various ACZs in Karnataka. Fig. 9 illustrates a decrease in arable land area per capita across all 10 ACZs of Karnataka, with the most significant changes observed in the north-eastern dry zone, northern dry zone and north-eastern transition zone.

Table 1. Share under different land use types in India from 2001–02 to 2020–21

Land use category	Percentage share of land use (%)			
	India		Karnataka	
	2001–02	2020–21	2001–02	2020–21
Forests	22.84	23.44	16.11	16.13
Area under non-agricultural uses	7.8	9.03	6.89	7.96
Barren and unculturable land	5.7	5.43	4.17	3.91
Permanent pasture and other grazing land	3.45	3.4	5.04	4.58
Land under misc. Tree crops and groves not included in NSA	1.13	0.98	1.59	1.11
Culturable waste land	4.43	3.9	2.24	2.06
Total fallow	8.47	7.75	9.32	4.13
Net sown area	46.12	46.15	54.65	64.49
Gross cropped area	61.61	70.39	60.12	78.26
Cropping intensity	133.6	152.7	110.0	121.3

Source: Authors' compilation based on land-use statistics from the Directorate of Economics and Statistics (DES), Government of Karnataka and Directorate of Economics and Statistics, Government of India.

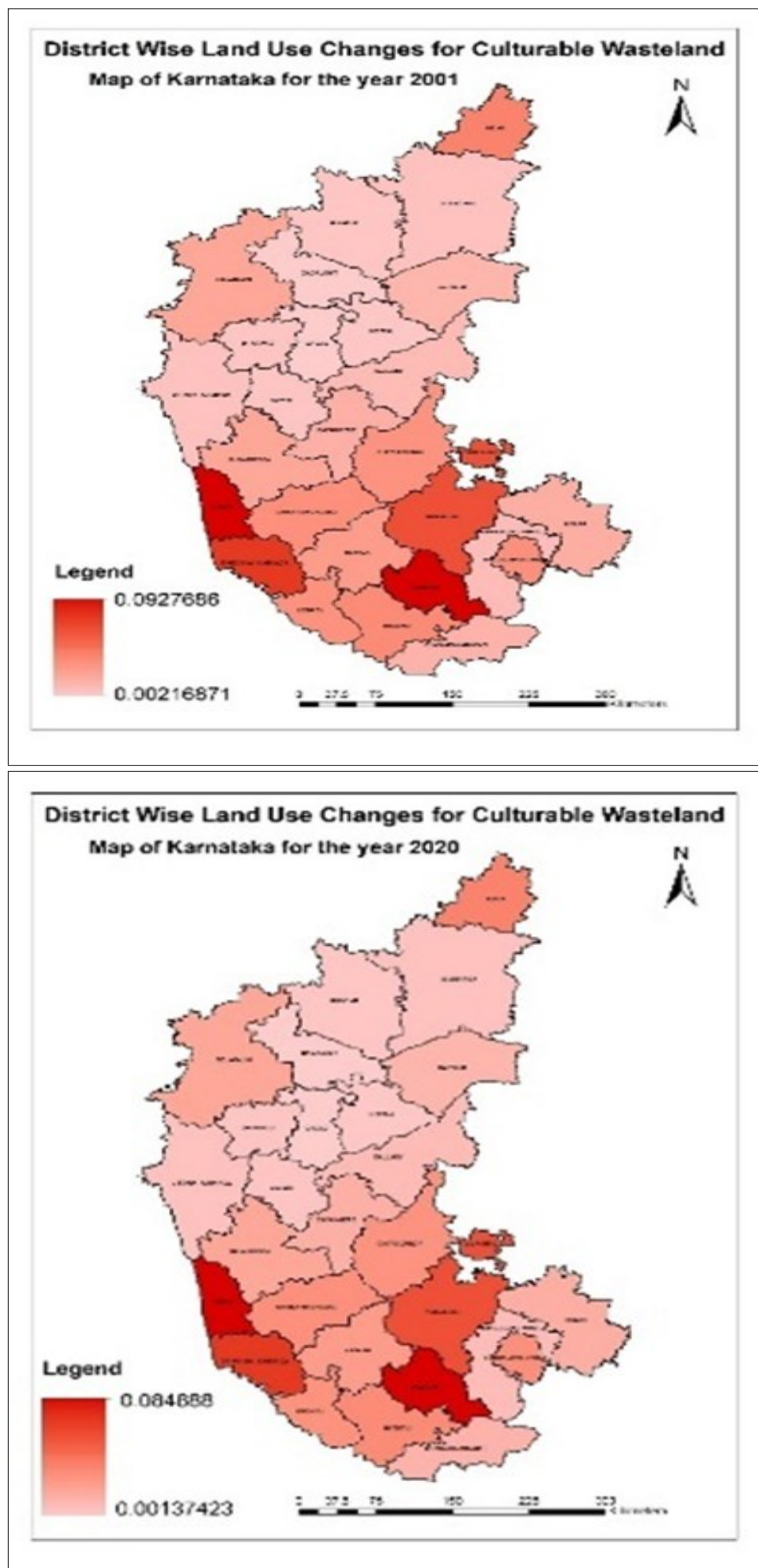


Fig. 3. District-wise distribution of culturable wasteland area in Karnataka, 2001 and 2020.

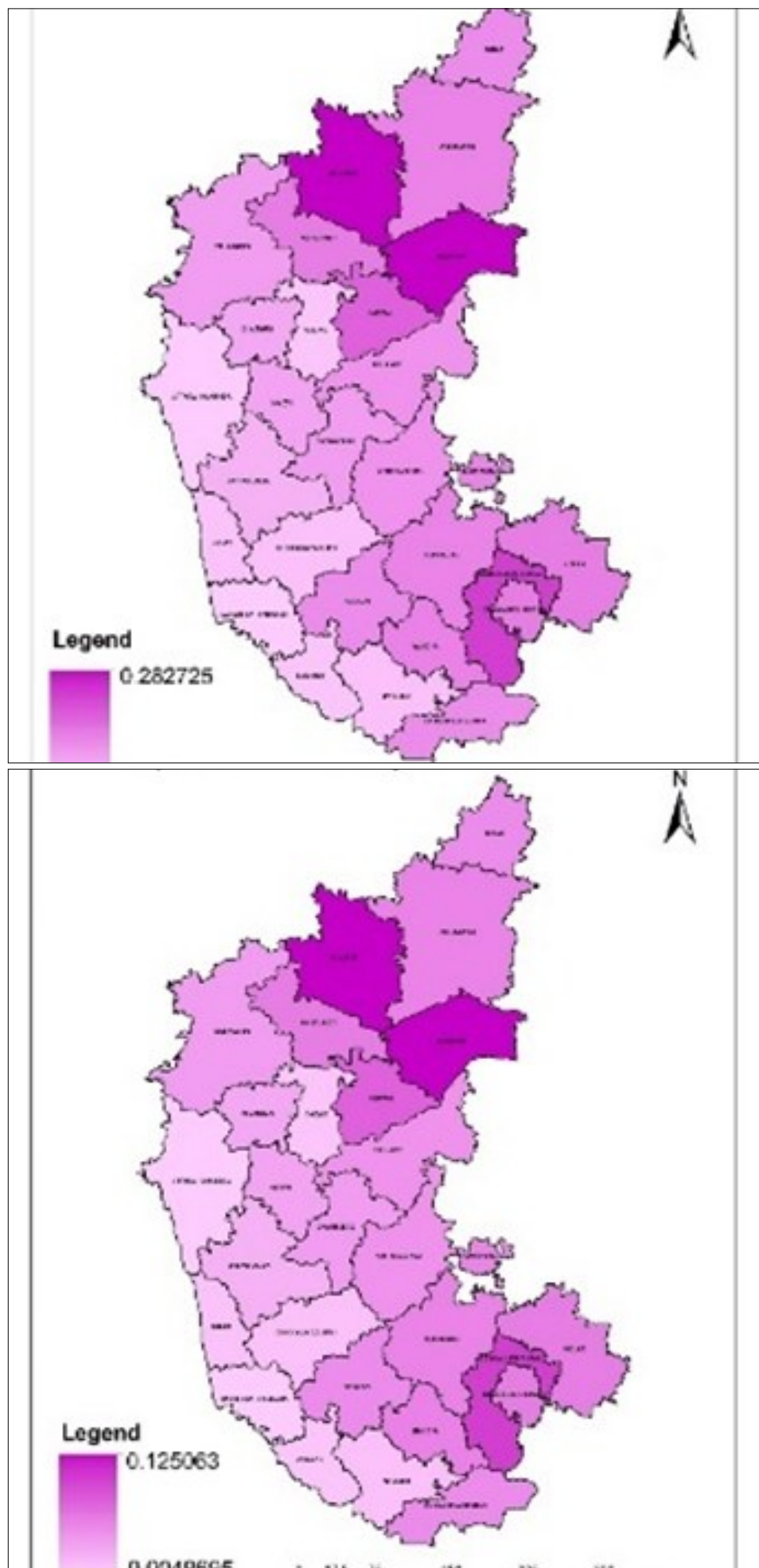


Fig. 4. District-wise distribution of total fallow land area in Karnataka, 2001 and 2020.

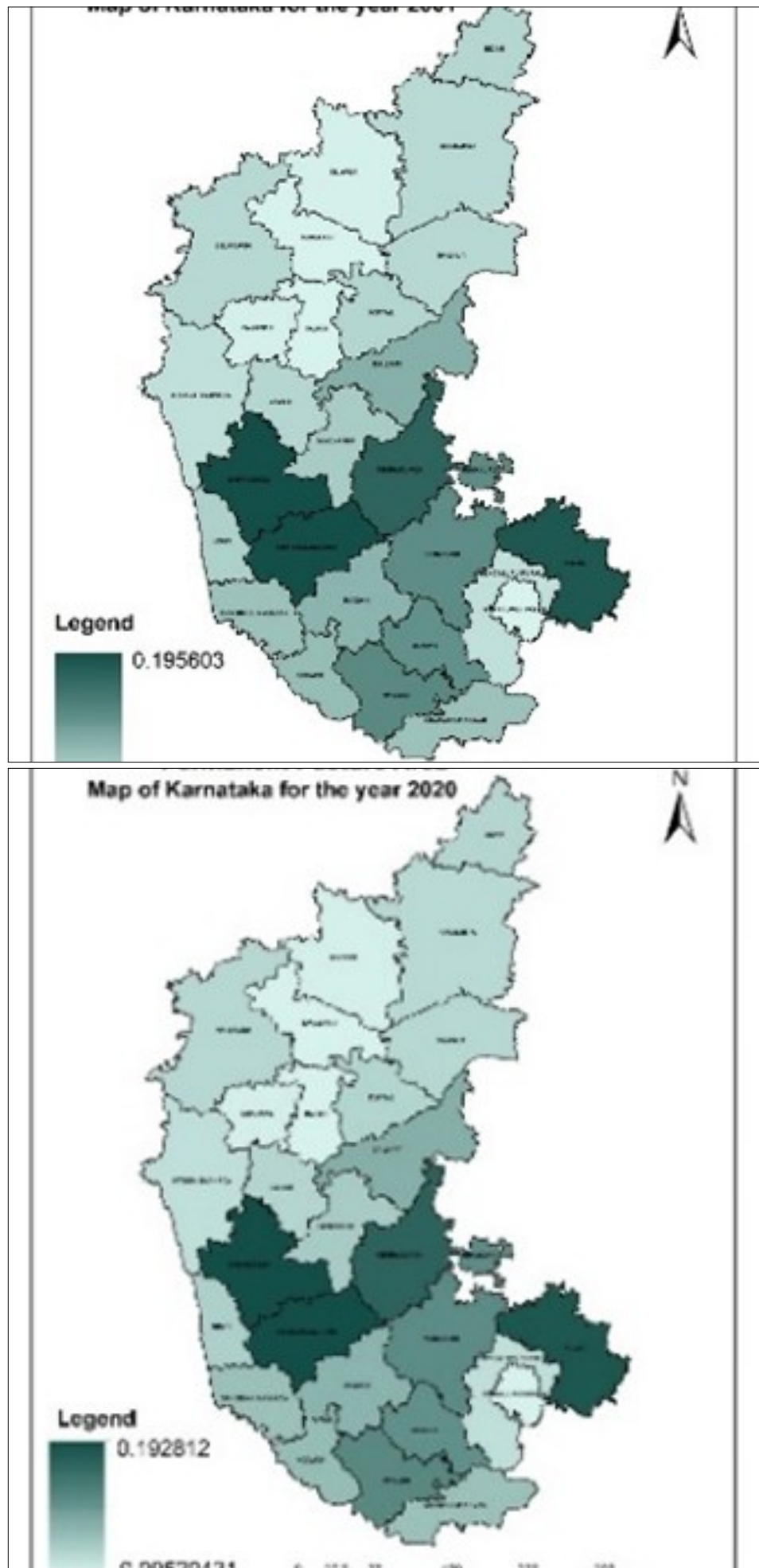


Fig. 5. District-wise distribution of permanent pasture area in Karnataka, 2001 and 2020.

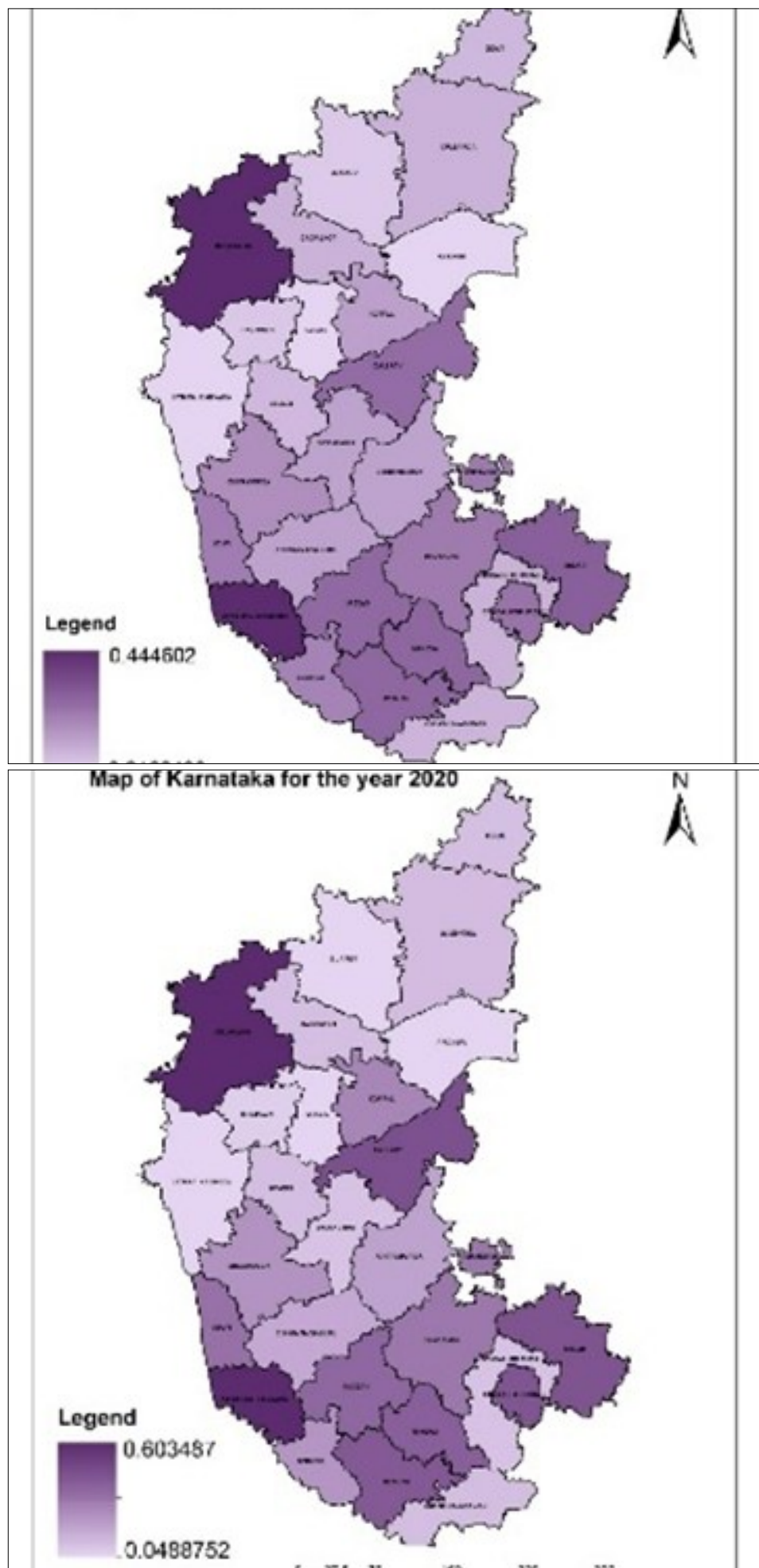


Fig. 6. District-wise distribution of non -cultivable area in Karnataka, 2001 and 2020.

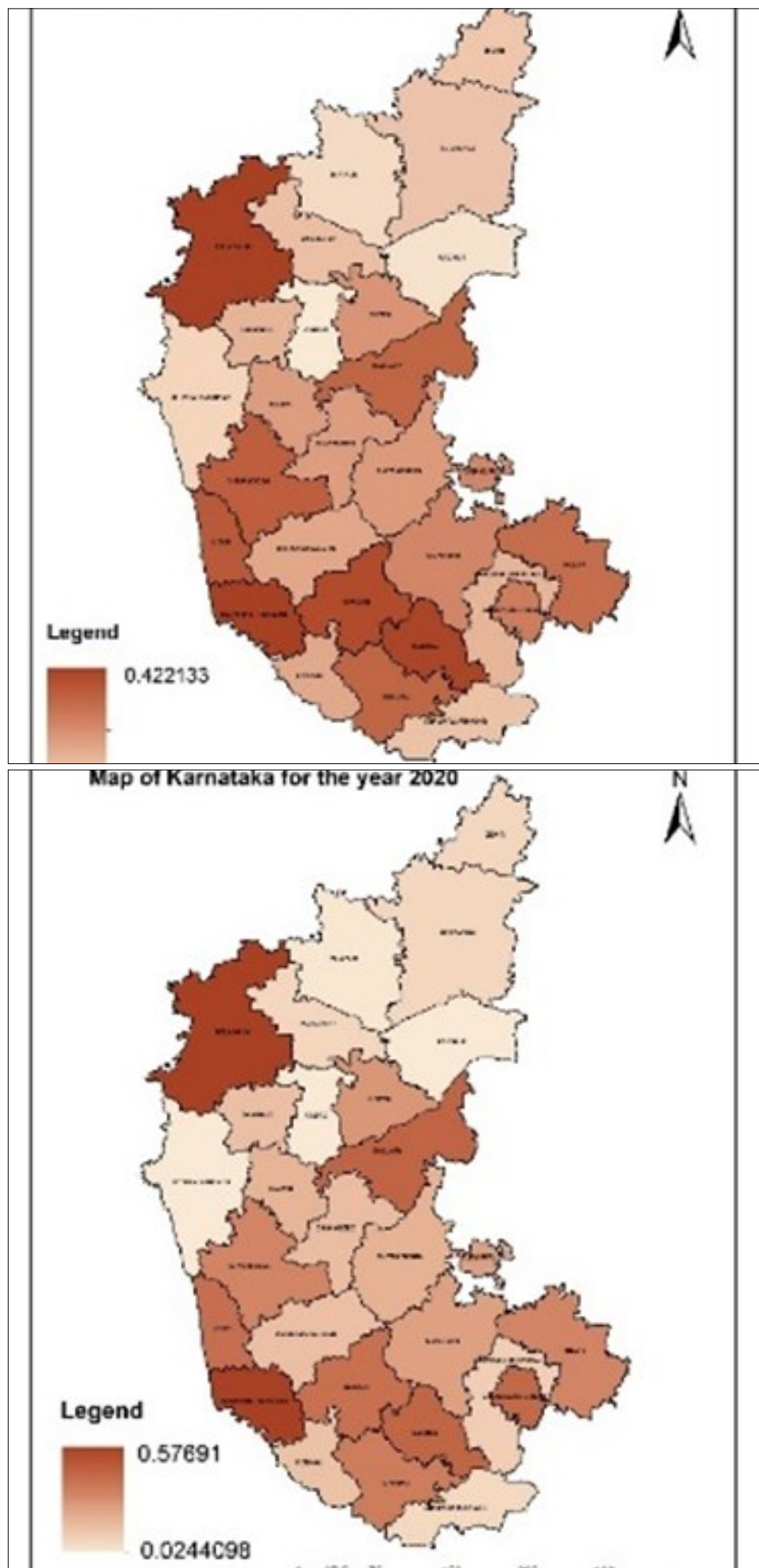


Fig. 7. District-wise distribution of non-agricultural area in Karnataka, 2001 and 2020.

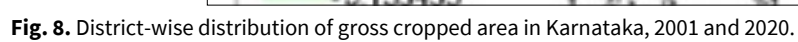
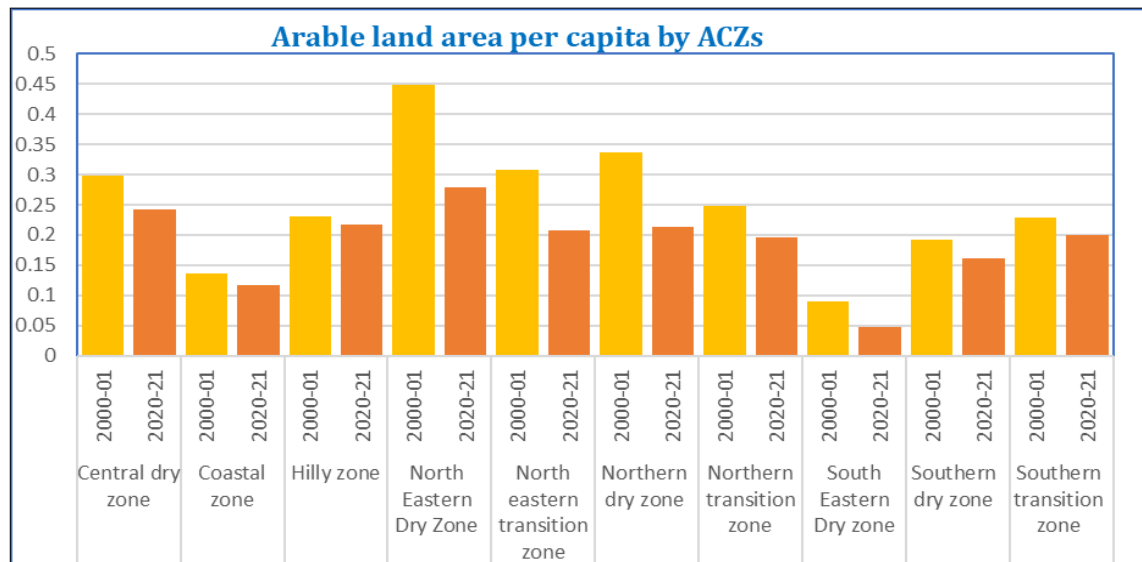


Table 2. Districts classified under different agro climatic zones in Karnataka

Districts	ACZ Name	ACZ code
Bidar	North eastern transition zone	1
Gulbarga, Raichur	North eastern dry zone	2
Bagalkote, Bijapur, Gadag, Belgaum, Bellary, Koppal	Northern dry zone	3
Chitradurga, Tumkur, Davanagere	Central dry zone	4
Bangalore Rural, Bangalore Urban, Kolar	South eastern dry zone	5
Chamarajanagar, Kodagu, Mysore, Mandya	Southern dry zone	6
Hassan, Shimoga	Southern transition zone	7
Dharwad, Haveri	Northern transition zone	8
Uttara Kannada, Chikmagalur, Kodagu	Hilly zone	9
Dakshina Kannada, Udupi	Coastal zone	10

Source: Authors' compilation based on land-use statistics from the Directorate of Economics and Statistics (DES), Government of Karnataka and Directorate of Economics and Statistics, Government of India.

**Fig. 9.** Change in arable land area per capita by agro climatic zones of Karnataka from 2000–01 to 2020–21.

Spatial distribution of different land uses from 2001–02 in Karnataka

The results on location coefficients are presented in Table 3, which shows the patterns of land use concentration. There is a marked decrease in the concentration of net sown area in Bangalore Urban district, accompanied by an increase in non-agricultural areas, particularly in Bangalore Urban and Rural, Mysore, Hassan, Mandya, Shimoga, Udupi and Dakshina Kannada districts. Conversely, higher concentrations of net sown area are found in Gadag, Dharwad, Haveri and Gulbarga districts. Additionally, culturable wasteland has increased in Mandya and Bangalore Urban, while Dakshina Kannada has sharply decreased.

There has been an increase in permanent pasture land in Shimoga but a decrease in Uttara Kannada, Dakshina Kannada and Chitradurga districts. Bagalkot, Belgaum, Bijapur, Haveri, Koppal and Mandya have experienced a decline in total fallow land concentration, which might have resulted from the augmentation in crop diversification to horticulture in Karnataka. The role of high-value crop adoption among farms is a key factor, as it helps them reap the price benefits by cropping more areas. Crops such as vegetables have a shorter production cycle with a regular stream of income and high-value crops such as vegetables, fruits, condiments and spices, flowers, aromatic and medicinal plants and plantation crops like tea and coffee generate higher net returns per unit of land compared to staples or other widely grown crops (15, 21). At the same time, increases have been noted in Bangalore Rural and Urban, Bidar, Chamarajanagara, Tumkur, Uttara Kannada, Udupi, Mysore and Chamarajanagara. These changes may be attributed to

erratic rainfall or instability in surface water availability.

Determinants of land use under different land use types

Table 4 presents the summary statistics of the variables used in the analysis. The regression results reported in Table 5, based on Equation 3, provide insights into the determinants influencing land allocation across different land use variables used in the model. The findings highlight the significant role of demographic, infrastructural and institutional factors in shaping land use patterns. Among these variables, district GDP does not exert a uniform effect across all land use variables used in the model and is statistically significant only for culturable wasteland, indicating a category-specific rather than a generalised effect.

Urbanisation emerges as one of the most influential drivers of land use change in Karnataka. A 1 % increase in urban population share reduces gross cropped area by 0.0087 units, indicating a measurable displacement effect. In contrast, economic variables such as district GDP show limited influence across different land use variables used in the model, reinforcing the dominant role of demographic and structural factors. The results demonstrate that a higher level of urbanisation significantly reduces the share of land under gross cropped area while simultaneously increasing the proportion of total fallow land. This trend reflects the intensifying land use competition in districts with higher population densities, where agricultural lands are increasingly diverted to meet the growing demand for residential settlements, industrial expansion and infrastructure development. Similar trends have been documented in earlier studies, which report a continuous diversion of agriculturally productive land toward non-agricultural uses (1).

Table 3. Location coefficients of major land use types at district level in Karnataka

Districts	Net sown area		Non -Agrl Area		Cul. Waste land		Permanent pasture		Total fallow	
	2001-02	2020-21	2001-02	2020-21	2001-02	2020-21	2001-02	2020-21	2001-02	2020-21
Bagalkot	1.24	1.28	0.64	0.57	0.14	0.15	0.10	0.11	1.15	0.41
Bangalore Rural	0.93	0.86	1.44	1.65	0.47	0.42	1.04	1.07	0.97	2.22
Bangalore Urban	0.72	0.28	5.80	7.25	0.84	1.26	0.51	0.68	0.95	3.02
Belgaum	1.19	1.23	0.75	0.66	0.42	0.34	0.37	0.35	0.99	0.37
Bellary	1.10	1.02	1.22	1.60	1.36	1.09	0.13	0.16	0.96	1.12
Bidar	1.26	1.18	0.59	0.59	1.59	1.74	0.51	0.56	1.09	1.79
Bijapur	1.30	1.48	0.43	0.44	0.23	0.25	0.18	0.20	2.30	0.80
Chamarajanagar	0.51	0.52	0.62	0.54	0.60	0.65	0.79	0.87	1.00	1.46
Chikmagalur	0.72	0.71	0.86	0.76	1.33	1.30	2.69	2.54	0.40	0.58
Chitradurga	0.98	0.97	0.97	0.91	1.25	1.36	2.29	2.52	1.22	1.43
Dakshina Kannada	0.51	0.66	1.74	2.04	3.18	1.81	0.81	0.37	0.28	0.25
Davanagere	1.19	1.21	0.95	0.79	0.69	0.56	0.65	0.53	0.49	0.12
Dharwad	1.42	1.34	0.73	0.76	0.28	0.30	0.17	0.18	0.73	0.67
Gadag	1.54	1.40	0.32	0.31	0.10	0.07	0.11	0.12	0.37	0.67
Gulbarga	1.31	1.33	0.60	0.57	0.33	0.36	0.46	0.51	1.39	1.03
Hassan	1.05	1.05	1.70	1.53	1.18	1.04	1.00	1.09	0.98	0.80
Haveri	1.33	1.29	0.94	0.87	0.28	0.30	0.51	0.55	0.67	0.22
Kodagu	0.65	0.81	0.84	0.74	1.30	0.88	0.86	0.64	0.33	0.29
Kolar	0.85	0.88	1.38	1.33	0.72	0.69	2.52	2.58	1.16	1.09
Koppal	1.18	1.26	1.02	1.15	0.21	0.23	0.53	0.71	1.80	0.38
Mandya	0.91	0.97	1.77	1.63	3.76	4.08	1.52	1.41	1.30	0.87
Mysore	1.05	0.93	1.44	1.40	1.42	1.53	1.65	1.51	0.47	1.33
Raichur	1.26	1.33	0.36	0.31	0.57	1.17	0.47	0.52	1.99	1.76
Shimoga	0.47	0.49	1.51	1.32	0.91	0.93	3.89	4.21	0.53	0.39
Tumkur	1.04	0.91	1.14	1.07	2.63	2.85	1.61	1.57	0.98	2.73
Udupi	0.52	0.51	1.57	1.54	4.12	4.12	0.60	0.65	0.41	0.83
Uttara Kannada	0.20	0.20	0.43	0.43	0.35	0.31	0.38	0.14	0.16	0.49

Source: Authors' estimates using district-level land-use data from the Directorate of Economics and Statistics, Government of Karnataka.

Note: Values greater than 1 indicate higher concentration of a particular land-use category relative to the state average.

Table 4. Summary statistics of variables used in regression analysis

Variables	Mean	SD	Min	Max
Dependent variable				
Share of area under Not available for cultivation (Non agricultural and barren and unculturable land) (%)	13.2	0.097	4.7	60.3
Share of area under gross cropped area (Percentage)	64.8	0.276	11.6	130.2
Share of area under total fallow land (current and other fallow land) (Percentage)	9.4	0.069	0.5	32.9
Share of area under culturable waste land (Percentage)	2.4	0.024	0.1	10.8
Share of area under permanent pasture land (Percentage)	4.7	0.045	0.5	19.6
Independent variables				
Per capita gross district domestic product (INR-Indian Rupees*)	11.20	.99	9.26	13.22
Road density (per 100 Km ²)	36.56	13.06	14	76.01
Credit Institutions (no. of banks per 1000 km ²)	37.30	24.72	9.31	147.59
Average Annual rainfall (in cm)	116.42	101.61	34.46	471.42
Average annual temperature (°C)	25.52	1.89	19.87	29.76
Share of the irrigated area under the total cropped area (Percentage)	44.12	53.92	0.3	100.0
Share of the urban population in the total population (Percentage)	30.21	15.43	13.74	93.24
Average land size (ha)	1.62	0.671	0.57	3.25
Share of land holdings belonging to schedule caste (SC) and Schedule Tribe (ST)	16.40	8.15	4.24	36.45

Source: Authors' estimates based on district-level panel data.

Note: Summary statistics are computed using observations from 27 districts across five time periods (2001–02, 2006–07, 2011–12, 2016–17 and 2020–21).

The sharp decline in net sown area in Bangalore Urban corresponds with a substantial increase in non-agricultural land concentration, highlighting direct displacement of agricultural land due to urban expansion.

Moreover, the post-liberalisation economic transformation has accelerated rural-to-urban migration, particularly among agricultural labourers and marginal cultivators who are attracted by better employment opportunities and higher wages in urban and non-farm sectors. This structural shift in labour availability has contributed to the expansion of fallow land and non-agricultural land use types, thereby influencing overall land use dynamics (3, 4). Supporting this observation, Rathee reported that non-agricultural land has expanded significantly in India, often at the expense of both arable and barren land uses (2).

Among the structural determinants, average landholding size plays a crucial role in influencing land use allocation, significantly affecting four of the five land use variables considered in this study. Interestingly, average land size exhibits a positive association with fallow land, which contrasts with the widely observed tendency of small and marginal farms to maintain fallow land due to low technical efficiency and increased risk of soil degradation. Instead, the results suggest that larger landholdings in certain districts may be associated with strategic fallowing practices, particularly in areas experiencing low agricultural productivity, limited irrigation availability, inadequate market linkages, insufficient knowledge dissemination and weak institutional support systems (12). This association may reflect strategic or involuntary fallowing in larger holdings due to labour constraints, market access limitations, or risk

Table 5. Determinants of land allotted to major land use types

Variables	Gross cropped area	Not available for cultivation (non agri land + barren land)	Total fallow land	Culturable waste land	Permanent pasture land
Share of urban population	-0.0087** (0.0040)	0.0007 (0.0009)	0.0036** (0.0015)	-0.0010* (0.0005)	-0.0002 (0.0005)
Land share under irrigation	0.0002 (0.0001)	0.0000 (0.0000)	0.0000 (0.0001)	-0.0000 (0.0000)	-0.0000 (0.0000)
District GDP (Log value)	-0.0488 (0.0573)	0.0038 (0.0108)	0.0135 (0.0243)	0.0048*** (0.0014)	-0.0001 (0.0025)
Road density	-0.0024 (0.0015)	-0.0004 (0.0004)	0.0022** (0.0009)	-0.0000 (0.0001)	-0.0001 (0.0001)
Credit institutions	-0.0009 (0.0007)	0.0004 (0.0003)	0.0000 (0.0003)	0.0000* (0.0000)	0.0000 (0.0000)
Rainfall (cm)	-0.0002 (0.0003)	0.0000 (0.0000)	-0.0000 (0.0002)	0.0000 (0.0000)	0.0000 (0.0000)
Temperature (°C)	0.0048 (0.0099)	-0.0004 (0.0010)	-0.0057 (0.0054)	0.0003 (0.0003)	0.0002 (0.0003)
Land share owned with SC and ST category	0.0011 (0.0043)	-0.0013 (0.0011)	0.0005 (0.0020)	0.0002 (0.0001)	-0.0000 (0.0002)
Average land size	-0.0381 (0.0828)	-0.0259** (0.0117)	0.0796* (0.0413)	-0.0039** (0.0018)	-0.0143*** (0.0030)
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Constant	1.3509** (0.6240)	0.1396 (0.1012)	-0.1868 (0.2898)	0.0021 (0.0203)	0.0780*** (0.0275)
R-squared	0.5605	0.3470	0.4293	0.3234	0.4589

Source: Authors' estimates using fixed-effects panel regression analysis.

Note: Robust standard errors are reported in parentheses. ***p < 0.01, **p < 0.05, *p < 0.10. Year fixed effects are included in all models.

management behaviour, rather than purely efficiency considerations. The expansion of fallow land is also influenced by several biophysical and infrastructural factors. Previous studies have emphasised the role of irrigation availability, rainfall variability, operational holding size and infrastructural and institutional development, including road connectivity and access to institutional finance, in shaping fallow land dynamics (1, 22, 23).

Several explanatory variables used in the model, including rainfall, temperature, irrigation share and the proportion of land owned by Scheduled Caste and Scheduled Tribe groups, were not statistically significant across the land use variables used in the model. This suggests that, within the fixed-effects framework, these variables do not exert a measurable influence on land use allocation at the district level over time. Climatic variables such as rainfall and temperature were not statistically significant in the model, likely due to their limited temporal variation within the study period within the fixed effects modelling framework. Previous studies have reported a negative relationship between rainfall and the extent of current fallow land, indicating that improved rainfall conditions can encourage cultivation and reduce fallowing (24). Similarly, irrigation share and social composition variables may influence land use decisions indirectly or operate at finer spatial scales not captured in the present analysis. The positive and statistically significant association between district GDP and culturable wasteland suggests that economic growth may be linked to transitional land use dynamics, possibly reflecting land speculation or delayed conversion processes.

Overall, these findings highlight the complex interplay between urbanisation, structural agricultural characteristics and infrastructural development in shaping land use transitions. The results suggest that while technological advancement and irrigation expansion have facilitated the conversion of fallow land into cultivated land, increasing urban pressures continue to divert productive agricultural land toward non-agricultural uses. These

competing forces underline the importance of region-specific land management policies that balance agricultural sustainability with urban development requirements. Strengthening irrigation infrastructure, improving market accessibility, enhancing institutional credit support and promoting sustainable land use planning could play a critical role in optimising land utilisation and ensuring long-term agricultural resilience in Karnataka.

The findings are consistent with studies from other Indian states such as Tamil Nadu and Haryana, where urban expansion has contributed to the conversion of agricultural land into non-agricultural uses. Similar patterns of increasing fallow land and declining cultivated area have been reported in regions experiencing labour migration and infrastructure expansion. From a theoretical perspective, the results align with land use transition theory, which posits that economic development and structural transformation lead to shifts from agricultural to non-agricultural land uses. The observed increase in fallow land in districts with larger holdings may reflect transitional inefficiencies in land markets and labour allocation during this process.

Conclusion

The findings of this study indicate that land-use dynamics in Karnataka vary significantly across categories, reflecting the complex interaction of demographic, structural and infrastructural factors. Urbanisation emerges as a key driver, reducing the share of land under gross cropped area while increasing fallow land, indicating diversion of agricultural land to non-agricultural uses. Average landholding size is positively associated with fallow land, suggesting underutilization of land resources in districts with larger operational holdings. In contrast, district GDP exhibits a category-specific effect, significantly influencing only cultivable wasteland, while climatic variables were not statistically significant in the model. The results also show a decline in productive land-use categories such as

permanent pasture, culturable wasteland and land under tree crops, raising concerns about long-term ecological sustainability. These changes may lead to biodiversity loss, reduced ecosystem services and increased land degradation risks, highlighting the need for conservation-oriented land management strategies. From a policy perspective, the findings emphasise the need for targeted interventions, including land-leasing reforms to improve land-use efficiency, strengthened irrigation and market support systems and integrated land-use planning to manage urban expansion. Zoning regulations and district-level planning frameworks are essential to balance agricultural sustainability with development pressures. Overall, the study underscores the importance of region-specific, evidence-based policy frameworks that address the diverse socio-economic and agro-ecological conditions across districts. Future research should focus on micro-level land-use decisions, incorporate land market dynamics and utilise high-resolution spatial data to better capture localized variations in land-use change.

Acknowledgements

The authors acknowledge the support for this study from Christ (Deemed to be University) in Bangalore, Karnataka. This study has been conducted as a part of the PhD thesis work done at Christ (Deemed to be) University, Bengaluru, India. The authors acknowledge the provision of data and reports from the Directorate of Economics and Statistics, Department of Agriculture and Department of Horticulture, GoK and IMD, Pune.

Authors' contributions

RC conceptualised the idea, reviewed the literature, collected and analysed the data and conducted data analysis. ME coordinated research, helped in the discussion of results and edited the document. RS helped in conceptualising the research idea and suggested the econometric model. All the authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.