

ARTICLE

Spatio-Temporal Assessment of Land Use Changes in Sonipat, Haryana: Socio Economic Impacts and Policy Intervention

Niraj Kumar¹ , Tejbir Singh Rana² , Subhash Anand^{1*} , Nishit³ 

¹ Department of Geography, Delhi School of Economics, University of Delhi, Delhi 110007, India

² Department of Geography, Shivaji College, University of Delhi, Delhi 110027, India

³ Department of Geography, Shaheed Bhagat Singh Evening College, University of Delhi, Delhi 110017, India

ABSTRACT

This study examines the effects of rapid land use changes in India, with a specific focus on Sonipat District in Haryana—a region undergoing significant urban expansion. Over the past two decades, rural landscapes in Sonipat have undergone notable transformation, as open spaces and agricultural lands are increasingly converted into residential colonies, commercial hubs, and industrial zones. While such changes reflect economic development and urban growth, they also raise critical concerns about sustainability, especially in terms of food security, groundwater depletion, and environmental degradation. The study examines land use changes between 2000 and 2024 using remote sensing techniques and spatial analysis. It further incorporates secondary data and insights from community-level interactions to assess the socio-economic and ecological impacts of this transformation. The findings indicate rising land fragmentation, loss of agricultural livelihoods, pressure on civic infrastructure, and increasing pollution—factors that threaten long-term regional sustainability. The study underscores the urgent need to reconcile urban development with environmental and social sustainability. By offering a detailed case study of Sonipat, this research contributes to the broader discourse on India's urbanisation pathways. It aims to provide policymakers, planners, and researchers with evidence-based recommendations to manage land transitions more responsibly, promoting urban growth models that ensure ecological integrity, equitable development, and long-term resilience.

Keywords: Land Use; Spatio-Temporal Dynamics; Socio-Economic Impacts; Urbanization; Policy

*CORRESPONDING AUTHOR:

Subhash Anand, Department of Geography, Delhi School of Economics, University of Delhi, Delhi 110007, India; Email: sanandpvs@gmail.com

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1. Introduction

India's land use patterns have undergone substantial shifts driven by urbanization, industrialization, and infrastructure expansion. With more than 31% of the population now living in urban areas, the process of urban growth has accelerated, leading to the widespread conversion of agricultural land and open spaces into urban settlements. While major cities were the initial hubs of this growth, since 1991, adjoining districts have increasingly experienced urban sprawl, contributing to the rise in residential, commercial, and retail developments ^[1].

According to the World Bank, by 2036, around 600 million people—approximately 40% of India's population—are expected to live in urban areas. This urban expansion is extending beyond metropolitan centres into rural districts, notably in states such as Karnataka, Punjab, Tamil Nadu, Haryana, and Kerala. As a result, cropland and water bodies are diminishing, making way for urban infrastructure. These changes in land use present multiple challenges. The loss of agricultural land poses threats to food security and environmental quality, including air and water pollution. To address these concerns, adopting sustainable land management practices is essential for ensuring that economic growth does not come at the cost of environmental degradation.

In this context, the study presents a detailed case analysis of Sonipat District in Haryana. Through remote sensing and spatial analysis, it investigates the implications of land use changes on both socioeconomic dynamics and environmental sustainability. By integrating these insights, the research aims to offer a deeper understanding of the local impacts while contributing to broader discussions on sustainable urban development in India.

2. Review of Literature

2.1. Environmental Impacts of Land Use Change

Understanding the spatiotemporal dynamics of land use change requires a comprehensive examination of various methodologies and data sources across different geographic contexts. This section reviews key studies that have investigated these dynamics, emphasizing prominent

patterns and findings. In Jinan, China, Zheng et al. (2012) analyzed land use changes over time using a System Dynamics (SD) model to simulate land use demands from 1997 to 2005 ^[2]. Their study offered valuable insights into evolving urban and agricultural land use patterns, contributing a broad perspective on the drivers and trends of land transformation. Similarly, Gidey et al. (2017) investigated land use changes in Raya, Northern Ethiopia ^[3], from 1984 to 2015 by applying remote sensing and GIS techniques. The research identified eight primary land use categories and documented notable declines in grasslands, water bodies, and floodplain areas. By employing Landsat imagery and post-classification change detection, the study presented a rigorous framework for assessing land use transformations over time. Between 2008 and 2017, Akubia and Bruns (2019) investigated changes in land usage in Ghana's Greater Accra Metropolitan Area ^[4]. Their findings showed reductions in open space and farmland, with increases in urban built-up areas, indicating urban sprawl and uneven expansion. This necessitated a call for strategic spatial planning to address the rapid urbanization. Using spatiotemporal variables, Sapena and Ruiz (2019) presented a unique way to measure the gap between urban growth and population ^[5]. Six European cities were examined in order to address the disparity between the growth of residential areas and population changes, contributing to sustainable policy-making. Kogo et al. (2021) studied land use changes in western Kenya, observing significant transformations due to population growth ^[6]. The use of multi-spectral Landsat images from 1995 to 2017 revealed a drastic increase in built-up areas and a decline in forestland, grassland, and water resources. The study emphasized how human activity affects delicate ecosystems and how sustainable land management is essential. Veloso et al. (2021) looked at how land use changed in Brazil between 1985 and 2018, finding that natural vegetation gave way to areas used for agriculture and cattle. This transition, driven by human activities, had profound impacts on the Jaguaribe River basin, emphasizing the environmental consequences of land use changes. Abraham and Kundapura (2022) used the Land Change Model (LCM) to forecast changes in land use for 2021 ^[7], confirming the model's accuracy using real data. The projections indicated a decline in agricultural land alongside an expansion of urban areas,

sparkling concerns about potential impacts on food security. This study's foresight into future trends highlighted the importance of sustainable development.

In India, several studies addressed land use changes over different time spans. Saini and Kaushik (2011) examined land use changes in the Haryana sub-region, noting a transition from agricultural land to built-up areas^[8]. Mondal et al. (2013) investigated land use dynamics within the Brahmaputra River Basin^[9], whereas Kar et al. (2017) studied urban and peri-urban transformations in Nagpur City^[10], highlighting significant urban growth fuelled by rising population pressures. Moulds et al. (2018) generated high-resolution gridded land use maps for India from 1960 to 2010^[11], providing a broader context for understanding land use changes. Similar studies by Mishra et al. (2018) and Rani (2019) reported a consistent reduction in agricultural land alongside a rise in built-up areas^[12,13]. Nishit et al. (2021) examined the environmental consequences of land use changes^[14], highlighting issues such as inadequate solid waste management, waterlogging, loss of green spaces, vertical urban growth, water scarcity, and the emergence of urban heat islands. In Sonipat, Haryana, Kumar et al. (2025) documented a 19% decline in agricultural land over the last 20 years, accompanied by a rise in residential and industrial development^[15]. Collectively, these studies offer valuable insights into the complex interplay between land use transformations and human activities.

2.2. Socio-Economic Impacts of Land Use Change

Land use changes have significant influences on both the economy and society, affecting biodiversity, ecosystem services, and socio-economic factors. This literature review explores these dynamics across different geographical regions and suggests the importance of integrated approaches to manage land use sustainably. In Botswana's Kalahari area, Thomas and Sporton (2007) investigated how land use changes affect the environment and society^[16]. They focused on concurrent structural land use and environmental changes, revealing the need to consider both social and ecological aspects for regions with high temporal variability and rapid social shifts. Similarly, Kumpula et al. (2011) studied land use changes in Russia's arctic region, emphasizing the impact on indigenous Nenets rein-

deer herders^[17]. Their findings pointed to infrastructure expansion, competition for freshwater fish, and tundra transformation. The study highlighted the need for communication between stakeholders to ensure effective policy implementation. In southeastern Australia, Williams and Schirmer (2012) explained the socioeconomic effects of land use changes^[18]. Their study showed that locals were often unaware of the scale and nature of these changes, struggling to connect them with social shifts. This underscores the value of understanding social changes for policy and impact assessments. Quintas-Soriano et al. (2016) investigated land use changes in Spanish drylands and identified four key transformations: urban intensification, rural abandonment, greenhouse horticulture, and conservation efforts^[19]. They examined how these changes will affect ecosystem services on a social level. They underlined the need for innovative land management techniques to balance urbanisation and environmental preservation. Studies focusing on ecological impacts also reveal significant findings. Bhattarai et al. (2008) analysed land use changes in Alabama's Wiregrass region and their effects on water quality and economic returns^[20]. The study emphasized the need for a decision support system to guide land management. Using high spatial-resolution satellite imagery, Deng et al. (2009) examined the dynamics of land use in Hangzhou, China^[21]. Concerns regarding food productivity were raised by the changes in land use and landscape patterns due to fast urbanisation. Polasky et al. (2011) examined land use changes in Minnesota using the InVEST model, demonstrating a disconnect between net societal benefits and private rewards to landowners^[22], with extensive agricultural growth resulting in substantial ecological losses. In their 2018 study, Ma et al. examined the spatio-temporal dynamics of land use intensity in China^[23]. The study highlighted the impact of various policies and technological advancements on land use patterns. Lawler et al. (2014) forecasted land-use changes in the United States^[24], showing that scenarios with high crop demand can lead to significant reductions in habitat species, underscoring the need for policy interventions to influence land-use changes positively. Arunyawat and Shrestha (2016) explored land use changes in Northern Thailand^[25], using the InVEST model to evaluate influences on ecosystem services. The study indicated a general decline in ecosystem services

due to increased cultivation and urban growth. Tolessa et al. (2017) observed land use changes in Ethiopia's central highlands ^[26], showing a consistent decrease in forestland and a corresponding decline in ecosystem services.

Jose and Padmanabhan (2016) studied the impacts of land use changes in Kerala, India ^[27], with an emphasis on the decline in paddy farming brought on by population pressure, labour shortages, and economic considerations. This shift reflects adaptive livelihood strategies and highlights unintended consequences of policy anomalies, pointing to the need for integrated policies to address food security. Kalyani et al. (2019) examine the socioeconomic effects of land use changes in Himachal Pradesh, India ^[28]. Their study revealed mixed impacts, with some regions experiencing tourism growth and improved transportation, while others faced livelihood loss and displacement. This study highlighted the need for more balanced land management strategies.

2.3. Food Security and Sustainability: Global and Indian Contexts

This section reviews the socio-economic and environmental impacts of land use changes, with particular attention to food security and sustainability in different regions. In the international context, Eickhout et al. (2007) analyzed four European land use scenarios ^[29], finding that new industrial changes promoted economic growth, but climate change and nutrient depletion threatened global agriculture, impacting food security. Rutten et al. (2014) examined land use trends in Vietnam using a global-to-local modeling method ^[30], emphasizing problems such as deforestation, biodiversity loss, and rising greenhouse gas emissions. The loss of agricultural land in key regions, driven by flood risks linked to climate change, has posed significant challenges to food security. In Kiambu County, Kenya, Musa and Odera (2015) studied changes in land use and land cover and discovered that agricultural land fell from 39.69% to 15.75% ^[31], while urban coverage increased from 1.88% to 33.50%. This shift pointed to food insecurity and increased housing demand. Dupras et al. (2016) studied coastal areas in Spain ^[32], showing urban expansion and reforestation displaced traditional agrarian landscapes, impacting ecosystem services and reducing total ecosystem value since the 1950s. Agidew and Singh

(2017) studied land use changes in northeastern Ethiopia ^[33], showing a rise in agricultural areas and rural settlements and a decline in woodland and shrub lands due to population development and rainfall shortages. Reduced agricultural yields and land degradation resulted from this, highlighting the necessity of sustainable land management techniques. Parven et al. (2022) studied land use changes in Bangladesh before and after disasters ^[34], revealing that aquaculture increased while agricultural lands decreased, impacting food security. The study highlighted the importance of incorporating community risk perceptions into local disaster management planning to alleviate food insecurity.

Several studies explored how land use changes affect food security and environmental sustainability in India. Rejula and Singh (2015) analysed land use patterns in Kerala ^[35], discovering a decline in total cropped area and a rise in monocropping with non-food crops. Rice and tapioca showed negative growth rates, raising concerns about food security. Singh et al. (2023) in the Sonipat district found that changes in agricultural land use affected the socio-economic setup, linking reduced cropland to dietary diversity issues ^[36]. Prakash et al. (2021) and Sarkar et al. (2019) observed similar patterns in groundwater quality decline and rapid transitions to built-up land ^[37,38], emphasizing ecological impacts due to changing land use patterns. Aggarwal et al. (2001) and Ahlawat and Kaur (2013) highlighted the spatial disparities in food security in Haryana ^[39,40], where industrialization and urbanization affected agricultural productivity, highlighting how important it is to prepare for sustainable land usage. Lone and Mayer (2018), in their analysis of land use changes in the Anantnag region of the Kashmir Valley, found that rapid urbanization is associated with reduced food security and highlights the growing need for sustainable land management practices ^[41]. Behera et al. (2016) examined the Meghalaya plateau's shifting land use ^[42], noting a transition to cash cropping and mono cropping, which affected traditional agricultural practices and food security. Reuter et al. (2021) focused on land acquisition practices in the Greater Mohali Area Development Authority in Chandigarh ^[43], showing how development efforts threatened food security and livelihoods. Khursheed et al. (2022) examined land use changes in Kashmir Valley ^[44], indicating a decline in paddy and

maize cultivation, with Srinagar and Shopian showing significant food deficiencies.

3. The Research Context

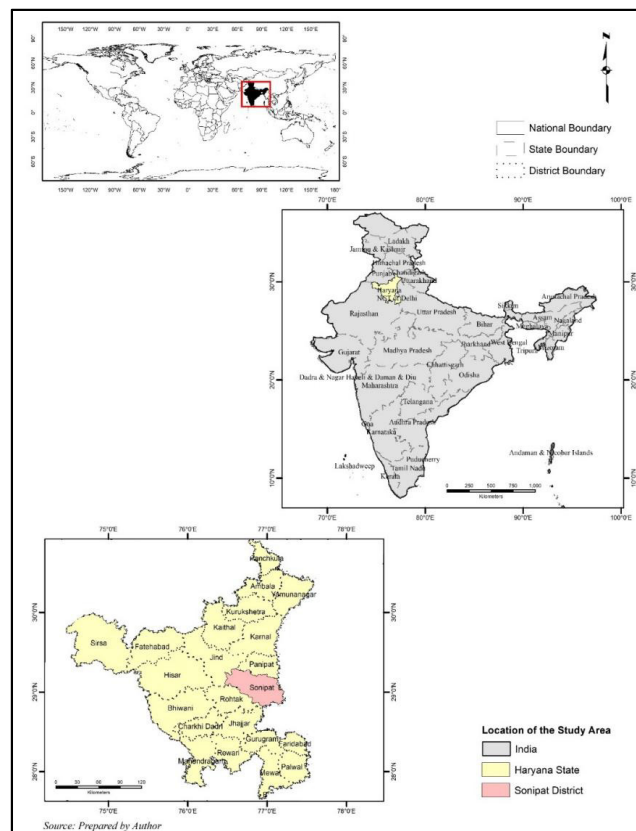
While prior studies have examined the patterns of land use change in various regions, assessing these shifts over time and space, however, understanding their environmental, social, and economic effects requires a more comprehensive analysis. Further, studies in this dimension are limited across the global south, especially in the Indian context. However, countries of the developing world have witnessed unprecedented urban growth and land use changes over the last two to three decades. Thus, this study intends to examine the temporal and geographical dynamics of land use changes in the context of a district in the Global South that is quickly urbanizing, with an emphasis on the changing character of land use and its wider ramifications.

The core questions driving this research are: What spatial trends regarding land use change can be observed?

How do these trends differ at various scales within the area? What impacts do these changes have on society and the economy? Finally, based on focus-group discussions, how do the local population perceive the changes and their implications?

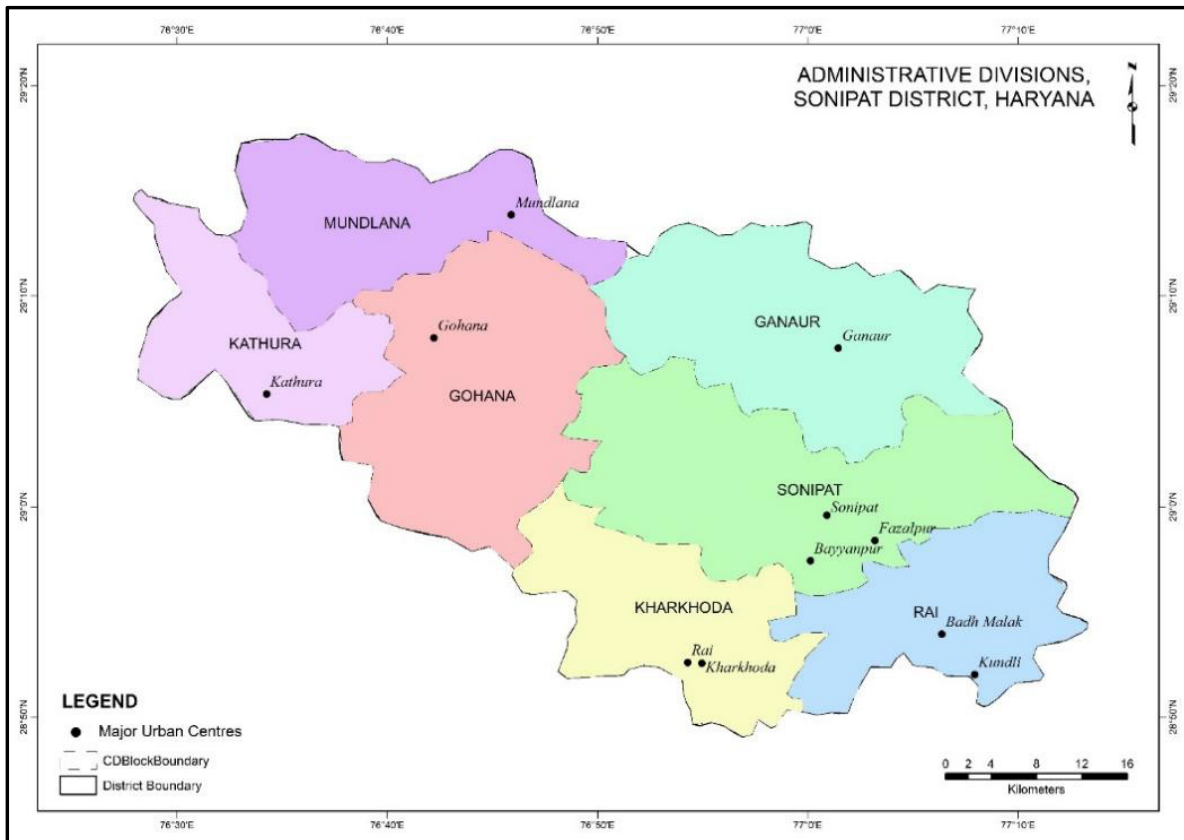
4. Study Area

Haryana holds a crucial place in India's geography, history, and politics, connecting the southern Aravali mountains with the northern Shivalik Himalayas (**Figure 1**). This location has shaped the history of the Indo-Gangetic plains. The Sonapat District, located in Haryana's eastern region, showcases a balance between rich history and modern economic growth. Spanning 2,122 square kilometres 1972, it was separated from the former Rohtak District. The Yamuna River irrigates Sonapat's lush fields, which yield rice and wheat. Once a prehistoric community, Sonapat evolved through centuries of changing empires, emerging as a vibrant industrial hub with units in textiles, steel, and automotive components (**Figure 1 (a)**).



(a)

Figure 1. Cont.



(b)

Figure 1. Geographical Location of the Study Setting. (a) Haryana State Map; (b) Sonipat District Map.

Sonipat's strategic location near Delhi, its robust infrastructure, and major highways like NH-1, NH-17, and the Kundli-Manesar-Palwal Expressway fuel its growth. There are eight community development blocks and four tehsils in the district's administrative structure: Kathura, Sonipat, Mundlana, Gohana, Kharkhoda, Rai, Ganaur, and Murthal, with Sonipat city serving as the district headquarters. Its educational institutions, cultural events, and historical landmarks make it a dynamic place for residents and visitors. Adjacent to Delhi, Sonipat's inclusion in the National Capital Region (NCR) has boosted its role in commerce, transportation, and education. The district shares borders with several key regions, emphasizing its importance as a transit hub and a point of connectivity in northern India (Figure 1 (b)).

5. Materials and Methods

The study draws on a wide range of secondary data sources, including both raster and vector datasets, as well as information from the Census of India, land resource da-

tabases, groundwater data from the Central Ground Water Board (CGWB), and air quality data from the Central Pollution Control Board (CPCB). It also incorporates reports from the Haryana State Industrial and Infrastructure Development Corporation (HSIIDC) and urban development plans provided by the Sonipat Metropolitan Development Authority.

A Land Use and Land Cover (LULC) layer was created using ERDAS IMAGINE and ArcGIS 10.3 to interpret Landsat-8 images (Figure 2). Seven different land use categories were classified using the greatest likelihood approach, and the maps were created by assigning a unique color code to each kind. Land Use Maps based on Raster were produced for the years 2000, 2005, 2010, 2015, 2020, and 2024, demonstrating the changing landscape of Sonipat District. Further, to understand spatial variations in land use, buffer rings at distances of 5 km, 10 km, and the outer district boundary were created using ArcGIS 10.3. These rings help illustrate the relationship between land use and proximity to Sonipat City.

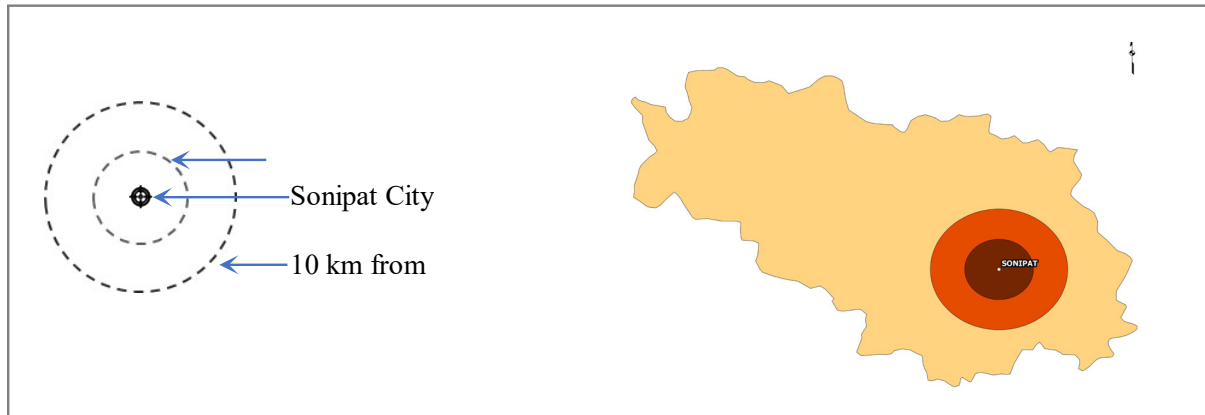


Figure 2. Methodology of Delineating Multiple Ring Buffers in the Study Area.

Source: Prepared by Authors.

The Shannon entropy index, which ranges from 0 to 1, was calculated to assess the distribution and diversity of land use, using the formula mentioned below, where higher values indicate a more balanced land use pattern.

$$\text{Land Use Entropy Index} = - \left[\sum_{j=1}^k P^j \ln(P^j) \right] / \ln(k) \quad (1)$$

In this context, P^j represents the proportion of a particular land use category relative to the total, while $\ln(P^j)$ denotes its natural logarithm. The denominator, $\ln(k)$, provides the natural logarithm of the total number of land use categories.

To illustrate how land use change affects social-economic parameters, worker composition, urbanization trends, agricultural production, and groundwater quality, further analyses used a variety of cartographic methodologies. Using ArcGIS 10.3, maps were generated with inverse distance weighting to explore how land use changes affect air quality.

Along with secondary data and metrics, 20 villages in the Sonipat district were specifically chosen based on their

primary land use changes, and 183 household surveys and in-depth interviews with the local population were conducted in these villages. These villages, include Kundli, Rasoi, Badh Khalsa, Pitampura, Asawarpur, Badmalik, Jatheri, Liwan, Rathdhana, Pipli, Saidpur, Kundal, Butana, Issepur Kheri, Barhi, Lalheri Khurd, Garhi Jhanjhara, Jhundpur, Tanda and Jagdishpur.

6. Results and Discussion

6.1. Urban Expansion and Land Use Transformation: A Comprehensive Spatio-Temporal Analysis

With regards to the spatio-temporal changing aspects of land use, Sonipat district in Haryana, India, has experienced significant transformations in land use between 2000 and 2024 (**Table 1**). The district's evolution has been shaped by urbanization, industrialization, and government policies, leading to a complex tapestry of land use changes.

Table 1. Categories of Functional Land Use from 2000 to 2024, Sonipat.

Land Use Types	2000	2005	2010	2015	2020	2024
<i>Commercial and Retail</i>	1.72	1.81	1.93	2.23	2.54	2.77
<i>Manufacturing</i>	2.61	2.61	2.66	2.66	2.66	2.69
<i>Transportation</i>	6.33	6.37	6.41	6.45	6.83	6.91

Table 1. *Cont.*

Land Use Types	2000	2005	2010	2015	2020	2024
<i>Residential</i>	22.31	24.83	27.76	29.21	31.6	33.4
<i>Agricultural Land</i>	62.86	60.53	57.46	55.72	52.92	50.8
<i>Water Bodies</i>	2.2	1.98	1.96	1.94	1.93	1.93
<i>Open Spaces</i>	1.97	1.87	1.82	1.79	1.52	1.5

Source: Prepared by Authors based on LANDSAT – Earth Explorer Satellite Images, USGS, 2024.

Agricultural land, once the dominant land use type in Sonipat, has declined steadily over the years, dropping from 62.86% of the total geographical area in 2000 to 50.8% in 2024. This trend is mainly due to urbanization and industrialization, which have converted large tracts of agricultural land into housing, commercial, and industrial zones. The fragmentation of land due to inheritance laws and infrastructure development projects, such as roads and highways, has further reduced the area available for agriculture. The pace of this decline has varied, with a significant drop of 3.07% between 2005 and 2010, followed by a steadier decrease of 2.8% from 2015 to 2020.

Residential land, on the other hand, has seen rapid expansion, reflecting Sonipat's transformation into a burgeoning urban area. From 22.31% in 2000, the share of residential land has increased to 33.4% in 2024. This growth is driven by a surge in population, improved infrastructure, and government policies. The establishment of educational and healthcare facilities, along with the influx of prominent real estate developers, has fueled this residential boom. The proximity to Delhi and the development of expressways have made Sonipat an attractive location for new housing projects, contributing to this upward trend in residential land use.

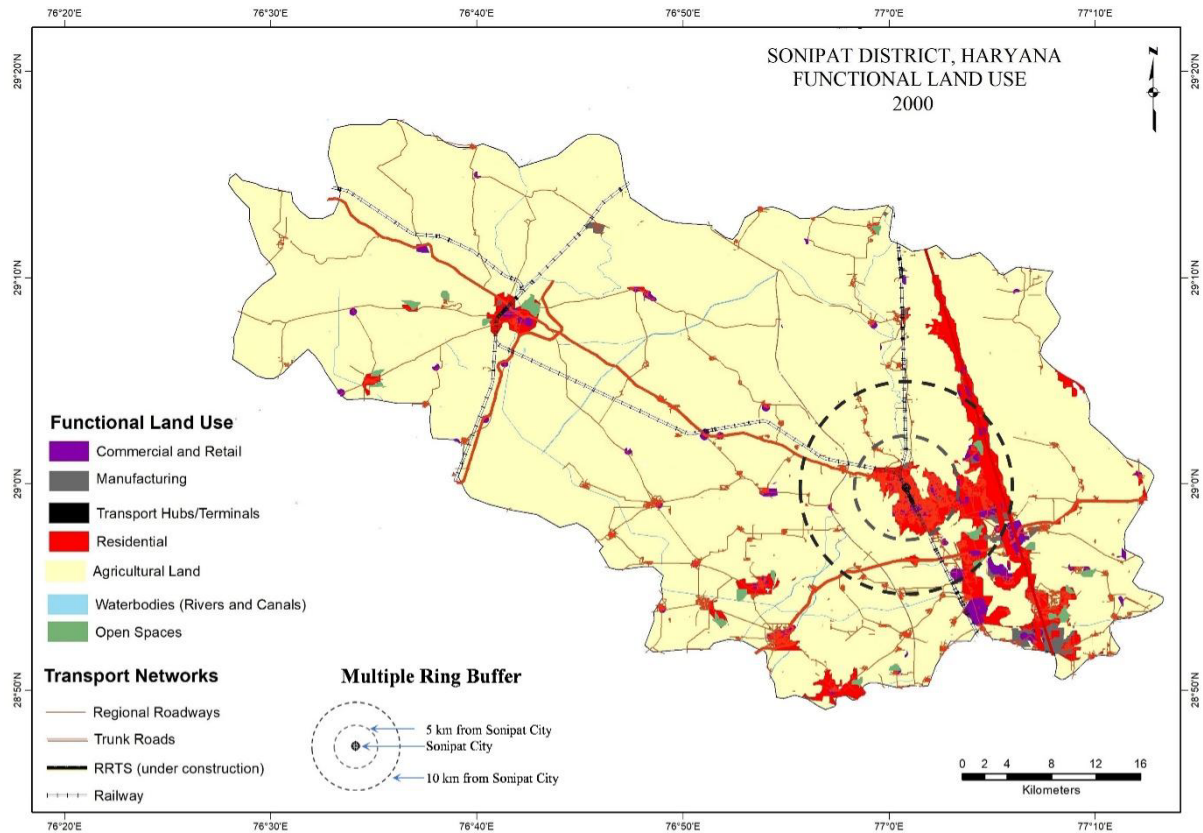
The transportation sector has also experienced growth, though at a more moderate pace compared to residential land. Its share increased from 6.33% in 2000 to 6.91% in 2024, indicating ongoing investment in infrastructure. Projects like the Sonipat Regional Rapid Transit System (RRTS) and the Delhi Metro's Yellow Line extension have strengthened the district's connectivity, enhancing its appeal for residential and commercial development. This

improved transportation infrastructure plays a key role in supporting Sonipat's expanding urban and industrial landscape.

Commercial and retail land use has shown a modest but consistent growth, rising from 1.72% in 2000 to 2.77% in 2024. This increase is driven by enhanced infrastructure, strategic location near Delhi, and supportive government policies that attract businesses and retail chains. The development of mixed-use projects, combining residential, commercial, and recreational elements, has contributed to this growth. The district's evolving commercial landscape reflects the changing consumer demands and the influx of national and international retail brands.

The usage of land for manufacturing has stayed largely constant, with a slight increase from 2.61% in 2000 to 2.69% in 2024. Despite limited growth, Sonipat has emerged as an industrial hub, thanks to its strategic location and government initiatives that promote industrial expansion. The district hosts various industrial areas, such as Kundli and Barhi, which cater to a diverse range of manufacturing sectors. These industrial zones provide employment opportunities and contribute to the district's economic growth.

Water bodies and open spaces have both experienced a decline in their share of Sonipat's geographical area, indicating the effects of urbanization and industrialization. Water bodies have reduced from 2.2% in 2000 to 1.93% in 2024, while open spaces have decreased from 1.97% to 1.5% during the same period. This reduction in natural and open areas underscores the necessity for sustainable land management to maintain environmental stability amidst ongoing development (**Figures 3-8**).



Functional Land Use Types	5km from Sonipat City (%)	10km from Sonipat City (%)	District Outer Limit (%)
Commercial and Retail	3.40	7.94	1.72
Manufacturing	0.15	1.12	2.61
Transportation	4.30	4.32	6.33
Residential	61.30	31.50	22.31
Agricultural Land	30.77	51.32	62.86
Water Bodies	0.02	0.60	2.20
Open Spaces	0.06	3.20	1.97

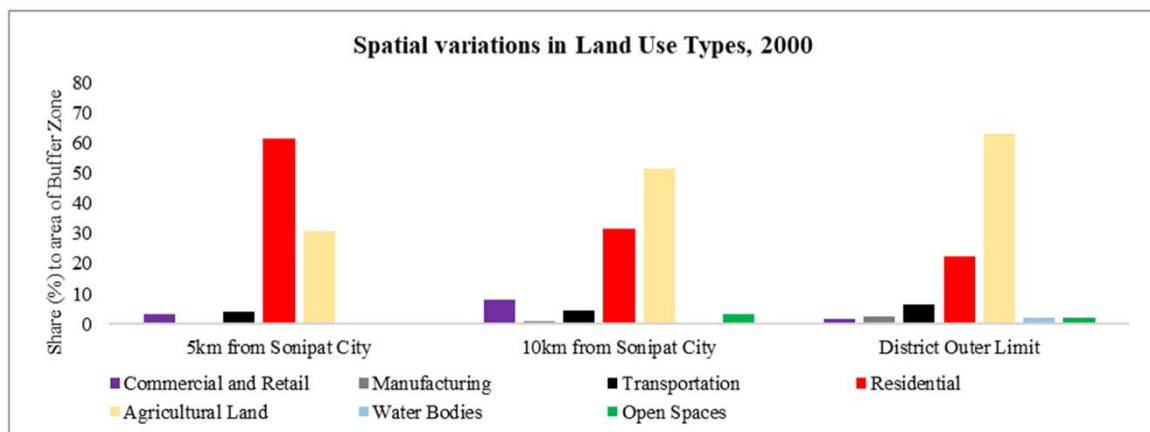
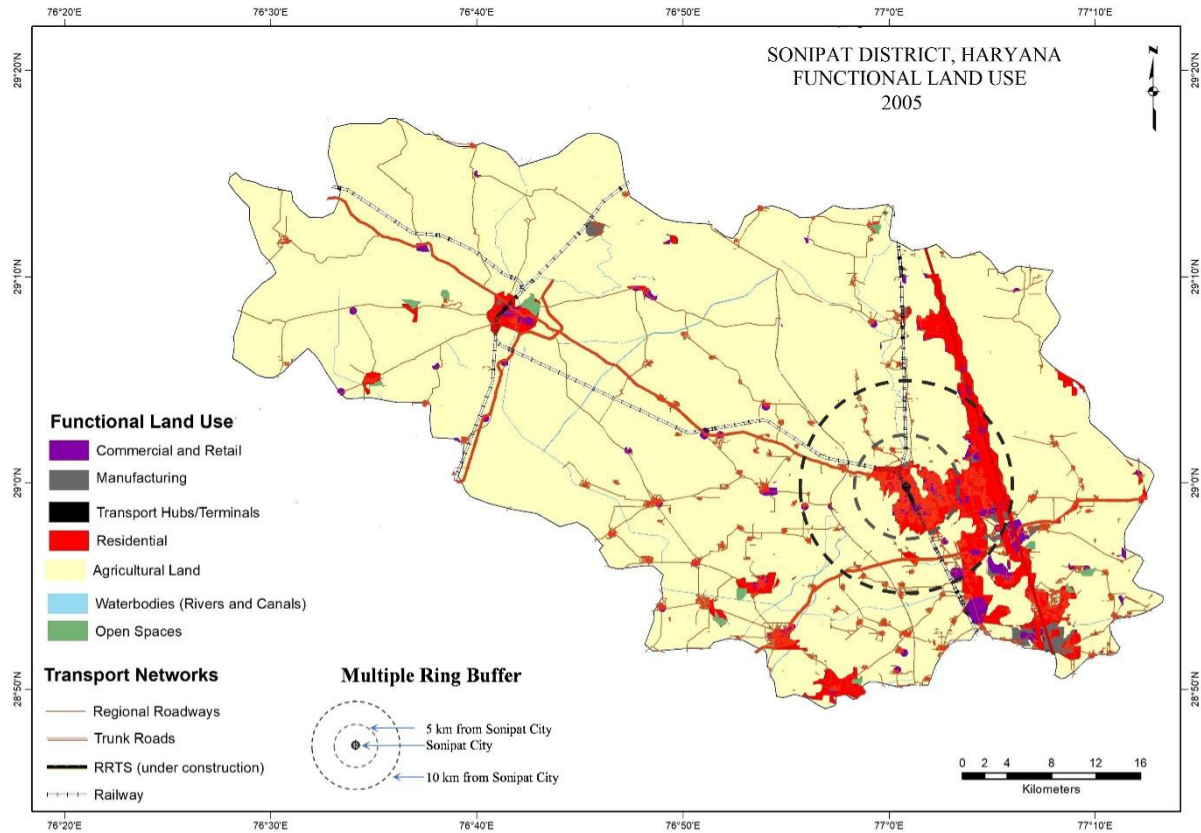


Figure 3. Spatial Patterns of Land Use Change, Sonipat, 2000.

Source: Computed based on supervised classification of satellite images.



Functional Land Use Types	5km from Sonipat City	10km from Sonipat City	District Outer Limit
Commercial and Retail	3.70	8.21	1.81
Manufacturing	0.15	1.12	2.61
Transportation	4.30	4.36	6.37
Residential	63.40	32.10	24.83
Agricultural Land	28.37	52.07	60.53
Water Bodies	0.02	0.54	1.98
Open Spaces	0.06	1.60	1.87

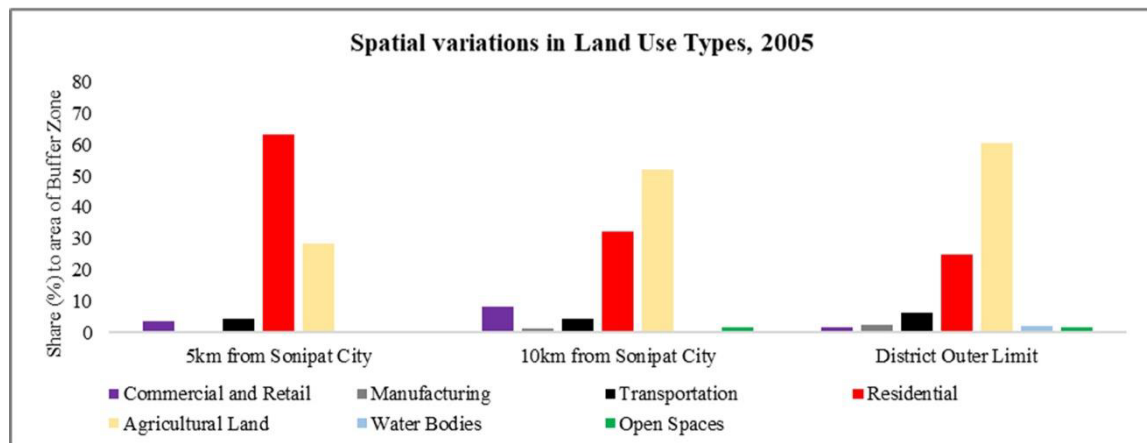
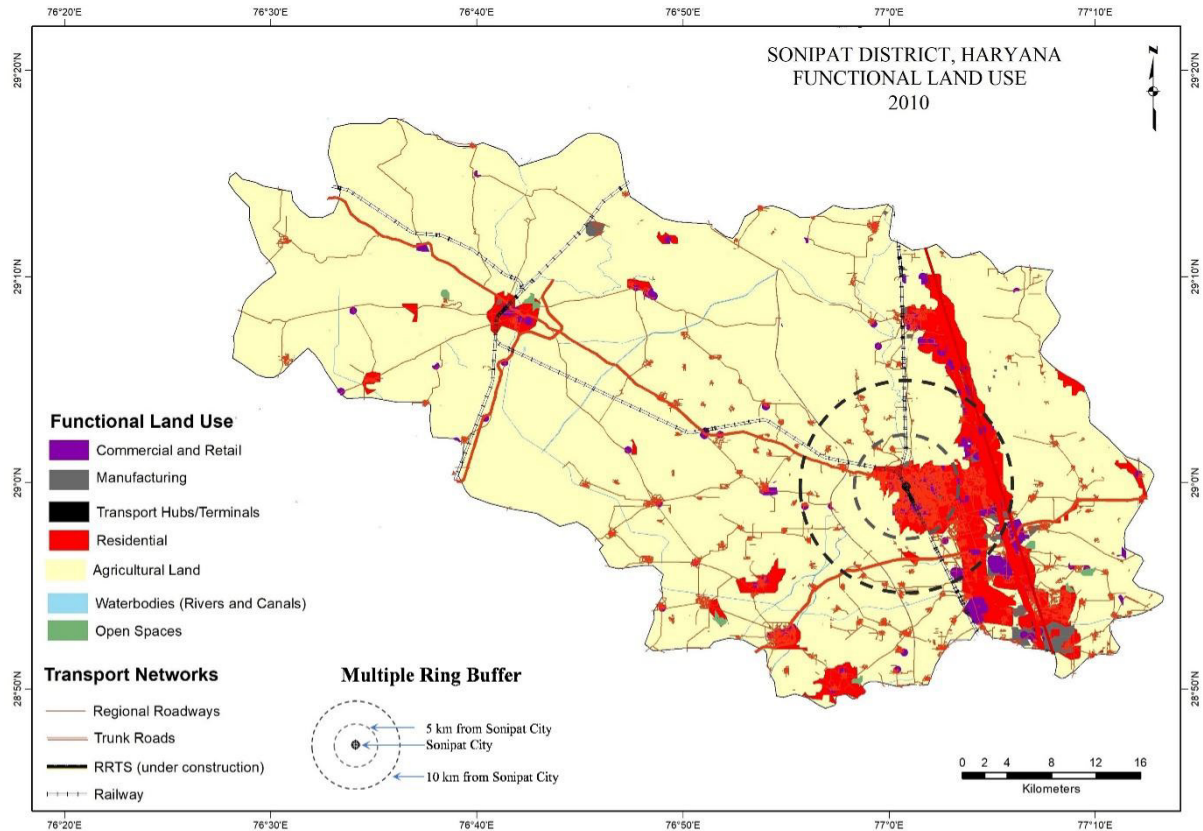


Figure 4. Spatial Dynamics of Land Use Changes, Sonipat, 2005.

Source: Computed based on supervised classification of satellite images.



Functional Land Use Types	5km from Sonipat City	10km from Sonipat City	District Outer Limit
Commercial and Retail	4.10	8.87	1.93
Manufacturing	0.17	1.24	2.66
Transportation	4.33	4.37	6.41
Residential	66.50	33.70	27.76
Agricultural Land	24.88	49.77	57.46
Water Bodies	0.02	0.52	1.96
Open Spaces	0.00	1.53	1.82

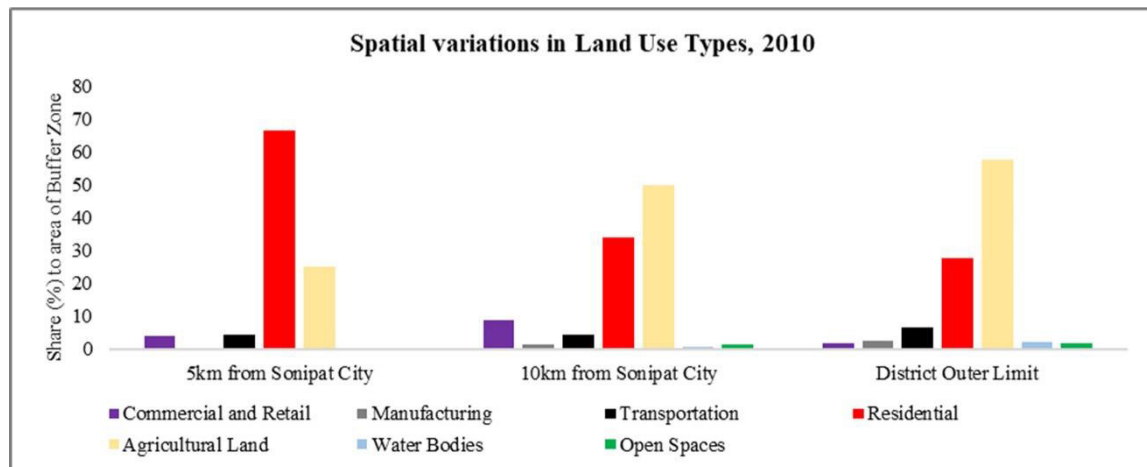
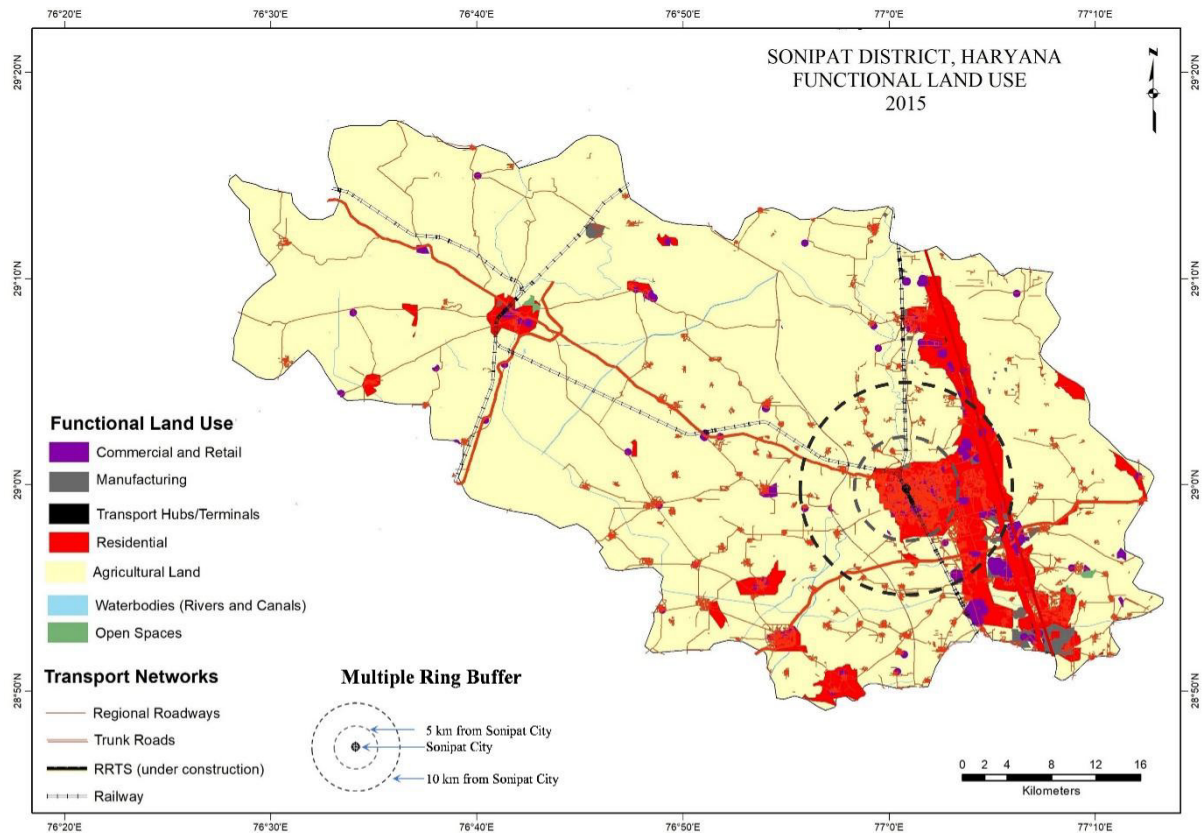


Figure 5. Spatial Dynamics of Land Use Changes, Sonipat, 2010.

Source: Computed based on supervised classification of satellite images.



Functional Land Use Types	5km from Sonipat City	10km from Sonipat City	District Outer Limit
Commercial and Retail	4.30	9.10	2.23
Manufacturing	0.19	1.24	2.66
Transportation	4.41	4.42	6.45
Residential	68.40	35.30	29.21
Agricultural Land	22.68	47.98	55.72
Water Bodies	0.02	0.49	1.94
Open Spaces	0.00	1.47	1.79

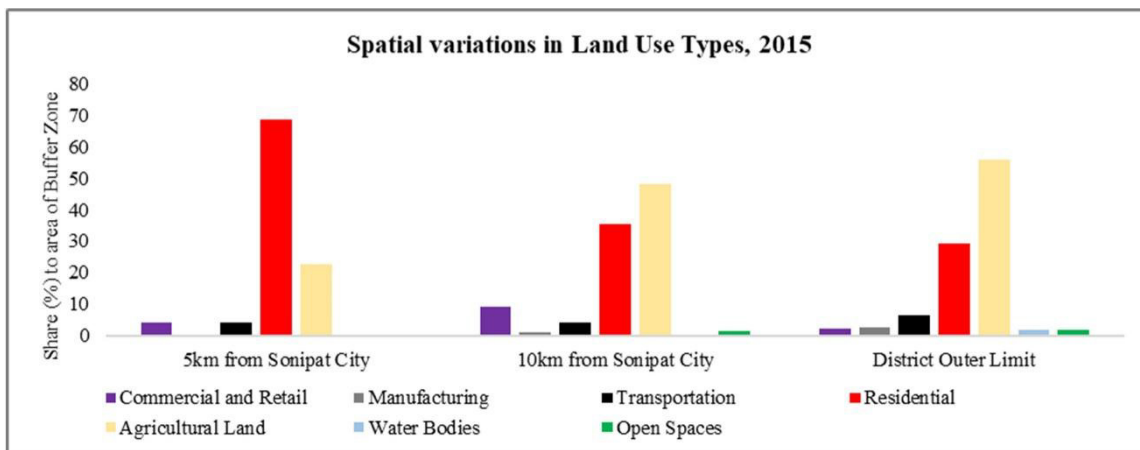
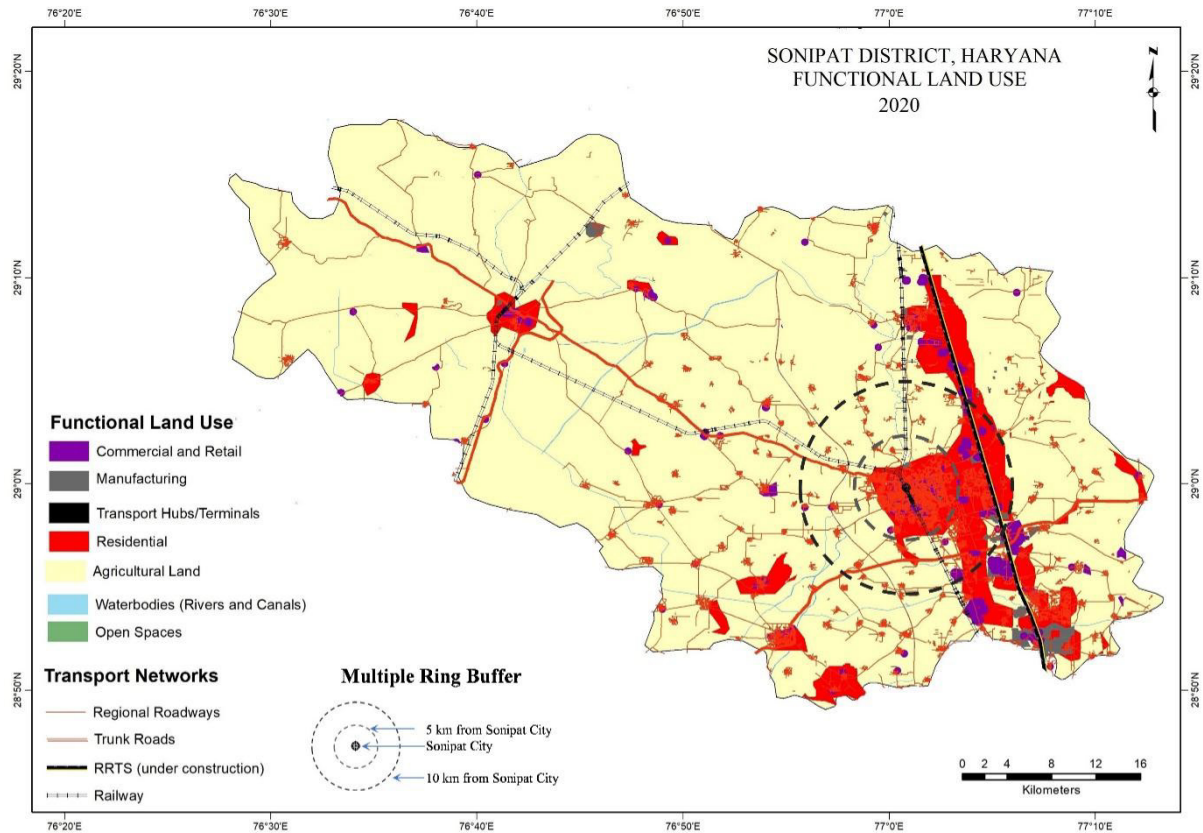


Figure 6. Spatial Dynamics of Land Use Changes, Sonipat, 2015.

Source: Computed based on supervised classification of satellite images.



Functional Land Use Types	5km from Sonipat City	10km from Sonipat City	District Outer Limit
Commercial and Retail	4.70	9.80	2.54
Manufacturing	0.19	1.24	2.66
Transportation	4.44	4.55	6.83
Residential	71.30	36.20	31.60
Agricultural Land	19.36	46.40	52.92
Water Bodies	0.01	0.48	1.93
Open Spaces	0.00	1.33	1.52

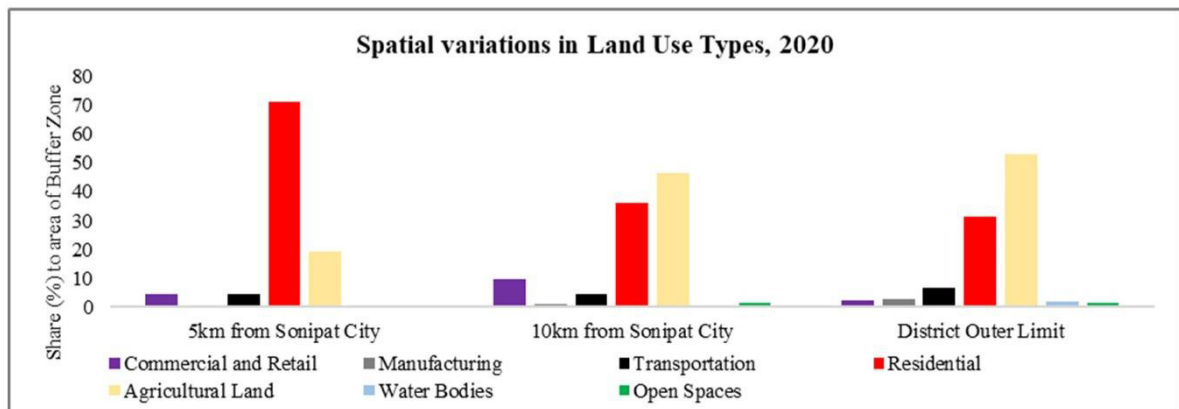
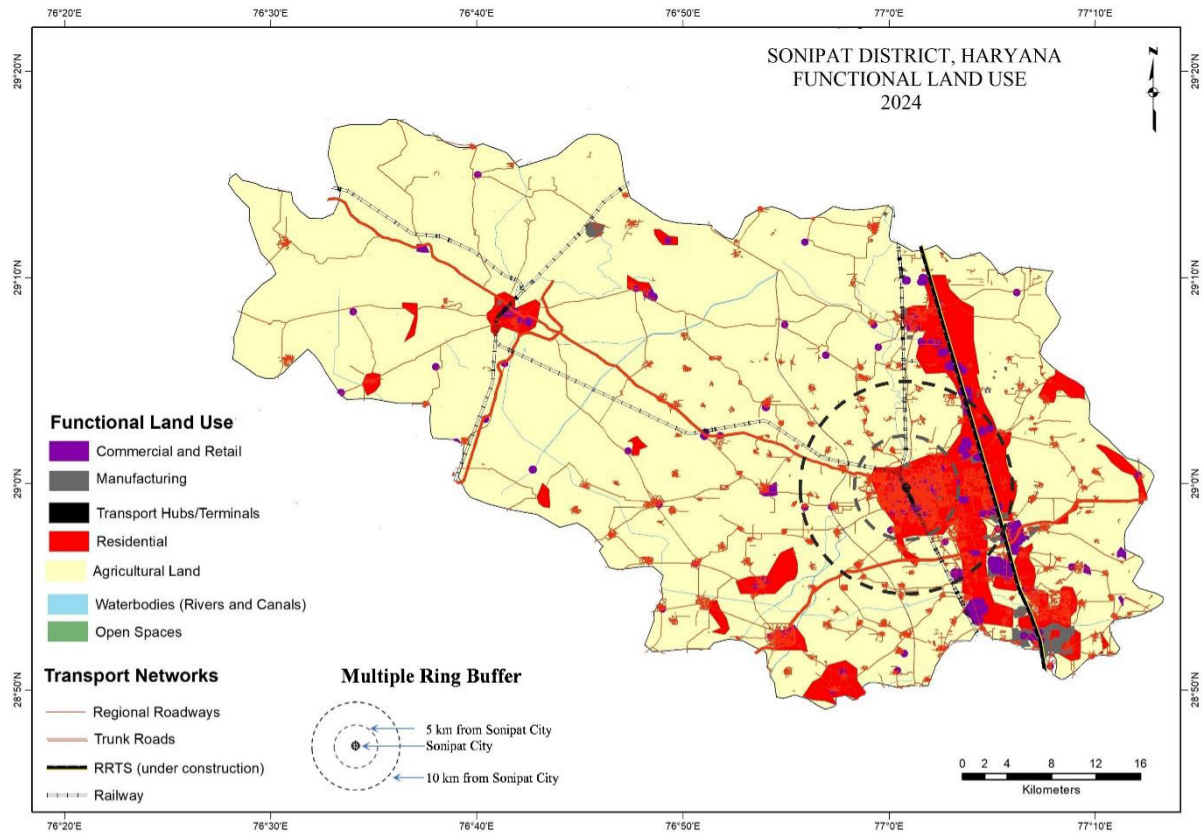


Figure 7. Spatial Dynamics of Land Use Changes, Sonipat, 2020.

Source: Computed based on supervised classification of satellite images.



Functional Land Use Types	5km from Sonipat City	10km from Sonipat City	District Outer Limit
Commercial and Retail	4.80	10.60	2.77
Manufacturing	0.19	1.35	2.69
Transportation	4.52	4.57	6.91
Residential	74.70	38.50	33.40
Agricultural Land	15.78	43.26	50.80
Water Bodies	0.01	0.44	1.93
Open Spaces	0.00	1.28	1.50

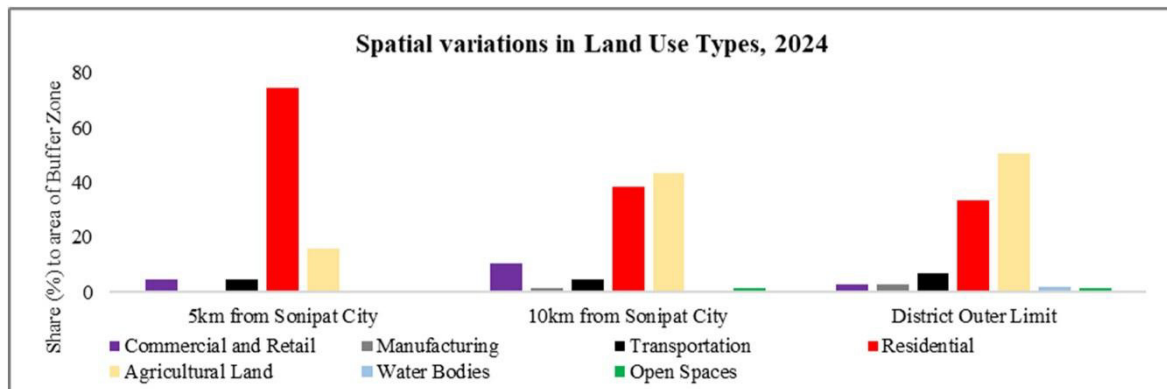


Figure 8. Spatial Dynamics of Land Use Changes, Sonipat, 2024.

Source: Computed based on supervised classification of satellite images.

Also crucial to mention at this juncture is that land use in Sonipat city reveals significant changes as one moves outward from the city centre. In 2000, residential areas dominated the 5km buffer zone around the city, accounting for 61.30% of the land. This share declined to 31.50% in the 10km buffer and 22.31% at the outer boundary of the district. However, by 2024, the share of residential areas in the 5km buffer zone had surged to 74.70%, reflecting a trend toward residential concentration closer to the city center. In the 10km buffer, the residential share increased to 38.50%, and further out, it reached 33.40%. This gradient in residential development aligns with the “distance decay” concept, indicating that urban expansion is more intense near the city center and declines with distance.

The distribution of agricultural land also follows a similar pattern. In 2000, the 5km buffer zone had 30.77% agricultural land, but this share dropped steadily over the years, reaching 15.78% in 2024. Similarly, in the 10km buffer, agricultural land decreased from 51.32% in 2000 to 43.26% in 2024. This trend illustrates the alteration of agricultural areas into housing and commercial developments, driven by economic factors and urbanization pressures. Despite this decline, the outer boundary zone retained a relatively higher share of agricultural land compared to the inner zones, suggesting a gradual transition from ur-

ban to rural land use. Commercial and retail development has also been concentrated near the city center, with the share decreasing as one moves outward. This trend can be explained by Sonipat’s role as a regional economic hub, attracting businesses and retailers due to its centrality, infrastructure, and accessibility. The high foot traffic and transportation networks near the city make it a prime location for commercial activities. Zoning regulations and land use policies have further reinforced this pattern, emphasizing commercial development in and around the city.

To understand land use diversity, the Land Use Entropy Index was assessed. This index evaluates the diversity of land use patterns within a given area, with higher scores indicating more diversity. The 5km buffer zone had a lower entropy score, reflecting the concentration of residential and commercial development. However, farther from the city, especially in the transition zone, the entropy score increased due to a mix of land uses, including residential, commercial, manufacturing, and agriculture. This diversity decreased again in the outer boundary zone due to the dominance of agricultural land. These findings highlight the multifaceted dynamics of land use in Sonipat, influenced by historical, economic, and policy factors, with implications for urban planning and sustainable development (Figure 9).

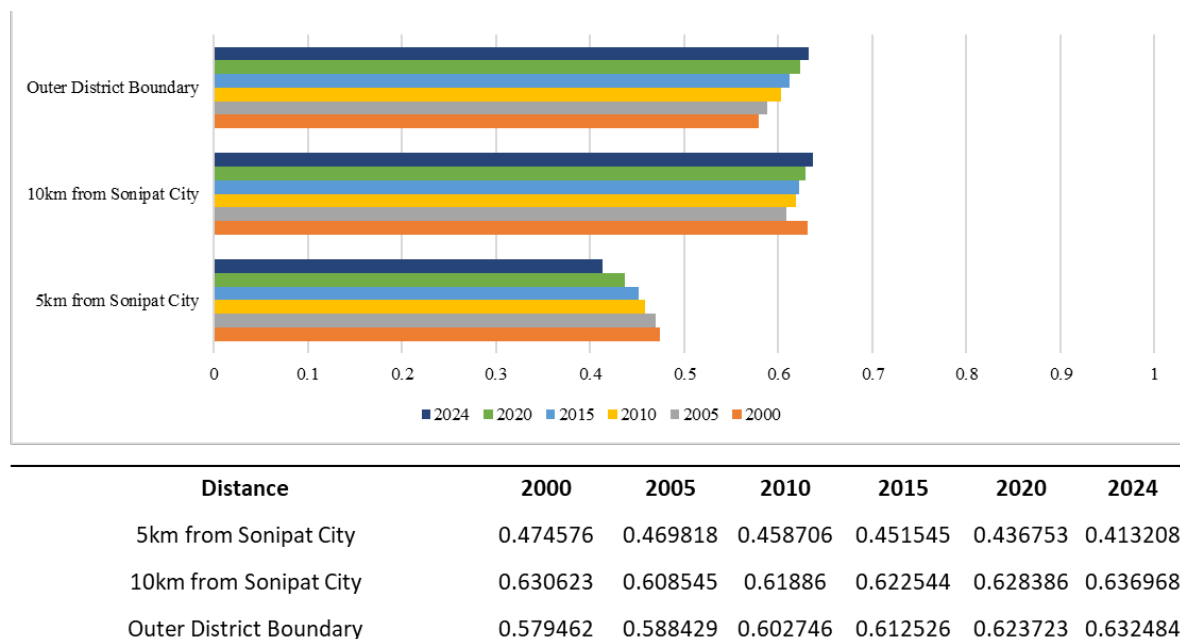


Figure 9. Land Use Entropy in Sonipat, from 2000 to 2024.

Source: Prepared by Authors based on LANDSAT – Earth Explorer Satellite Images, USGS, 2024

6.2. Socio-Economic Implications of Land Use Changes in Sonipat District, India: Insights from Secondary Data Analysis

Land use changes have a significant influence on socio-economic structures, influencing employment patterns, workforce composition, and the spatial distribution of jobs. As land transitions from agricultural to industrial or residential use, it leads to a shift in the types of employment available, affecting where people live and work. Traditional sectors, such as agriculture, may face a decline, while new job opportunities emerge in other industries. This pattern of transformation is evident in the land use changes in the study area.

Sonipat underwent considerable urban expansion in the past two decades, with a growing population, improved infrastructure, and economic development. Urban

land use increased from approximately 31.2% in 2000 to 37.3% in 2011. Key towns like Sonipat, Ganaur, Kharkhoda, Gohana, and Rai experienced notable population surges, leading to the development of roads, educational institutions, healthcare facilities, and commercial hubs. Industrial growth also contributed to the expansion, with new manufacturing units, service industries, and trading centers. However, this rapid urbanization brought its share of challenges, including congestion, pollution, and social inequalities. It also altered land usage. **Figure 10** shows a decline in agricultural land in Sonipat from 62.86% in 2000 to 50.8% in 2024. This decline is brought on by population expansion, urbanization, and the need for infrastructure, all of which alter land usage and raise issues with food security.

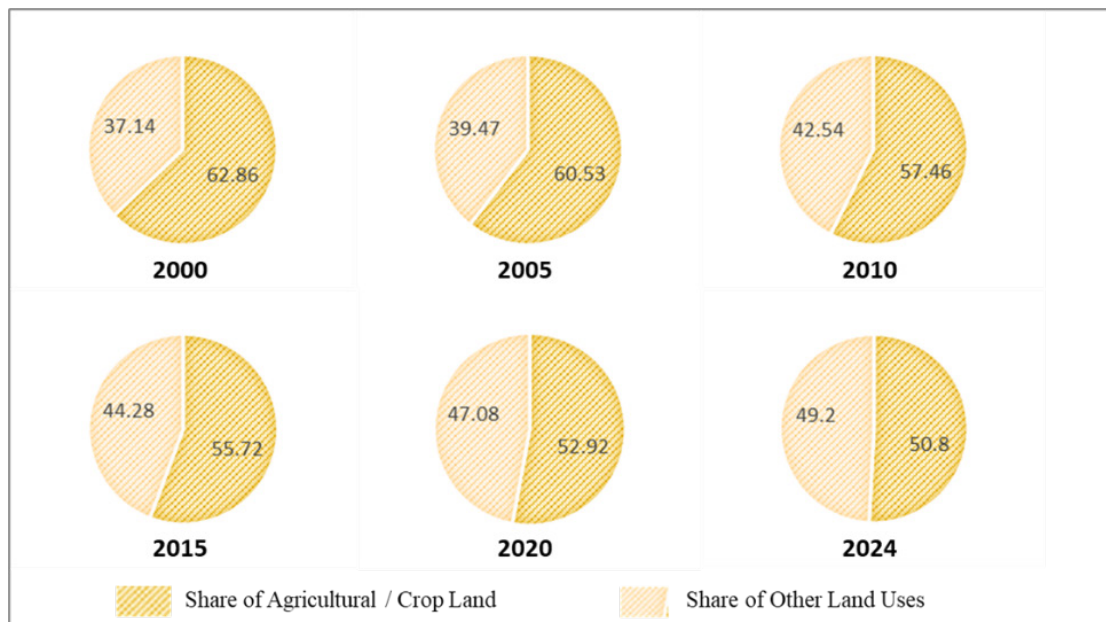


Figure 10. Changes in Agricultural/Crop Land in 2000–2024.

Source: Based on Land Resources Data obtained from India — WRIS.

Land use changes wield significant influence on the economic landscape, reshaping employment dynamics and necessitating adaptation within the workforce (**Figure 11**). A similar trajectory is also evident in context of the land use changes in the study setting. Between the 2001 and 2011 censuses, Sonipat district in Haryana, underwent substantial urban expansion characterized by increases in population, enhancements in infrastructure, and expansion

of the economy, as the urban built-up land grew from approximately 31.2-percent in 2000 to 37.3-percent in 2011. Key towns such as Sonipat, Ganaur, Kharkhoda, Gohana, and Rai experienced notable population surges, leading to the development of urban amenities including roads, educational institutions, healthcare facilities, and commercial hubs. Concurrently, there was a surge in industrial and economic growth, with the establishment of manufacturing

units, service industries, and trading centers. Nonetheless, alterations in land usage, congestion, pollution, and social this rapid urbanization brought about challenges including inequalities.

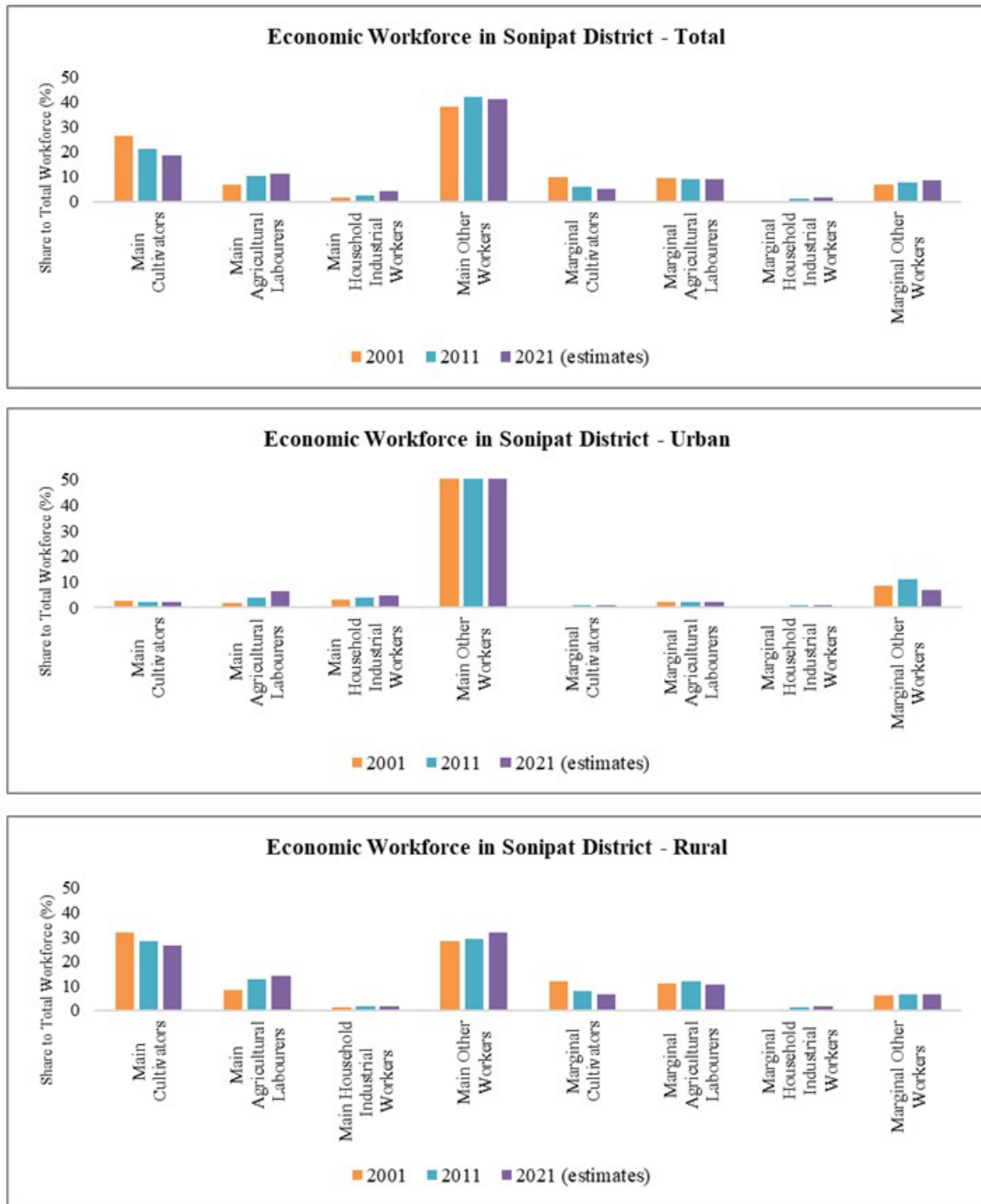


Figure 11. Changes in Economic Workforce in Sonipat District – Urban and Rural, 2000–2024.

Source: Computed based on data obtained from Census of India, 2011.

The given figure reflects significant shifts in occupational patterns in Sonipat district from 2001 to 2021. Notably, there has been a decline in the proportion of main cultivators, indicating a decreasing reliance on agriculture as

a primary occupation. Conversely, there is a slight increase in main agricultural laborers, suggesting a shift towards more labour-intensive agricultural practices. Additionally, there is a noticeable rise in main household industrial

workers, potentially indicating an increase in home-based industrial activities or industrialization. However, the percentage of main other workers remains relatively stable, suggesting consistency in other sectors. Overall, there is a slight decline in the percentage of marginal workers across various categories, implying potential shifts towards more formalized employment or changes in workforce structures over the years. These trends reflect the evolving economic landscape of Sonipat, marked by transitions away from traditional agricultural practices towards a more diversified workforce with increasing industrialization, and concomitant with the shift in land use and conversions of agricultural land. Further, for rural areas in Sonipat district, the data suggests a gradual shift away from agriculture as the primary occupation in rural areas of Sonipat, with an increase in other forms of employment, particularly in agricultural labor.

The data analysis for urban areas in Sonipat reveals striking shifts in occupational patterns over the years. While there has been a decrease in the proportion of primary cultivators, indicating reduced reliance on agriculture, an increase in the primary agricultural labourers suggests a potential resurgence in agricultural activities or a reclassification of labor. Additionally, there has been a slight increase in the proportion of primary household industrial workers, reflecting some involvement in industrial activities within urban settings. The majority of urban workers fall under the category of primary other workers, indicating a diverse range of non-agricultural occupations. Overall, these trends suggest dynamic changes in the urban

economy of Sonipat, influenced by factors such as industrialization, urbanization, and shifts in labor demand due to changing land use patterns.

6.3. Insights into Rural Land Use Transformation in Sonipat District: Trends, Socio-Economic Impacts, and Driving Forces

The narratives collected during the household survey provide an overview of multiple villages that were selected for the study, highlighting trends in land acquisition, industrial development, environmental impact, social dynamics, and economic changes, induced by land use transformations. The primary survey with the local population in the selected villages highlight significant industrial and commercial growth along major highways and expressways, especially NH-44, leading to a dramatic transformation of rural landscapes. Many villages, such as Kundli and Rasoi, are transitioning from agricultural to industrial/commercial zones, resulting in high property values and increased rent income. This development also contributes to the degradation of natural resources, with water tables decreasing and water bodies turning into dump yards. The local level discussions, emphasized that dominant castes, such as the Jats and Pandits, are key players in these transformations, while children increasingly attend private schools. However, this shift from traditional farming to industrial work has led to soil degradation, air and water pollution, and reduced agricultural land. Villages like Badkhalsa and Pitampura exemplify this transition, with growing industrial zones and a concurrent decline in water quality (**Figure 12**).

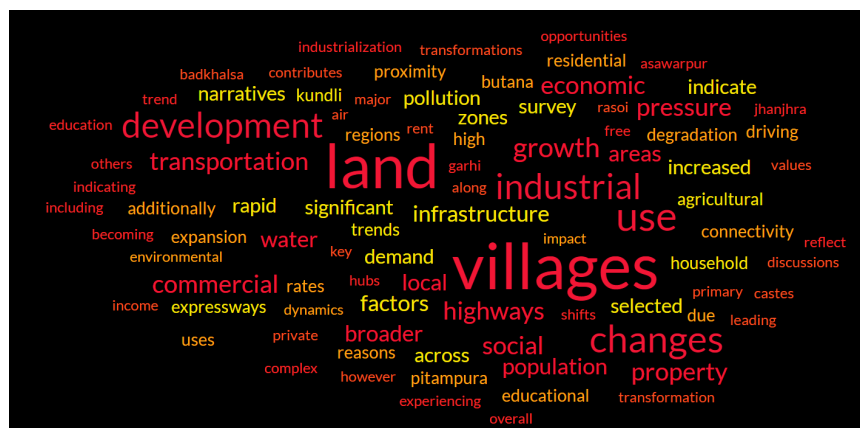


Figure 12. Word Cloud Generated from Narratives of the Local Population in the Village During the Local-Level Discussions on Land Use Changes.

Additionally, the narrative describes how some villages, like Asawarpur, are becoming educational hubs with institutions like Ashoka University and IIT Delhi's extended campus. This reflects a broader trend toward educational development, indicating a diversification of land use. Industrial growth often brings employment opportunities, as seen in villages like Jatheri and Garhi Jhanjhra, but it also results in high congestion and pollution. Villages such as Badmalik are becoming densely populated with migrant workers due to their proximity to industrial areas like Rai, leading to changes in the demographic makeup and increased air and water pollution. The social impact of these changes is also significant. Some landowning communities are experiencing increased wealth due to rent income and property sales, while others face the downside of industrialization, including pollution and loss of agricultural land. Additionally, narratives from villages like Kundal and Butana indicate underlying social tensions regarding government support for Scheduled Castes (SCs) and other reserved categories through benefits like free rations and education, which could contribute to shifts in social dynamics. Overall, these narratives reflect a complex and evolving landscape where industrialization and urbanization bring both opportunities and challenges. The environmental degradation and changing social structures indicate that further research and policies are needed to address sustainability and social equity.

6.3.1. Land Use Changes in Selected Villages, and Use of Land After Sale/Purchase

Additionally, the data obtained from a household survey, involving 183 respondents across the selected villages, reflect a consistent set of factors driving rapid land use changes in various villages. Across all villages, several common reasons are highlighted, including proximity to highways, ongoing industrial development, high property rates, increasing population pressure, and pressure from economic growth. The most frequent reasons for land use changes are these interconnected factors that collectively create a fertile environment for rapid transformation.

Many villages, such as Kundli, Pitampura, and others, attribute the rapid land use changes to a combination of all these factors. This suggests a strong relationship between transportation infrastructure, property values, and broad-

er development trends in these regions. The proximity to highways and the ongoing development indicate that connectivity and improved transportation networks are significant catalysts for change. Being part of the NCR also adds an extra layer of demand and pressure, as the capital region continues to expand and attract people and businesses. This leads to a higher demand for land, thereby driving up property rates. The pressure from economic growth further amplifies this trend. As local economies grow and diversify, there is an amplified need for commercial spaces, residential areas, and manufacturing zones. This expansion can lead to a ripple effect, with surrounding areas experiencing similar pressures to adapt and grow. The rise in population, whether from local growth or migration, compounds the demand for land and contributes to a continuous cycle of development. However, a few villages, such as Issepur Kheri and Butana Sangwan, indicate that the expansion of highways, expressways, and railways are the primary reasons for land use changes. This suggests that these particular villages are more heavily influenced by transportation networks, which act as a catalyst for broader development and land use shifts. This might be due to strategic locations along transportation corridors or the influence of major infrastructure projects in these areas.

Thus, a complex pattern of interconnected factors has contributed to rapid land use changes in these villages. Transportation infrastructure plays a key role, with highways and expressways facilitating greater connectivity and attracting further development. The broader context of the NCR adds to this pressure, driving up property rates and intensifying the demand for land. This is further compounded by economic growth and increasing population pressure, which together create a strong incentive for continuous development. The villages that rely solely on transportation-related factors suggest that infrastructure projects and improved connectivity can be an important driver of land use changes, pointing to the broader trends of urban expansion and economic growth that are reshaping these regions.

The household survey also drawn the various land uses in different villages following sale or purchase, illustrating a wide spectrum of applications across multiple locations. Villages like Kundli, Pitampura, Barhi, Lalheri Khurd, and Garhi Jhanjhra are used for a mix of industrial, commer-

cial, and residential purposes, suggesting a multi-functional environment. Rasoi, Badkhalsa, Rathdhana, and Barhi share a focus on residential and commercial uses, indicating a balance between living spaces and business activities. Asawarpur is unique with its emphasis on education and commercial, pointing to a possible educational hub. The villages of Pipli, Issepur Kheri, and Butana Sangwan serve as transportation hubs with their focus on highways and railways. Tanda, Jhundpur, and Jagdishpur are oriented towards free zones, private industry, and small-scale industry, reflecting areas with business-friendly policies and smaller manufacturing setups. The broad array of land uses across these villages indicates a diverse economic landscape, with each location catering to different needs and contributing uniquely to the region's overall infrastructure and economy.

6.3.2. Delving into the Social Consequences of Land Use Changes in Selected Villages

Conflict in Sharing the Money After Land Acquisition: Traditionally, in many societies, women have faced significant discrimination when it comes to inheriting or receiving money from land acquisitions within families. This often manifests as a social expectation that property and land should remain within male lineage, leading to a lack of property and land rights for women, particularly sisters. However, as awareness of gender equality has grown, women are increasingly demanding their fair share of inheritance and property. This shift towards asserting their rights has led to conflicts within families, challenging longstanding social norms and creating tension around the distribution of land and resources. The household survey across the 20 selected villages have illustrated a comprehensive examination of conflicts in various villages following land acquisition. A consistent pattern emerges across almost all villages: conflicts have increased in various forms, ranging from general disputes to specific family or sibling disagreements. This heightened level of discord suggests a significant social impact from land acquisition on traditional structures and relationships.

A striking trend in the data is the reluctance to share financial assets or property with females, with many households noting that both males and females oppose such sharing. This underscores a strong gender bias and reflects

deep-rooted patriarchal norms. These traditions have often marginalized women in terms of inheritance and property rights, resulting in an uneven distribution of assets that can lead to family discord. Family conflicts are specifically highlighted in many villages, indicating internal strife among family members. These disputes are likely tied to changes in property ownership and financial benefits after the land acquisition, leading to disagreement over asset division. In some villages, as Jatheri the conflicts have escalated to legal action, with reports of family members suing each other, pointing to a severe breakdown in familial relations. The root causes of these conflicts can be attributed to a combination of traditional gender roles, property and land acquisition dynamics, legal ambiguities, economic disparities, and shifts in traditional familial structures. Patriarchal systems tend to prioritize males in property inheritance, sidelining females.

Changes in Social Hierarchy: In examining the household survey detailing changes in social hierarchy across different villages over the past two decades, a general trend emerges. The majority of villages report notable shifts in social structure, often tied to generational changes and varying income levels. This suggests that economic prosperity plays a key role in transforming traditional social dynamics. Alongside this, some villages like Asawarpur and Pipli have noted an increase in assertiveness and aggression, indicating a possible breakdown in traditional power structures and an increase in individuals or groups asserting their viewpoints more forcefully. In contrast, Jatheri's data points to changes in social hierarchy accompanied by reduced social interaction, hinting at a move towards individualism or a decline in community-oriented practices. However, not all villages have seen such shifts; Issepur Kheri and Butana Sangwan report stability, suggesting that traditional hierarchies remain intact. Overall, these changes reflect a complex and varied landscape, with most villages undergoing significant transformation while others retain their long-standing social order.

The narratives collected from the villages during the household survey have highlighted that almost twenty years ago, there was a sense of communal harmony, with people cooperating and helping each other. However, as some gained financial power with rise in income levels, they began to focus on proving their superiority, disrupt-

ing the social harmony that once prevailed. This shift from joint family structures to nuclear families has changed the social fabric over time. People who used to spend 6 to 7 hours engaging in social activities on holidays are now increasingly isolated, with fewer interactions within the community. The close-knit ties that once defined the village society have given way to more individualistic attitudes, leading to a marked decline in communal connections.

Changes in Schooling Type of Children: The household survey indicated a strong preference for private schools among children in various villages. Initially, almost two decades back, nearly all the households in the selected villages had preference towards government schools. However, at present, most villages have all or nearly all children attending private schools, suggesting that parents generally favor private education over government schools. In two villages, Kundli and Saidpur, there's a noticeable presence of children attending government schools, but these are exceptions. The majority of villages, such as Pitampura, Badmalik, Liwan, and many others, have no indications of children attending government schools.

This trend reflects perceptions of better-quality education in private schools, but most importantly it indicates the broader trend of urbanisation in these villages, increase in income levels and hence preference towards private schooling, though it raises questions about the accessibility, cost, and equitable distribution of education in these regions.

Women's Frequency to Visit Markets: The household survey collected insights on the frequency of women's market visits in various villages, revealing significant patterns based on proximity to towns, level of urbanization, and possible cultural or social factors. Villages like Kundli, Pitampura, Badmalik, and Liwan, which are close to towns or markets, report daily visits, suggesting that proximity is a key factor in women's frequent market access. These villages have transformed into towns or are adjacent to larger markets, facilitating easy and regular visits. In contrast, villages such as Saidpur, Kundal, Pipli and Tanda, and others where women visit once or twice a month indicate a moderate level of access, which might be due to slightly farther markets or other logistical or social constraints. Meanwhile, villages like Rathdhana, Asawarpur, Rasoi,

Badkhalsa, and Barhi see annual visits, pointing to remote locations, limited transportation, or community-based economies where local sourcing is more common. This pattern indicates that a village's urbanization level and infrastructure play a significant role in women's market access, suggesting areas where improved transportation and closer markets could enhance economic participation and social connectivity.

Change in Food Habits: A comprehensive analysis of various villages reveals a consistent trend: the consumption of restaurant food and fast food has increased across nearly all locations. The common phrases "restaurant food increased" and "penetration of restaurant food" as collected through narratives during the household survey suggest a progressive and widespread shift in food habits. While some villages, like Pitampura noted a general increase in both fast food, packaged food and restaurant food, others, like Rathdhana mentioned that a significant portion (70%) still prefers homemade food despite the rising restaurant food trend. This growing reliance on restaurant and fast food indicates potential changes in lifestyle, urbanization, or economic factors, with implications for health and local economies. The increasing trend in restaurant food consumption reflects broader socio-economic shifts, due to land acquisition and transformation of agricultural land to more urban-centric and no-agricultural purposes, and highlights a potential transformation in traditional food practices within these communities.

6.3.3. Delving into the Economic Impacts of Land Use Changes in Selected Villages

Changes Observed in Livelihoods and Income Sources of Families After Land Acquisition: In examining the livelihoods of families across various villages over the last two decades, several patterns emerge. In Kundli, families have increased income from rent, though many rely on private jobs in the Kundli industrial area, with limited land acquisition. Similarly, in Pitampura, rental income plays a significant role, with some families investing in agricultural land and plots in places like Sonipat and Kundali. Badmalik features a mix of income sources, including agriculture, rent, and commercial ventures, with some families holding government jobs.

Liwan primarily reports income from agriculture and

rent, while Rathdhana shows a similar trend, with additional purchases of plots in Sonipat. Asawarpur and Rasoi both mention increased overall income and a better standard of living, with improved access to modern facilities. In Badkhalsa, families report an overall increase in income with enhanced facilities, similar to Barhi and Lalheri Khurd, which also note improved living standards due to increased rent and agricultural income.

In Garhi Jhanjhra, families earn from agriculture and rent, while in Kundal, income sources are more diverse, including private jobs, agriculture, rent, and government jobs. Saidpur and Pipli both indicate substantial agricultural land purchases, suggesting reinvestment into agriculture. Tanda stands out with significant agricultural land purchases, some as high as 35 acres. Similarly, Jhundpur shows substantial investments in agricultural land, alongside private business and rent income.

In Jagdishpur, families earn from a range of sources, including agriculture, rent, kiriyana stores, and transport businesses. Issepur Kheri reports income from agriculture and royalties, with families acquiring additional land. Butana Sangwan emphasizes agricultural activities, leading to further land purchases. Finally, in Jatheri, families have diversified income sources, including rent and agricultural income, with some opening shops or industrial units.

Overall, the data indicate a variety of income sources and a trend toward improved living standards across these villages, with a mix of agricultural pursuits, rental and royalty income, private jobs, government employment, and real-estate business or property-dealing ventures.

Changes in Family Assets After Land Acquisition:

The household survey has outlined changes in family assets over the last two decades across various villages and reveals a pattern of modernization and improved living standards, with specific trends noted in each village. In Kundli, the built-up land increased, and electric equipment, use of AC, and vehicles all saw a significant rise, along with more frequent trips to nearby cities and visits to medical practitioners, indicating increased connectivity and better healthcare access. Similarly, Pitampura experienced increased basic facilities alongside more frequent trips to cities and a rise in electric equipment and vehicles. Badmalik not only saw an increase in electric equipment

but also a rise in agricultural income and built-up land, suggesting a boost in local agriculture. Liwan had similar trends, with additional increases in rental income. In Asawarpur, agricultural income and the number of acres in agricultural land grew, signalling a more robust farming economy. Meanwhile, Rasoi and Badkhalsa both experienced increased built-up land and electric equipment, suggesting broader infrastructure development. Overall, these changes reflect a significant shift toward modernity and improved economic conditions in these villages.

7. Policy Implications

An assessment of land use in the Sonipat district from 2000 to 2024 reveals substantial changes in the way land is utilised. Agricultural areas have declined due to increased urbanisation, industrial growth, and government policies favouring non-agricultural development, as comprehended from the secondary data analysis and coupled with the local-level discussions conducted at the villages. This trend raises concerns about food security and environmental sustainability, signalling an urgent need for policy interventions that promote sustainable land management. To address these issues, policies should aim to balance economic development with the protection of agricultural land. This can be achieved by implementing transparent land acquisition processes, encouraging sustainable farming practices, and integrating land use planning with infrastructure development and environmental conservation. Coordinated planning is essential to manage the interconnected challenges related to land use, transportation, environment, and socio-economic factors.

The specific, actionable policy recommendations are mentioned in the following:

- **Protect Agricultural Land through Zoning and Incentives**

To prevent further loss of farmland, the government should designate agricultural protection zones, especially in peri-urban areas, to restrict non-agricultural development. Farmers who retain land under cultivation should receive targeted support through subsidies, tax relief, or incentives to make agriculture viable.

- **Make Land Acquisition Transparent and Inclusive**

Land acquisition processes should include mandatory public consultations and social impact assessments to ensure participation from smallholders, women, and marginalized groups. Local grievance redressal committees can help resolve disputes and promote fair compensation, reducing familial tensions and gender-based conflicts.

- **Align Land Use Planning with Infrastructure and Environment**

A district-level land use plan should integrate urban expansion with infrastructure development and environmental protection. Planning must incorporate green infrastructure, such as ecological buffers and open spaces, to maintain ecological balance as urban areas grow.

- **Promote Sustainable Agriculture and Market Linkages**

Support for sustainable farming—such as organic practices, climate-resilient crops, and low-input technologies—should be expanded. Strengthening farmer cooperatives and producer groups can improve access to markets and support income stability amid land use shifts.

- **Ensure Women's Property Rights**

Awareness campaigns on women's legal rights to land are essential. Legal support services should be scaled up, and joint land titling in government housing and land schemes should be encouraged to promote gender equity in inheritance and ownership.

- **Expand Women's Access to Markets and Mobility**

Improving rural connectivity and safe transport can enhance women's access to markets and services. Setting up women-led market hubs and providing entrepreneurship and digital training can further economic participation.

- **Support Traditional Diets and Public Health**

Public health campaigns should promote traditional diets through school-based nutrition education and community outreach. Farm-to-market programs can encourage the local production and consumption of nutritious, seasonal foods.

- **Strengthen Governance and Monitoring**

A multi-stakeholder District Land Governance Council should be established to oversee planning and implementation. Regular GIS-based monitoring of land use changes will support evidence-based policy decisions and ensure environmental accountability.

8. Concluding Remarks

The study explored how land use in Sonipat district has shifted over the past two decades. It revealed an increasing trend toward residential and commercial development, coupled with a steady decline in agricultural land. This shift raises concerns about food security and agricultural sustainability. The study also notes that urban sprawl is extending from Sonipat city into surrounding areas. This expansion is impacting the socio-economic structure, crop land, groundwater levels, and air quality.

The insights from the household survey have outlined that, the transformations in land use, family income sources, social dynamics, education, and daily habits paint a comprehensive picture of evolving village life, with each shift contributing to a more urbanized, economically vibrant, but also socially fragmented community. To address these challenges, urban planning should prioritize efficient land use, green infrastructure, enhanced public transport, and the developing social harmony. By adopting these strategies, the adverse impacts of changing land use can be mitigated, fostering socio-economic and environmental sustainability.

Author Contributions

Conceptualization, N.K. and T.S.R.; methodology, N.K.; software, N.K.; validation, N.K., T.S.R. and S.A.; formal analysis, N.K.; investigation, N.K.; resources, N.K.; data curation, N.K.; writing—original draft preparation, N.K.; writing—review and editing, N.K., T.S.R, S.A, and N.; visualization, T.S.R and S.A.; supervision, T.S.R. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of University of Delhi.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

All data supporting the reported results are provided within the manuscript. Additional data can be made available upon reasonable request.

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Conflicts of Interest

The authors declare no conflict of interest.

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