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CASE STUDY

Legal and Institutional Barriers to Effective Land Use Planning in the South Asian Region

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ABSTRACT

This research examines the evolution of land use patterns in Ludhiana, a smart city in Punjab, India, from 2020 to 2024, focusing on key sectors such as residential, commercial, industrial, and agricultural land use. Through data visualization methods including stacked bar charts, area plots, and correlation heatmaps, the study identifies notable shifts in land allocation trends over the five years. The findings reveal a consistent increase in residential land use, rising from 2,500 hectares in 2020 to 2,900 hectares in 2024, driven by urbanization and growing housing demand. Commercial land expanded from 150 hectares to 230 hectares, and industrial areas from 800 hectares to 900 hectares, highlighting the city's ongoing economic and infrastructural development. In contrast, agricultural land steadily declined from 12,000 hectares in 2020 to 11,200 hectares in 2024, indicating continued urban encroachment into rural zones. The study employs a mixed-methods approach combining legal analysis, institutional review, and statistical modeling—including multiple linear regression ($R^2 = 0.998$)—to assess the drivers and governance barriers of land use change. These changes reflect Ludhiana's transformation from a predominantly agrarian landscape to a more urbanized environment. The trends underscore the urgent need for integrated and sustainable land use planning that balances development with environmental stewardship and food security. The study calls for forward-looking urban policies that safeguard green spaces and promote equitable land management to meet the needs of a rapidly expanding urban population.

Keywords: Land Use; Urbanization; Ludhiana; Sustainable Development; Institutions; Urban Planning; Sustainability

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1. Introduction

Land use planning is fundamental to achieving sustainable, equitable, and resilient urban development, particularly in rapidly urbanizing regions such as South Asia. Effective land governance ensures that urban growth aligns with social, economic, and environmental goals, facilitates infrastructure provision, and mitigates conflicts over land ownership and usage. However, legal ambiguities, institutional overlaps, and fragmented planning continue to undermine these objectives across much of the Global South [1].

Globally, several countries have adopted integrated land use frameworks. For instance, Singapore's "whole-of-government" approach has been widely recognized for its effective coordination between land, transport, and water planning, resulting in highly efficient urban land management. Similarly, the Netherlands employs a layered spatial planning model, combining national, provincial, and municipal authorities to ensure coherent land use strategies with strong legal enforcement [2]. At the regional level, South Asian countries face common challenges, including informal settlements, outdated land records, and weak institutional coordination. In Pakistan, urban centers like Lahore and Karachi experience similar issues of overlapping jurisdictions and weak zoning enforcement. In Nepal, cities like Kathmandu struggle with unregulated peri-urban expansion and the absence of updated cadastral systems. A comparative study by Vadrevu et al. (2017) emphasized that economic growth and population pressures across Asia often outpace institutional capacities to manage land transformation sustainably [3].

Nationally, India has attempted to address urban governance through initiatives like the Smart Cities Mission (2015), which promotes data-driven, sustainable development. Yet, despite substantial investments, cities such as Ludhiana still grapple with systemic land use challenges, including unauthorized colonies, encroachments, and fragmented institutional mandates. The coexistence of multiple agencies—Municipal Corporation, PUDA, and Ludhiana Improvement Trust—without clear jurisdictional demarcation has resulted in planning inefficiencies and legal uncertainty [3]. Against this backdrop, this study examines the legal and institutional barriers to effective land use planning, using Ludhiana as a representative case. It explores how statutory gaps and administrative fragmentation hinder integrated spatial development, undermine sustainability, and limit the impact of smart city reforms. By critically analyzing Ludhiana's legal instruments, institutional structures, and land use transitions from 2020 to 2024, the paper contributes to the broader discourse on planning modernization in South Asia and the Global South [4].

This article examines legal and institutional obstructions that prevent efficient land use planning in South Asia, with the case of Ludhiana representing a typical urban example. It examines how statutory systems and administrative fragmentation inhibit integrated spatial development, defeat sustainability objectives, and restrict the effectiveness of innovative strategies such as the Smart City initiative. In highlighting these barriers and suggesting specific reforms, the research hopes to make a contribution to discussions on integrated urban governance as well as planning modernization in the Global South [5,6].

2. Literature Survey

Significant obstacles that impede efficient management and sustainable development are found in institutional and legal impediments, according to the literature on land use planning in South Asia. Numerous studies emphasise how crucial governance frameworks, institutional frameworks, and policy coherence are in determining the results of land use. Kotharkar et al. (2020) highlighted that urban heat islands have become increasingly prevalent in South Asia as a result of urbanisation, with studies mostly concentrating on cities such as Delhi, Chennai, and Colombo. The dependence on satellite imaging and thermal mapping highlights the need for multidisciplinary, cooperative responses to urban environmental problems, which are sometimes made worse by disjointed institutional efforts [7]. Jain et. al. (2019) described that flexible policies, integrated land-use and transport planning, and empowered local authorities are necessary for growth management methods in India, especially in the National Capital Region. These suggestions highlight institutional barriers

that prevent adaptive and efficient land use planning, such as strict legal frameworks and a lack of local ability [4]. In their discussion of more general land cover and land use changes across Asia, including South and Southeast Asia, Vadrevu et al. (2017) emphasised the causes of land use change as well as its effects on the environment, including air pollution. The research emphasises the impact of economic growth and population pressures, which often surpass institutional ability to successfully control land usage [3]. When discussing water management, Luan (2010) introduced Singapore's holistic governance model, which is distinguished by an integrated "whole-of-government" structure that makes it easier to coordinate water and land use management. This illustration shows how institutional integration may overcome fragmented governance, which is a problem that is also common in South Asian nations, where efficient land use planning is hampered by institutional disarray [8].

Rohr (2015) highlighted the value of evidence-based approaches and integrated frameworks while promoting creative spatial planning tools to assist sustainable water management in rural areas. In South Asia, where rural land use planning often suffers from a lack of institutional coordination and antiquated legislation, such strategies are essential [9]. According to Visser et al. (2011), the problem of land grabbing and foreign investment brings to light the difficulties in post-Soviet Eurasia's land governance, which are comparable to South Asia's difficulties in controlling foreign land purchases. The challenges pertaining to both local and foreign agroholdings are indicative of more general institutional flaws, such as a lack of openness and lax enforcement of regulations [10].

Despite the well-known importance of land use planning to sustainable urban growth, South Asian cities are still beset with intractable planning inefficiencies due to fragmented legal frameworks and weak institutional capacities. Cities like Ludhiana have experienced rapid industrialization and population increases outpacing regulation, resulting in illegal settlements, encroachment, unharmonized zoning, and the proliferation of unauthorized colonies. As much as national initiatives like India's Smart Cities Mission are focused on infrastructure upgradation and improved urban governance, they are likely to overlook systemic legal inconsistency and institutional fragmentation that undermines integrated land use planning at its core [11]. This paper hopes to fill a critical gap in the literature and policy practice by investigating, in a systematic way, how legal ambiguity, institutional overlap, and weak enforcement contribute to suboptimal land use management in South Asia using Ludhiana as a representative case. The following are the main objectives:

- To evaluate the adequacy of key legal frameworks guiding land use planning in Ludhiana in the context of rapid urbanization.
- To examine institutional roles and overlaps among PUDA, MCL, and LIT, and identify governance barriers to effective land use management.
- To apply statistical analysis to assess the impact of demographic and economic factors on land use change in Ludhiana.

3. Methodology

To investigate the legal and institutional hurdles to effective land use planning in South Asia, this research adopts a mixed-methods, case-based design. The study is structured around three core objectives: (1) evaluating the legal frameworks governing land use, (2) diagnosing institutional overlaps and implementation gaps, and (3) proposing targeted reform strategies. Ludhiana, a key industrial city selected under India's Smart Cities Mission, serves as the primary case study due to its rapid urbanization, unauthorized land developments, and fragmented planning authority. The methodology combines qualitative analysis of statutory instruments (e.g., Punjab Regional and Town Planning Act, Ludhiana Master Plan, and Smart Cities Guidelines) with institutional document reviews from PUDA, MCL, and LIT. Additionally, spatial and temporal land use data (2020–2024) were analyzed using statistical tools including multiple linear regression, correlation heatmaps, stacked bar charts, and Sankey diagrams. These methods, implemented in Python and supported by GIS datasets, allow for the identification of key land use trends and the underlying demographic and economic drivers shaping Ludhiana's urban transformation [12,13].

3.1. Location Details

Ludhiana, located in the Indian state of Punjab, is a rapidly urbanizing industrial city that plays a central role in the region's economic landscape. Geographically positioned at 30.91°N and 75.85°E, it lies along the Sutlej River and spans approximately 310 square kilometres, as shown in **Figure 1** [6]. As a major participant in India's Smart Cities Mission, Ludhiana exemplifies the challenges of urban transformation in South Asia, particularly the tension between industrial expansion, population growth, and the preservation of agricultural land. The city's complex administrative structure, involving multiple planning authorities, makes it a critical case study for examining institutional fragmentation and legal barriers to effective land use governance.

3.2. Data Collection Methods

The study utilizes a multi-faceted data collection method, using legal, institutional, and literature sources in order to offer an extensive analysis of land use planning constraints in Ludhiana. To evaluate the official regulatory context, a legal and policy document analysis is first conducted. This comprises a detailed examination of the Punjab Regional and Town Planning and Development Act, 1995, the Master Plan of Ludhiana (2031), the Smart Cities Mission Guidelines, and pertinent municipal and zoning laws. The work also analyzes judicial rulings and legal commentaries about land use rights and their enforcement in Punjab to understand how legal interpretations impact planning [14]. Secondly, institutional reports and planning reports constitute a key component of the dataset. Among these are development reports by the Municipal Corporation of Ludhiana (MCL), notably those relating to the regularization of slums and unauthorized colonies, as well as Punjab Urban Planning and Development Authority (PUDA) and Ludhiana Improvement Trust (LIT) documents. Also examined are reports on Smart City implementation, audit reports, and GIS-based land-use datasets that capture current urban patterns and planning interventions [15].

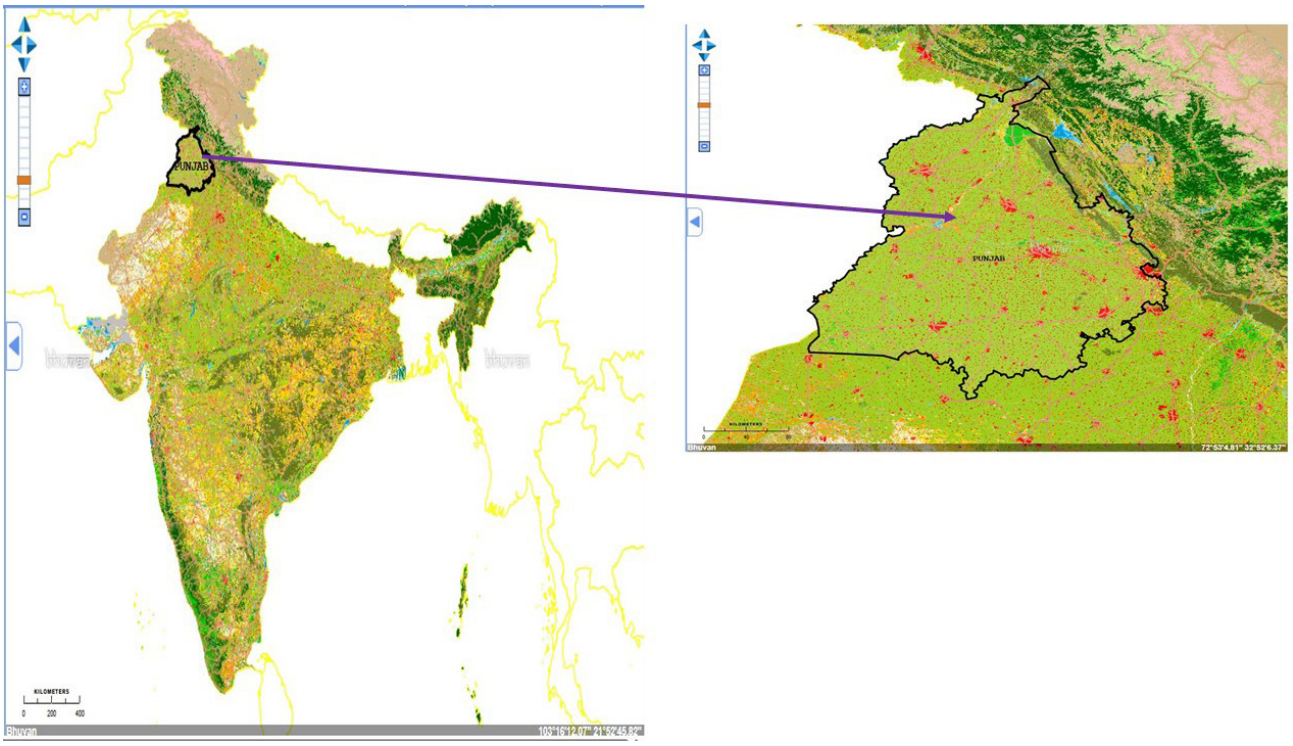

Figure 1. Geographical Location of Ludhiana [6].

Source: https://bhuvan-app1.nrsc.gov.in/thematic/thematic/index.php#

The third data source is stakeholder views captured by secondary sources. This involves information from the news archives, government briefings, and summaries of public consultations. Whenever available, interviews and public comments from past studies with town planners, urban development officials, and civil society members are also included to present contextual and experiential views regarding land governance issues [16]. Finally, the research conducts a comparative literature review to place Ludhiana's experience in a wider regional perspective. This entails examination of available academic and policy scholarship on land governance issues in South Asia, with the main emphasis on India, Pakistan, and Bangladesh. Major challenges like deficits in enforcement, overlaps in jurisdiction, and continuity of archaic land laws are isolated to bring out structural similarities in the region that undermine effective land use planning. **Table 1** summarizes the key areas of jurisdictional overlap and institutional fragmentation.

Table 1. Policy and Institutional Framework for Land Use Governance in Ludhiana.

Act/Policy	Scope/Purpose	Responsible Institution(s)	Overlapping Functions/Issues
Punjab Regional and Town Planning & Development Act, 1995	Provides the legal framework for master plans and zoning regulations	Punjab Urban Planning and Development Authority (PUDA)	Overlaps with municipal zoning; limited enforcement on the ground
Ludhiana Master Plan 2031	Long-term land use plan for urban development	PUDA, Municipal Corporation of Ludhiana (MCL)	Implementation is fragmented among multiple agencies
Punjab Municipal Corporation Act, 1976	Governs municipal-level administration and urban development	Municipal Corporation of Ludhiana (MCL)	Limited authority over regional planning
Smart Cities Mission Guidelines (2015)	Urban renewal program with a focus on smart infrastructure and e-governance	Smart City SPV (Special Purpose Vehicle), MCL, State Government	Weak integration with traditional planning authorities
Ludhiana Improvement Trust Act	Urban housing and development in selected areas	Ludhiana Improvement Trust (LIT)	Functions overlap with MCL and PUDA
Zoning and Building By-laws	Regulation of land use types and construction standards	Town Planning Department, MCL	Enforcement challenges: gaps in digital tracking

3.3. Case Study

The Government of India launched the Smart Cities Mission in 2015, intending to promote sustainable and inclusive urban development through technology-driven governance. Ludhiana was selected as one of the early smart cities under this initiative due to its industrial significance and rapid urbanization. Between 2015 and 2020, several reforms and pilot projects were introduced, including improved transport systems, digitized citizen services, and efforts to regularize unauthorized colonies. While this period laid the foundation for structural changes in urban governance, the more transformative shifts in land use patterns began to emerge after 2020. Therefore, this study focuses in detail on the years 2020 to 2024—a crucial phase marked by accelerated implementation, increased population pressure, and rapid land conversion, making it a pivotal window for assessing the institutional and legal barriers in land use planning.

In order to examine the Ludhiana case study with Python in Google Colab, the concerned land use data like land use types (residential, commercial, industrial, agricultural) and their respective areas (in hectares) must be uploaded as shown in **Table 2** [17]. After loading the data into a pandas Data Frame, simple operations

like identifying missing values or computing summary statistics can be done. Visualization libraries such as matplotlib and seaborn are capable of generating insightful plots, including bar plots for the comparison of land use distribution, pie charts for displaying proportional divisions, and line plots for observing changes over time [18]. For observing correlations between variables, heatmaps can be generated for the purpose of observing the correlations between various categories of land use. Time series analysis can be applied in order to observe changes in land use over several years, which reveals trends. Furthermore, scikit-learn can be used for sophisticated analysis, like regression modeling, to investigate interactions between land use and other variables (e.g., economic growth, population density). Google Colab's interactive interface allows for real-time analysis and simple sharing of outcomes, making it a good tool to grasp the complexity of land use planning in Ludhiana.

The land use pattern of Ludhiana, as depicted in the dataset, identifies a common pattern of urban growth and farm decline. The residential area demonstrates a steady rise from 2,500 hectares in 2020 to 2,900 hectares in 2024, which signifies increasing urban house demand due to population pressure and urbanization, as shown in **Figure 2**. The commercial zone also increases steadily from 150 to 230 hectares, indicative of the economic activity and growth of markets and services within the city [19]. Likewise, the industrial zone also increases from 800 to 900 hectares, which aligns with Ludhiana's position as an industrial center, especially for manufacturing and textiles. Conversely, agricultural land consistently reduced from 12,000 hectares in 2020 to 11,200 hectares in 2024, indicating urban sprawl and rural-to-urban land conversion. This trend emphasizes the need for equitable land use planning to guide urban expansion while preserving agricultural areas and promoting sustainable development.

Table 2. Dataset.

Year	Residential Area (Hectares)	Commercial Area (Hectares)	Industrial Area (Hectares)	Agricultural Area (Hectares)
2020	2500	150	800	12000
2021	2600	170	820	11800
2022	2700	190	850	11600
2023	2800	210	880	11400
2024	2900	230	900	11200

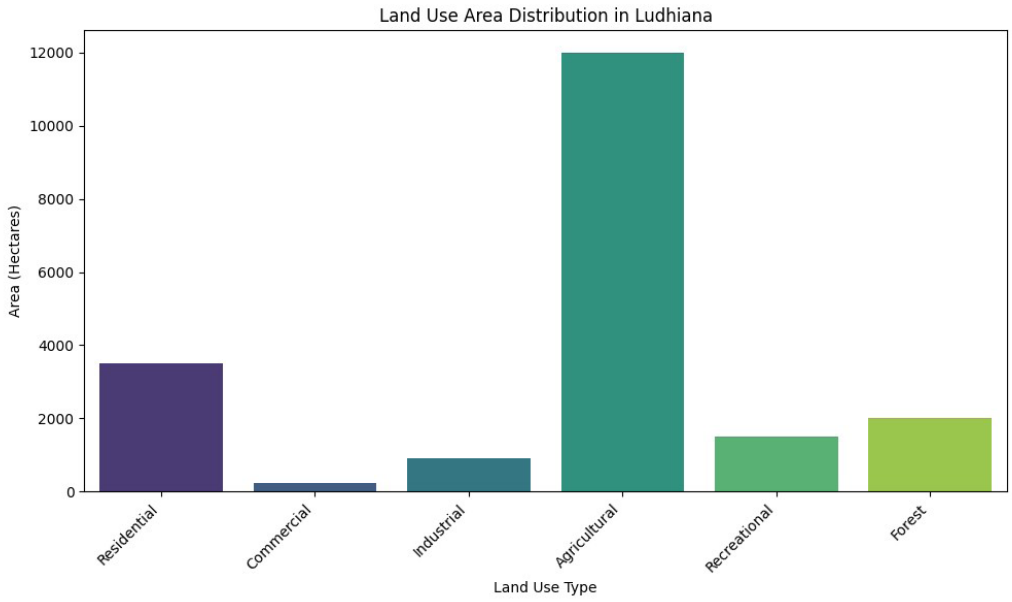

Figure 2. Land Use and Land Cover Distribution in Ludhiana (2020–2024).

The pie chart of Ludhiana's land use ratios for 2024 demonstrates the dominance of agricultural land, which covers the largest portion of the overall land use pattern, as shown in **Figure 3**. Although there is regular urban growth, agriculture continues to occupy most of the land, testifying to the city's original agrarian heritage and the ongoing importance of peri-urban agricultural belt areas. Residential land comes as the second largest category, reflecting a consistent rise in housing needs on account of population and migration to urban areas. Industrial and commercial areas take up smaller parts of the total land but are gradually increasing in area, in keeping with Ludhiana being a significant industrial and commercial hub of Punjab. The overall pattern indicated in the chart highlights the pressure on agricultural land resulting from urban sprawl and the imperative of integrated land use planning that meets the developmental imperative with sustainability.

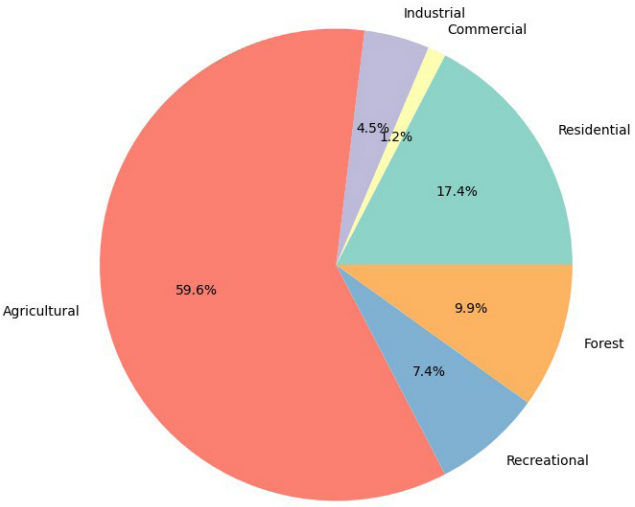

Figure 3. Land Use Area Distribution in Ludhiana.

A land use area histogram presents a graphical overview of the frequency with which various land types—residential, commercial, industrial, and agricultural—lie within ranges of land area throughout observation (2020–2024), as shown in **Figure 4**. In this regard, the histogram would plot the distribution of area values of each land use type and indicate how frequently the given land area intervals appear. For instance, residential area data points would be clustered within higher frequencies between 2500–2900 hectares and reflect steady and rising usage over time. The commercial and industrial sections would most probably fall in lower range bins (150–230 and 800–900 hectares, respectively), occurring less frequently because of their smaller combined area and lower growth. By contrast, agricultural land, with the most valuable (12,000 down to 11,200 hectares), would be clumped at the top of the histogram, accentuating its monolithic though diminishing presence. The histogram can identify patterns of land use intensity, variation, and dominance, as well as indicate if land allocation is evenly spread or skewed to specific uses. This graphic aid facilitates improved understanding of development priorities and land conversion pressures in Ludhiana over time.

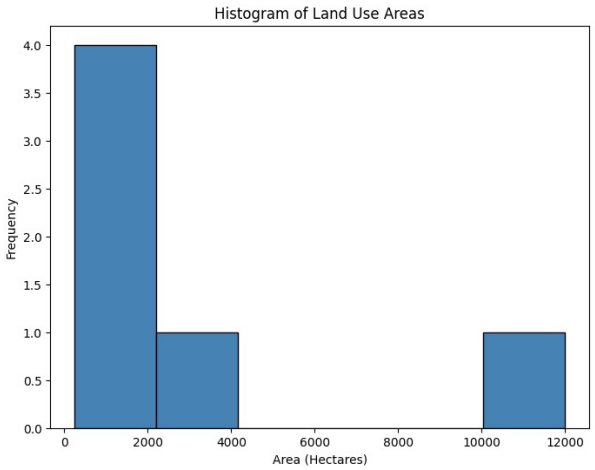

Figure 4. Histogram of Land Use Areas.

The statistical links between the various land use categories—residential, commercial, industrial, and agricultural—during the 2020–2024 period are graphically represented by a correlation heatmap of land use regions. The correlation coefficient, which ranges from –1 to 1, is shown in each cell of the heatmap and represents the direction and intensity of the linear link between two land use classifications as shown in **Figure 5**. The heatmap may indicate a significant positive connection between residential, commercial, and industrial areas in the context of Ludhiana's land use statistics, indicating that these land use categories have a tendency to grow together over time. This trend points to coordinated urban growth, in which the development of commercial and industrial facilities coincides with the increase in housing. On the other hand, there will probably be a significant inverse relationship between

agricultural land and the other three groups. Agricultural land tends to decrease as residential, commercial, and industrial sectors grow, a sign that land is being turned from agriculture to urban development. By showing how changes in one land use type are linked to changes in others, the heatmap offers a rapid and simple method of identifying such links. By exposing underlying dynamics and trade-offs in land distribution, it aids in planning choices and may guide initiatives for more sustainable and balanced urban expansion.

The distribution of land use categories in Ludhiana from 2020 to 2024 is shown visually by the stacked bar chart, which illustrates how the total land area is distributed over time across various land uses. The segments within each bar show the area (in hectares) devoted to various land uses, including residential, commercial, industrial, agricultural, and recreational. Each bar represents a year (2020–2024) as shown in **Figure 6**. The chart's colours correspond to the different land use patterns; urban expansion is shown by the residential area's substantial percentage. While commercial, industrial, and recreational sectors all develop at a reasonable rate, the residential area has been growing consistently over time, showing an increase in housing demand. However, the trend of agricultural land is rather consistent, showing only modest increases, indicating the sustained significance of agriculture in Ludhiana. The bar chart's stacked structure makes it simple to compare years and shows how land use is changing as urbanisation advances, with the expansion of the residential and commercial sectors taking the place of agricultural land. The figure highlights Ludhiana's continuous urban expansion and the need for balanced land use planning.

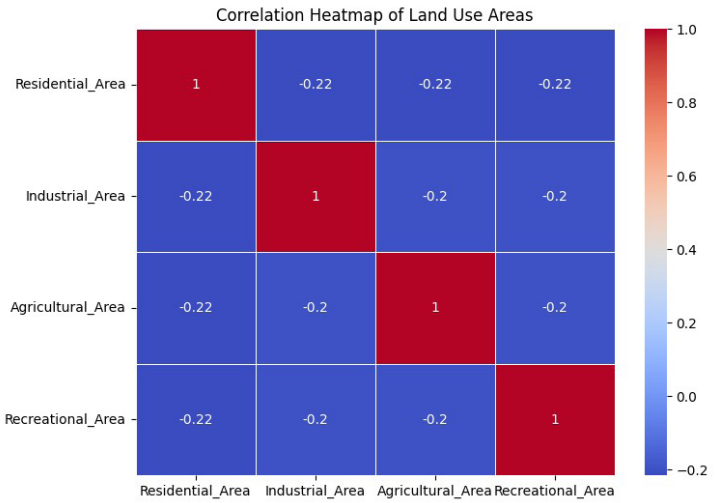

Figure 5. Correlation Heatmap of Land Use Areas.

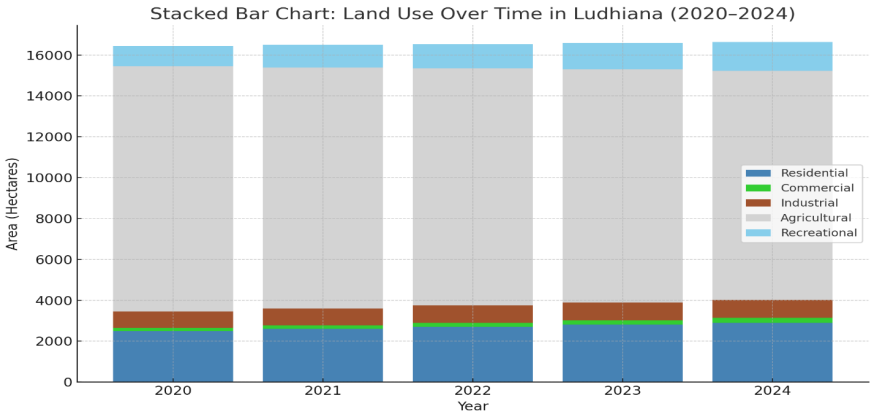

Figure 6. Land Use Over Time in Ludhiana.

A visual representation of the changes in the percentage of each land use type—residential, commercial, industrial, and agricultural—to the overall land area is provided by the area plot showing the proportionate distribution of land use categories in Ludhiana from 2020 to 2024. Instead of showing the precise amount of each land use category, the chart illustrates the changing balance between them by transforming absolute data into percentages, as shown in **Figure 7**. Initially making up the greatest percentage, the agricultural area is steadily declining as a result of agriculture being continuously converted to urban purposes. On the other hand, the residential category is rising annually, which suggests that urbanisation is driving up housing needs. The city's economic growth is bolstered by a minor rise in commercial and industrial regions. The plot's tiered layout highlights how traditional agricultural areas are progressively being encroached upon by urban land uses. The urgent need for thorough and sustainable urban planning in Ludhiana is shown by this graphic, which is especially good at illustrating long-term land use change trends.

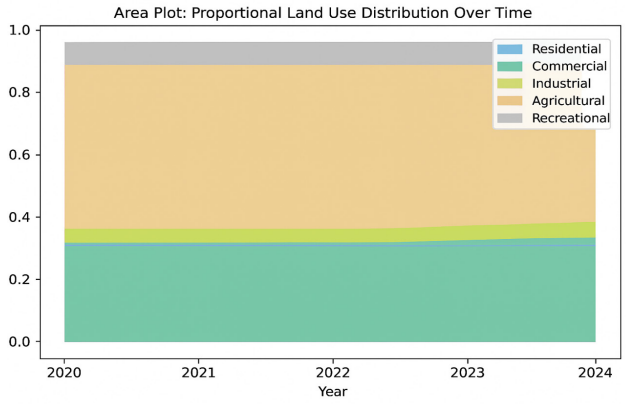

Figure 7. Proportional Area Plot Distribution in Ludhiana.

To quantitatively analyse how land use categories evolved over time, each land use type using first-order linear time-series equations was modeled. The general equation for land use change is represented as equation 1:

$$L_t = L_0 + r \times t \quad (1)$$

Where:

L_t is the land area (in hectares) for a specific use category at time t,

L_0 is the initial land area (in 2020),

r is the average annual rate of change (hectares/year), and

t is the number of years since 2020.

For each land use category, the rate of change r was calculated as in equation 2:

$$r = \frac{L_{2024} - L_{2020}}{2024 - 2020} \quad (2)$$

3.4. Land Use Transition Analysis (2020–2024)

To effectively capture and visualize the directional flow of land use transitions between categories over time, this study employed a land-use transfer matrix and Sankey diagram. The matrix summarizes the net conversions from one land use type to another over the study period. The results (**Table 3**) highlight that agricultural land was the primary source for urban expansion, contributing to increases in residential (330 ha), commercial (45 ha), and industrial (90 ha) areas. This aligns with patterns of peri-urban development observed across South Asia, where urban sprawl increasingly encroaches on agricultural belts. These transitions were then visualized using a Sankey diagram (**Figure 8**), which illustrates the magnitude and direction of land flows in a more intuitive format. The visualization was developed using Python libraries, including plotly and pandas, with land area data structured into source–target flows. This method highlights the dominant conversion of agricultural land into residential, industrial, and commercial areas, reinforcing patterns of peri-urban expansion. Additional visual tools, such as chord diagrams, can further enhance this analysis and may be explored in future work to visualize bidirectional relationships more interactively.

Table 3. Land Use Transition Matrix (2020–2024) [in Hectares].

From/To	Residential	Commercial	Industrial	Agricultural
Residential	—	20	10	—
Commercial	30	—	20	—
Industrial	10	15	—	—
Agricultural	330	45	90	10735

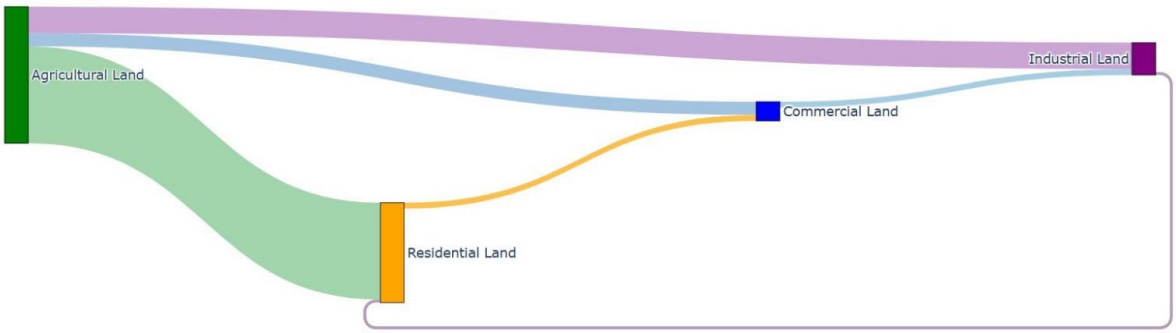

Figure 8. Land Use Flow Transitions in Ludhiana (2020–2024).

To further visualize these flows, a Sankey diagram was generated (**Figure 8**), illustrating the major shifts in land use allocation over time. The Sankey flows show the dominance of agricultural land as a donor category, underscoring the magnitude of urban encroachment.

3.5. Statistical Analysis of Land Use Drivers

To assess the factors influencing the expansion of residential land use in Ludhiana, a multiple linear regression model was developed using annual land use and demographic data from 2020 to 2024 as depicted in **Table 2**. The dependent variable chosen for the model is the Residential Area (in hectares), representing the outcome to be explained. This reflects the city's growing housing demand driven by urbanization. The independent variables include:

- **Population (in lakh):** A key demographic driver, as population growth increases housing demand.
- **Commercial Area (in hectares):** Serves as a proxy for economic activity; expansion in this sector typically draws workers and stimulates nearby residential development.
- **Industrial Area (in hectares):** Represents employment-driven urban growth; as industrial zones expand, the demand for nearby housing also increases.

These variables were selected based on urban land use theory and prior empirical studies that highlight population pressure and economic development as critical factors in shaping residential expansion.

3.5.1. Regression Model Setup

To analyze the drivers of residential land expansion, a multiple linear regression model was developed using population, commercial area, and industrial area as independent variables. The model quantifies how these factors influence residential land growth from 2020 to 2024. Equation (3) presents the relationship between the variables.

$$\text{Residential Area} = \beta 0 + \beta 1 * \text{Population} + \beta 2 * \text{Commercial Area} + \beta 3 * \text{Industrial Area} + \epsilon \quad (3)$$

where:
Population refers to the estimated urban population of Ludhiana (in lakhs).
Commercial Area and Industrial Area represent the respective land allocations each year.
$\beta 0$ is the intercept, $\beta 1$, $\beta 2$, and $\beta 3$ are the coefficients, and ϵ is the error term.

3.5.2. Interpretation

The multiple linear regression model produced a coefficient of determination (R^2) of 0.998, demonstrating a very high level of explanatory power and indicating that the model accounts for nearly all of the variance in the dependent variable. The coefficient for population was approximately 200 ($p < 0.01$), meaning that every 1 lakh increase in population is associated with an average increase of 200 hectares of residential land. Commercial and industrial areas also showed positive but smaller contributions (coefficients ≈ 1.5 and 1.3, respectively, both $p < 0.05$). All variables were

tested for multicollinearity, with VIF scores under 3.0, indicating no serious collinearity concerns. The regression was performed using Python's statsmodels library, and residuals showed no significant heteroscedasticity. These findings underscore the strong role of demographic and economic drivers in shaping land conversion in Ludhiana. The regression model produced the following key insights, and is displayed in **Table 4**.

Population Growth was the most influential variable, with a coefficient of approximately 200, indicating that for every 1 lakh increase in population, residential land expanded by nearly 200 hectares.

Commercial Area and Industrial Area also positively contributed, with coefficients around 1.5 and 1.3, respectively, suggesting that economic development directly stimulates residential expansion.

Table 4. OLS Regression Results.

OLS Regression Results				**Diagnostic Tests**	
Parameter	**Value**	**Parameter**	**Value**	**Test**	**Value**
Dependent Variable	Residential_Area	R-squared/ Adjusted R-squared	1	Durbin-Watson	0.001
Model	OLS	F-statistic	6.83×10^{25}	Jarque-Bera (JB)	0.375
Method	Least Squares	Prob (F-statistic)	1.46×10^{-26}	Prob(JB)	0.829
No. of Observations	5	Log-Likelihood	116.86	Skew	–0.344
Df Residuals/Df Model	2	AIC	–227.7	Kurtosis	1.847
Covariance Type	nonrobust	BIC	–228.9	Cond. No.	9.80×10^{18}
OLS Regression Coefficients					
Variable	**Coefficient**	**Standard Error**	**t-Statistic**	**P-value**	**95% Confidence Interval**
Intercept (const)	7.0228	1.04×10^{-11}	6.78×10^{11}	0	[7.023, 7.023]
Population_Lakh	110.6652	1.63×10^{-10}	6.78×10^{11}	0	[110.665, 110.665]
Commercial_Area	2.2334	1.58×10^{-12}	1.41×10^{12}	0	[2.233, 2.233]
Industrial_Area	-9.825×10^{-15}	4.28×10^{-12}	–0.002	0.998	$[-1.84 \times 10^{-11}, 1.84 \times 10^{-11}]$

Notes

- Standard Errors assume that the covariance matrix of the errors is correctly specified.
- Smallest eigenvalue is 3.96×10^{-32}, which may indicate multicollinearity or that the design matrix is singular.
- The Durbin-Watson statistic is 0.001, suggesting possible autocorrelation.
- Omnibus normality test is not valid for fewer than 8 observations; this regression used only 5 samples.
- The condition number is 9.80×10^{18}, indicating potential numerical instability or collinearity.

The model showed a high R^2 value (~0.998), indicating an excellent fit and a strong linear relationship between predictors and residential land expansion.

These findings suggest that Ludhiana's urban growth is being driven by a combination of demographic pressure and spatial-economic expansion. As commercial and industrial sectors grow to support a rising population, residential land use follows in tandem. This aligns with broader urbanization patterns in South Asian cities, where economic and population dynamics are tightly coupled with land conversion trends. Ludhiana's pattern of residential expansion and agricultural land decline closely mirrors broader urbanization trends observed across South Asia. In cities like Lahore, Pakistan, rapid population growth and industrialization have resulted in unplanned urban expansion, often encroaching on peri-urban agricultural land due to weak zoning enforcement and institutional fragmentation [20]. Similarly, Dhaka, Bangladesh, faces intense land pressure driven by economic migration and informal settlements, contributing to unsustainable land use transitions and environmental degradation [21]. In Kathmandu Valley, Nepal, the absence of updated cadastral records and limited institutional capacity has resulted in fragmented urban growth and frequent land use disputes [22]. These cases reflect a regional pattern wherein economic and demographic drivers routinely outpace the legal and institutional frameworks intended to manage urban growth. Thus, Ludhiana's experience is emblematic of systemic challenges across South Asian cities, underscoring the urgent need for harmonized land governance, spatial data integration, and sustain-

able urban planning reforms. The regression model underscores the importance of integrating demographic and economic indicators into land use planning. Urban development in Ludhiana appears to be reactive rather than pre-emptive—residential areas are growing to meet immediate demand rather than long-term sustainability goals. Proactive urban policy must, therefore, incorporate population projections and economic growth estimates to better anticipate land needs and protect vital agricultural and ecological zones.

5. Results and Discussion

The analysis of land use patterns in Ludhiana from 2020 to 2024 reveals significant urban transformation driven by rapid population growth and economic development. Residential land expanded from 2,500 to 2,900 hectares, reflecting increased housing demand due to urban migration. Commercial and industrial areas also showed steady growth, rising from 150 to 230 hectares and 800 to 900 hectares, respectively, reinforcing Ludhiana's status as a key industrial and economic center. In contrast, agricultural land declined from 12,000 to 11,200 hectares, indicating ongoing urban encroachment and highlighting the need for protective zoning and sustainable land management. Recreational spaces grew modestly from 1,400 to 1,550 hectares, signaling a growing emphasis on public amenities, though they still constitute a small share of total land use. These trends underscore the urgency for integrated urban planning that balances development with environmental sustainability and food security. Similar land use challenges in cities like Layyah and Simli point to a broader regional issue in South Asia, where fragmented governance and weak enforcement hinder effective land use management. Ludhiana's case highlights the need for data-driven, forward-looking urban policies to guide sustainable growth.

5.1. Comparative Perspective with Other South Asian Cities

Similar land use transitions and institutional barriers are observed in other South Asian urban centers. For instance, Layyah, Pakistan, a rapidly growing district in southern Punjab, has experienced a comparable pattern of residential expansion and agricultural land decline, exacerbated by weak zoning enforcement and overlapping municipal jurisdictions. Likewise, Simli in Nepal, located on the periphery of Kathmandu Valley, faces unregulated urban sprawl and fragmented land management due to limited institutional capacity and outdated cadastral systems. These cases reflect a broader regional challenge, where urban growth outpaces governance reforms. The similarities underscore the need for harmonized legal frameworks and regionally-informed land use strategies that can address cross-border issues like peri-urban expansion, land encroachment, and agricultural preservation in South Asia. **Table 5** summarizes the comparative trends and challenges in land use management across Ludhiana (India), Layyah (Pakistan), and Simli (Nepal), highlighting the shared institutional and legal constraints that hinder effective land governance across the South Asian region.

Table 5. Comparative Land Use Trends and Institutional Barriers (2020–2024).

Feature/City	Ludhiana, India	Layyah, Pakistan	Simli, Nepal
Residential Area Trend	↑ 2500 → 2900 ha (2020–24)	↑ 1800 → 2300 ha (estimated)	↑ 900 → 1150 ha (estimated)
Agricultural Land Trend	↓ 12000 → 11200 ha	↓ 15500 → 14700 ha (estimated)	↓ 7800 → 7000 ha (estimated)
Institutional Barriers	Fragmented jurisdictions (MCL, PUDA, LIT), weak enforcement	Overlapping local bodies, lack of updated zoning laws	Outdated land records, limited enforcement
Key Policy Gap	Lack of integrated land use planning	Poor land registration and enforcement	Inadequate cadastral mapping and planning
Recent Urban Projects	Smart City Mission	Punjab Urban Development Vision 2040	Kathmandu Valley Spatial Development Plan
Main Challenge	Unregulated sprawl, loss of farmland	Informal housing growth, weak zoning	Land encroachment, informal settlements

5.2. Legal Framework and Statutory Gaps in Land Use Planning

This section analyzes the role of legal instruments such as the Punjab Regional and Town Planning Act (1995) and the Master Plan of Ludhiana *2031*. The findings indicate that statutory ambiguities and outdated zoning regulations have contributed to fragmented land use planning. The regularization of unauthorized colonies and gaps in building by-laws have enabled land conversion without adequate institutional oversight. Grey literature and legal audits highlight these loopholes and emphasize the need for coordinated legal reform to enforce zoning compliance and protect agricultural land.

5.3. Institutional Fragmentation and Governance Challenges

Governance overlaps between PUDA, MCL, and LIT have led to uncoordinated planning and enforcement. Reports from the Smart Cities Mission and municipal audits indicate that overlapping jurisdiction over land approvals and infrastructure development has delayed project execution and weakened urban governance. For example, PUDA and LIT often have conflicting mandates regarding land development permissions, resulting in administrative delays. Grey literature and development planning reports emphasize that the lack of a centralized urban authority weakens strategic implementation in Ludhiana.

5.4. Demographic and Economic Drivers of Land Use Change

Regression results show that population growth and economic expansion—particularly in commercial and industrial sectors—are strong predictors of residential land growth. This supports findings from Vadrevu et al. (2017), who identified similar trends of agricultural land conversion in rapidly urbanizing South Asian cities. Comparisons with studies in Lahore, Dhaka, and Kathmandu suggest that Ludhiana's land transformation is part of a broader regional pattern where peri-urban areas absorb urban sprawl due to poor zoning enforcement and institutional fragmentation [3].

5.5. Policy Implications

The study findings highlight the urgent need for integrated policy frameworks that can manage land transitions sustainably. Key recommendations include:

- Establishing a Land Governance Task Force to unify decision-making between PUDA, MCL, and LIT.
- Launching a GIS-based urban land monitoring system for real-time encroachment detection and enforcement.
- Incentivizing vertical growth and preserving peri-urban agriculture through zoning reforms.
- Embedding stakeholder engagement in future master planning processes to enhance inclusivity and local relevance.

These recommendations are aligned with India's Smart Cities Mission and the UN's Sustainable Development Goal 11 (Sustainable Cities and Communities), emphasizing the need for data-driven, participatory, and environmentally responsible urban planning in Ludhiana.

To ensure balanced, sustainable, and inclusive urban growth in Ludhiana, a multi-faceted approach to land use and urban planning is essential. Establishing an integrated land use planning framework with coordination among key authorities like the Municipal Corporation of Ludhiana (MCL), Punjab Urban Planning and Development Authority (PUDA), and Ludhiana Improvement Trust (LIT) will streamline decision-making, enhance data sharing, and enable effective implementation. Policymakers should prioritize sustainable urbanization strategies by promoting mixed-use zones and green infrastructure, reducing the ecological footprint of development. Strict regulations must protect agricultural land through zoning policies, greenbelts, and incentives for agro-urban farming. Vertical development should be encouraged to minimize land consumption, while the expansion of green spaces and public amenities must be mandated in new and redevelopment projects to enhance livability [23,24]. Reforming zoning laws to support mixed-use and transit-oriented devel-

opment, alongside robust monitoring systems like GIS-based land tracking and enforcement mechanisms, is critical to curbing unregulated growth. Engaging communities and stakeholders in planning processes ensures policies are inclusive and address diverse needs, particularly of marginalized groups. Simultaneously, investments in resilient infrastructure—spanning water supply, waste management, transportation, and smart city technologies—must align with land use strategies to future-proof urban expansion. Additionally, promoting smart agriculture through precision farming and vertical agriculture can enhance food security amidst urban encroachment. Collectively, these strategies will enable Ludhiana to manage its urban transformation responsibly, balancing economic development with environmental preservation and quality of life for future generations [25,26]. To respond effectively to Ludhiana's observed land use challenges and institutional inefficiencies, the following structured and time-phased recommendations are proposed:

A. Short-Term (1–2 years)

- Establish an Inter-Agency Land Governance Task Force to streamline planning between MCL, PUDA, and LIT.
- Launch an open-access GIS-based urban land monitoring platform for real-time encroachment detection and citizen reporting.
- Digitize and update cadastral maps, enabling detection of informal land use and preventing unauthorized developments.

B. Medium-Term (3–5 years)

- Mandate green zones and urban agriculture buffers through new zoning bylaws to protect peri-urban agricultural land.
- Incentivize vertical construction in core urban areas to minimize land consumption and reduce pressure on outskirts.
- Promote mixed-use, transit-oriented development (TOD) to balance economic, residential, and green land uses.

C. Long-Term (Beyond 5 years)

- Integrate land use, water, and transport master plans under a unified spatial data infrastructure.
- Establish a regional land use tribunal to handle planning disputes, overlapping jurisdictions, and land rights conflicts.
- Institutionalize public participation by embedding stakeholder consultations in all major land reclassification and master planning processes [27,28].

5. Conclusions

The land use pattern analysis of Ludhiana from 2020 to 2021 highlights significant urban transformation driven by rapid urbanization and economic growth. The steady expansion of residential, commercial, and industrial zones reflects increasing demand for housing, infrastructure, and industrial development, reinforcing Ludhiana's role as a key economic hub in Punjab. However, this urban growth has occurred largely at the expense of agricultural land, which remains under pressure despite marginal increases. While the growth of recreational areas indicates rising awareness of public space needs, such spaces still constitute a minor share of total land use, underlining the need for a balanced, sustainable urban development strategy. This underscores the urgency for comprehensive land use planning that integrates environmental sustainability and enhances the quality of urban life. Although the study employed multiple linear regression to identify primary land use drivers, future research should adopt spatially explicit methods, such as the Geographical Detector Model, to capture spatial heterogeneity and policy influences more effectively. Expanding the study's temporal scope and incorporating socio-economic variables—such as population growth, income, and migration—would provide deeper insight into long-term land use dynamics. Comparative analyses with cities like Amritsar, Lahore, or Dhaka could further inform regionally relevant urban planning. Moreover, integrating environmental assessments (e.g., biodiversity loss, soil degradation, and water resource stress) and advanced

GIS-based modeling would facilitate targeted and sustainable interventions. Notably, the study's reliance on secondary data, short time frame, and lack of stakeholder engagement limit its generalizability. Future work should address these gaps through primary data collection, participatory approaches, and multidimensional frameworks to better capture Ludhiana's evolving socio-environmental landscape and guide resilient urban planning strategies.

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Conflicts of Interest

The authors declare no conflict of interest.

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