BILINGUAL PUBLISHING GROUP

Journal of Environmental & Earth Sciences

https://journals.bilpubgroup.com/index.php/jees

ARTICLE

Exploring the Interplay of Land Use Transformation and Its Environmental Impacts: A Case Study of Sonipat District, Haryana

***Niraj Kumar* [1], *Tejbir Singh Rana* [2], *Subhash Anand* [1*]**

[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*

ABSTRACT

Land use transformations in Sonipat District, Haryana, driven by urbanization, industrialization, and land acquisitions, have posed significant ecological and socio-economic challenges, particularly concerning food security. This study investigates the interplay between these land use changes and their environmental implications at macro (district) and micro (village) levels, focusing on agricultural productivity and resource sustainability. The study employs a mixed-method approach, integrating secondary data from official datasets and primary data gathered through structured household surveys, focus group discussions, and visual analysis techniques. Data from 20 villages, selected based on predominant land use characteristics, were analysed using statistical and geospatial tools, including ArcGIS and STATA, to quantify food grain losses and evaluate environmental degradation. Findings of this study reveal a 19% reduction in agricultural land over two decades (2000–2024), correlating with increased residential and industrial areas. Groundwater resources face severe overexploitation, with pollution from industrial clusters further degrading water and soil quality. The study estimates a total food grain loss of 1.5 million kilograms across surveyed villages due to land acquisitions. A strong positive correlation ($R^2 = 0.98$) between land acquisition and food loss underscores the direct impact of urbanization on agricultural output. The research underscores the urgency of sustainable land management practices, including preserving agricultural lands, optimizing groundwater usage, and enhancing community involvement in planning. By addressing these challenges, the study advocates for balanced urban expansion and food security to ensure ecological and economic resilience in the region.

Keywords: Environmental Impacts; Food Security; Land Acquisition; Land Use; Urbanization

*CORRESPONDING AUTHOR:

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

ARTICLE INFO

Received: 6 December 2024 | Revised: 17 December 2024 | Accepted: 20 December 2024 | Published Online: 23 January 2025
DOI: https://doi.org/10.30564/jees.v7i2.7997

CITATION

Kumar, N., Rana, T.S., Anand, S., 2025. Exploring the Interplay of Land Use Transformation and Its Environmental Impacts: A Case Study of Sonipat District, Haryana. Journal of Environmental & Earth Sciences. 7(2): 76–88. DOI: https://doi.org/10.30564/jees.v7i2.7997

1. Introduction

Changes in land use, particularly driven by land acquisitions, urbanization and industrial expansion, have profound socio-economic as well as environmental ramifications directly impacting food security[1]. Urban sprawl encroaches upon arable land, diminishing the expanse available for agriculture[2]. Consequently, local food production dwindles, affecting food accessibility and affordability, particularly for marginalized communities such as those with low incomes, racial and ethnic minorities, and socially disadvantaged groups. The fragmentation of agricultural land due to urban development disrupts traditional farming practices, rendering it arduous for farmers to maintain productivity and profitability[3].

These alterations in land use breed environmental fixes. Communities reliant on agriculture face economic volatility as fertile farmland gets converted into residential or commercial zones, displacing farmers and eroding traditional agricultural wisdom[4]. This displacement cascades through local economies, exacerbating unemployment and poverty in rural regions, and bringing diverse environmental degradation[5]. Moreover, the transformation of rural areas due to urban expansion reshapes societal dynamics, influencing dietary habits and consumer patterns[6]. The key findings from various regions highlighted significant environmental impacts, such as urbanization in China[7] and India[8], leading to land degradation, loss of agricultural land, and decreased food security[6, 9]. In developing countries, studies emphasized ecosystem service declines[10, 11], while others, such as Musa and Odera[12] and Agidew and Singh[13], linked urban expansion and agricultural land loss to threats in food production. The literature also underscored the role of sustainable practices in mitigating negative outcomes, with research focusing on integrating policies for SDG-2[14] and addressing challenges in agricultural productivity, biodiversity loss, and soil health[15, 16]. The studies advocate for a balanced approach to land use that supports food security while promoting environmental sustainability.

Addressing these challenges necessitates the promotion of sustainable land use strategies that harmonize urban growth with agricultural preservation to ensure food security in the long run. By confronting the environmental ramifications of land use transformations, societies can progress towards a more equitable and food-secure future. Against this background, this study is an exploratory attempt to comprehend the environmental implications of land use changes post land acquisitions across selected villages in Sonipat District of Haryana, and also understand its nexus with food security concerns.

Based on the review of existing studies that have been carried out so far, several research gaps can be noted. It is in this endeavour, that the present study has been undertaken, specifically to understand the land use dynamics and environmental impacts influencing food security, through the case of a rapidly urbanising district in the global south i.e., Sonipat District in Haryana, India. Although the existing studies provide a broad understanding of land use changes and their drivers across different regions, there lies a lack of specific analysis focused on the localised impact of land use dynamics. A detailed investigation into the environmental implications of land use changes in this district through household surveys across selected villages has been done to provide more precise insights. So, understanding these environmental repercussions in the context of Sonipat is the main objective of the study, and it can help in assessing sustainability and also long-term impacts on food security.

Accordingly, the study seeks to decipher answers to the following research questions: How do land use changes in Sonipat District affect rural villages' environment and food security? What types of changes occur and how do they impact natural resources crucial for agriculture? To what extent do land use changes resulting from land acquisitions in Sonipat District villages influence agricultural productivity and food security, and how does it spatially vary across the villages? Further addressing, how can integrated land use planning approaches be employed to balance the competing demands of urban expansion, environmental conservation, and food security within rural villages?

2. Materials and Methods

2.1. Study Area

Haryana occupies a significant position in the geography, history, and politics of India, linking the Shivalik Himalayas in the north to the Aravali ranges in the south. Sonipat District, situated in the eastern region of Haryana, epitomizes a blend of rich historical heritage and contemporary economic progress. The district, an essential component

of the National Capital Region (NCR), is bounded to the east by the Yamuna River, to the north by Panipat district, to the northwest by Jind district, to the southwest by Rohtak district and Jhajjar district and to the south by the NCT of Delhi. Covering an area of 2,122 square kilometers (District Census Handbook, 2011), it was established as a distinct entity from the former Rohtak District in 1972. The fertile lands of Sonipat, nourished by the Yamuna River, are renowned for the cultivation of wheat and rice. Once an ancient settlement, Sonipat's advantageous proximity to Delhi, coupled with its robust infrastructure and accessibility via major highways such as NH-44, NH-334-B, NH-352-A, NH-709, SH-9, SH-10, SH-18 and the Eastern and Western Peripheral Expressways, fuels its developmental trajectory. The district has 4 tehsils and 8 community development blocks namely, Mundlana, Ganaur, Gohana, Kathura, Sonipat, Kharkhoda, Rai, and Murthal. The study encompasses 20 villages spread across the district of Sonipat (**Table 1**, **Figure 1**).

Table 1. List of villages selected for the study.

Land Use	Villages
Predominantly industrial/manufacturing uses	Kundli Garhi, Pitampura, Badhmalik, Barhi, Lalheri Khurd, Jatheri, Liwan, Saidpur, Kundal
Mix of industrial and transportation uses	Garhi Jhanjhara
Predominantly residential uses	Rasoi, Badh Khalsa, Rathdhana
Predominantly transportation or logistics uses	Pipli, Butana, Issepur Kheri
Predominantly institutional (educational) uses	Asawarpur
Designated "Free Zones"	Jhundpur, Tanda, Jagdishpur

Source: Prepared by authors.

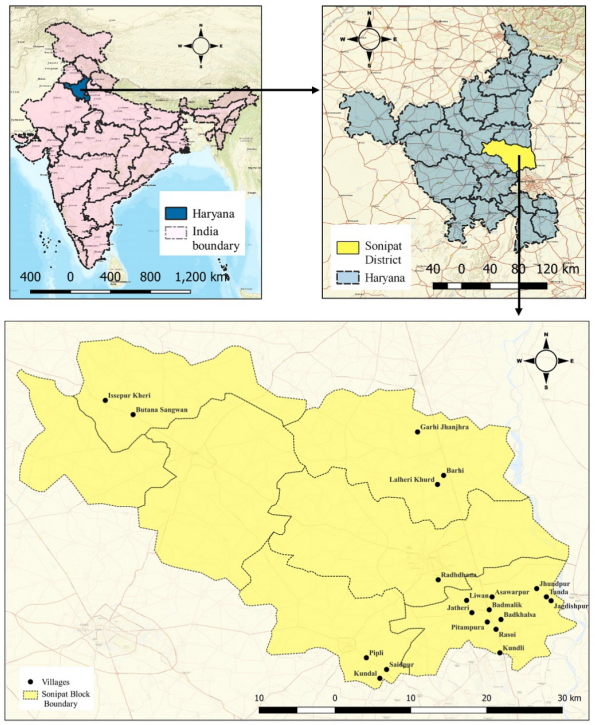


Figure 1. Location of the villages in Sonipat District, Haryana.

Source: Prepared authors.

2.2. Dataset

The study utilizes data from both secondary and primary sources. Secondary data sources include databases from the Water Resources Information System (WRIS), groundwater data from the Central Ground Water Board, and datasets from the Central Pollution Control Board. Average air pollutant concentration was calculated by averaging the annual concentrations of SO_2, NO_2, and PM_{10} levels.

In addition, a primary survey was conducted with 183 households across 20 villages in Haryana, selected through a multi-stage sampling procedure. Initially, villages were purposefully chosen based on predominant land use; subsequently, 183 households were randomly selected within these villages, ensuring that each household had an equal opportunity to participate. This approach minimized bias and enhanced data representativeness. The household survey was carried out by the author over four months, from May to August 2023, using a structured questionnaire. Selection criteria focused primarily on land-owning households while also including a subset of landless households to capture the full spectrum of livelihoods in the villages.

The survey aimed to assess the environmental implications of land use changes, particularly their impact on food security. Key indicators included land usage patterns and the environmental and social outcomes of sold land, with particular attention to increased pollution levels in the village or locality. These aspects provided a comprehensive overview of the village's environmental status and trends. Additionally, semi-structured question prompts guided focus group discussions with villagers, allowing for spontaneous dialogue and follow-up questions based on participants' responses.

Primary data was visually represented using various statistical diagrams, such as bar and column graphs, tree maps, donut charts, Sankey diagrams, and parallel plots, to illustrate respondents' narratives. Word clouds were also used to capture and emphasize individual voices in the study. Data analysis from the primary survey was conducted using ArcGIS, STATA, and NVivo software.

3. Analysis and Discussion

3.1. Environmental Implications of Land Use Changes in Sonipat District

The rapid land use changes in Sonipat District, driven by industrialization, urbanization, and intensive agricultural practices, have resulted in significant ecological and environmental impacts. As agricultural lands are transformed into industrial, commercial, and residential zones, several key consequences have emerged. **Table 2** illustrates the functional land use types in Sonipat District from 2000–2024, and it is reflected from the data, that over the span of 24 years from 2000 to 2024, there is a notable shift in land use patterns. Commercial and retail areas have exhibited a consistent rise, indicative of urban expansion and economic growth, notably accelerating after 2015. Residential land use steadily increased, reflecting population growth and urbanization. Transportation infrastructure has witnessed gradual but steady expansion, particularly notable from 2020 to 2024. Conversely, agricultural land decreased steadily over the years, signaling potential concerns for food security and environmental sustainability. Open spaces also diminished, highlighting challenges in preserving green areas amidst urban development.

Table 2. Functional land use types in Sonipat District from 2000–2024.

Functional Land Use Types	2000	2005	2010	2015	2020	2024
Commercial and retail	1.72	1.81	1.93	2.23	2.54	2.77
Manufacturing	2.61	2.61	2.66	2.66	2.66	2.69
Transportation	6.33	6.37	6.41	6.45	6.83	6.91
Residential	22.31	24.83	27.76	29.21	31.6	33.4
Agricultural land	62.86	60.53	57.46	55.72	52.92	50.8
Water bodies	2.2	1.98	1.96	1.94	1.93	1.93
Open spaces	1.97	1.87	1.82	1.79	1.52	1.5

Source: Prepared by authors based on datasets generated from the supervised classification of LANDSAT – Earth Explorer Satellite Images, USGS, 2024.

A notable consequence of changes in land usage within the Sonipat district is the diminishing proportion of agricultural land, offset by the expansion of land designated for residential, commercial, and retail purposes. The table above, illustrates the temporal evolution of agricultural land usage in Sonipat district from 2000 to 2024, highlighting a consistent decline in the allocation of land for agricultural or crop cultivation. Specifically, the analysis reveals a gradual decrease from 62.86% in 2000 to 55.72% in 2015, further dwindling to 50.8% by 2024. This decline in agricultural land allocation can be attributed to various factors such as urbanization, population growth, and consequent changes in land utilization prompted by infrastructure development, economic transformations, governmental policies, and land fragmentation, which has been further studied in detail in the next section, involving household surveys. Consequently, agricultural land is being converted into urban, industrial, and other non-agricultural purposes, diminishing the overall proportion of land available for farming endeavours. This trend raises significant concerns regarding the future sustainability of agriculture and food security within the district.

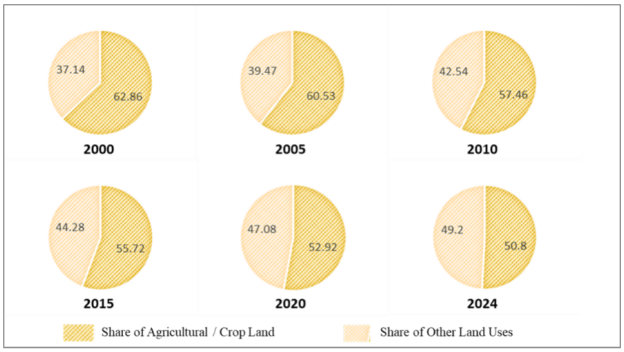
The changing ecological conditions in Sonipat District, Haryana, resulting from land use transformations, have profound environmental implications. The encroachment of urbanization and industrialization has drastically altered natural ecosystems, leading to significant challenges in maintaining ecological balance and sustainability.

3.2. Impact on Agricultural Sustainability

The reduction of agricultural land due to land acquisitions has diminished local food production, impacting food security and economic stability. Declining soil and water quality further threaten agricultural outputs, making it challenging to sustain traditional livelihoods in rural areas. In conclusion, the changing ecological conditions in Sonipat demand urgent interventions. Integrated land management policies, sustainable agricultural practices, and efforts to restore and

conserve natural ecosystems are essential to mitigate these environmental impacts and ensure ecological sustainability.

Figure 2 illustrates land use changes in Sonipat District from 2000 to 2024. Over time, there is a clear trend of declining agricultural land, which reduces from 62.86% in 2000 to 50.8% in 2024, while non-agricultural land increases correspondingly. The consistent decrease in agricultural land signifies the expansion of urban and industrial zones. This impacts food security, as fertile land is diverted from cultivation, resulting in reduced local agricultural output. For example, the decline by 12.06% over two decades contributes to food grain loss, as quantified in the study.



Source: Based on Land Resources Data obtained from India - WRIS

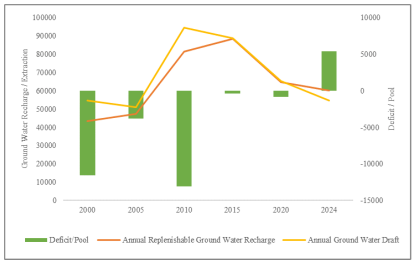
Figure 2. Changes in agricultural/crop land in Sonipat District, Haryana, 2000–2024.

The conversion of land for non-agricultural purposes disrupts ecosystems and habitats, leading to biodiversity loss. Wetlands and forests are often replaced by impervious surfaces, affecting local flora and fauna. The changing ecological conditions in Sonipat District have significantly impacted agriculture, particularly groundwater levels. Excessive irrigation, driven by monoculture farming of water-intensive crops like wheat and rice, has led to over-extraction and contamination of groundwater. Farmers' reliance on chemical fertilizers has further degraded soil and water quality. An examination of water bodies in Sonipat District reveals a concerning decline from 2.2 percent in 2000 to 1.93 percent in 2024, primarily due to rapid urban expansion into suburban areas (**Table 2**).

3.3. Impact on Groundwater

The changing ecological conditions in Sonipat District have profoundly impacted groundwater availability and quality, creating significant challenges for sustainability. Over-extraction of groundwater for agriculture, particularly for water-intensive monoculture crops like rice and wheat, has led to severe depletion. Urbanization and industrialization have further exacerbated this issue by increasing water demand and reducing recharge areas due to the conversion of agricultural and natural lands into built-up zones. From 2000 to 2010, instances of groundwater overdraft were particularly acute, with the situation marginally improving by 2015 but still remaining critical due to persistent overuse.

Figure 3 illustrates the trends in groundwater recharge, extraction, and deficits in Sonipat District from 2000 to 2024, highlighting critical imbalances. Between 2000 and 2010, groundwater extraction consistently exceeded annual replenishable recharge, creating significant deficits, such as in 2010 when the draft (94,535 MCM) surpassed recharge (81,500 MCM). This overdraft aligns with urbanization and water-intensive agriculture. However, post-2010, there is a gradual improvement, with the draft falling below recharge by 2024 (54,811 MCM vs. 60,257 MCM), indicating progress in groundwater management.



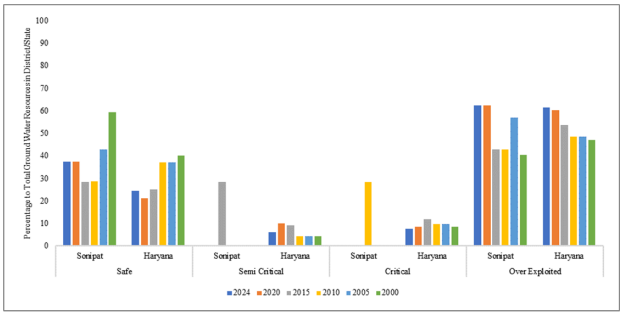
Year	Annual Replenishable Ground Water Recharge	Annual Ground Water Draft
2000	43356	54879
2005	47324	51110
2010	81500	94535
2015	88519	88861
2020	64679	65468
2024	60257	54811

Figure 3. State of groundwater replenishment and extraction in Sonipat District, 2000–2024.
Source: Prepared by authors based on the database of the Central Ground Water Control Board.

Despite this, fluctuations in recharge levels, peaking in 2015 and declining afterwards, underscore the ongoing impact of urban expansion and reduced natural recharge zones. This emphasizes the urgent need for sustainable water management to ensure long-term resource balance. The quality of groundwater in Sonipat has been significantly affected by changing ecological conditions driven by land use transformations, urbanization, and industrialization. Over-extraction for agriculture, particularly for water-intensive crops like rice and wheat, along with inefficient irrigation practices, has depleted resources and degraded water quality. Urban expansion and industrial growth, especially in clusters such as Kundli, Barhi, Rai, and Murthal, have increased water demand while reducing natural recharge areas, leading to

contamination from untreated industrial effluents and agricultural runoff laden with fertilizers and pesticides. This degradation has transitioned groundwater from "safe" to "over-exploited" categories, as population growth and land conversions escalate water demand, surpassing replenishment rates. These changes not only diminish groundwater quality but also impact agricultural productivity and food security, emphasizing the urgent need for sustainable land and water management practices to restore ecological balance.

Figure 4 also compares groundwater levels in Sonipat District and Haryana, highlighting a rapid increase in the share of groundwater resources labelled as "over-exploited" over the years. In Sonipat, the percentage of groundwater resources classified as "Safe" declined drastically from 59.4% in 2000 to 28.57% in 2015 and then slightly improved to 37.5% in 2024. This decline reflects the overuse of groundwater for agriculture, urbanization, and industrial purposes, reducing the availability of replenishable water resources.



	Safe		Semi Critical		Critical		Over Exploited	
Year	District Average	State Average	District Average	State Average	District Average	State Average	District Average	State Average
2000	59.4	40.1	0	4.23	0	8.54	40.6	47.1
2005	42.9	37.16	0	4.42	0	9.73	57.14	48.67
2010	28.6	37.16	0	4.42	28.57	9.73	42.85	48.67
2015	28.57	25.21	28.57	9.24	0	11.76	42.85	53.78
2020	37.5	21.28	0	9.93	0	8.51	62.5	60.28
2024	37.5	24.5	0	6.29	0	7.69	62.5	61.5

Source: Based on data obtained from Central Ground Water Board (CWGB)

Figure 4. Quality of Ground Water in Sonipat District, 2000–2024.

The share of "Over-Exploited" resources in Sonipat increased from 40.6% in 2000 to 42.85% in 2015, peaking during this period. Though it slightly reduced to 62.5% in 2024, the high percentage highlights the continued overextraction of groundwater due to agricultural practices, urbanization, and industrialization. The data reveals a troubling ecological trend in Sonipat, where excessive groundwater extraction has escalated the share of over-exploited zones. This is indicative of unsustainable water management practices that demand urgent interventions, such as efficient irrigation, land use planning, and recharge enhancement to mitigate the impact of ecological changes.

3.4. Effects on Water Table

Water quality and quantity disruptions emerged as a critical concern in villages experiencing industrialization and changes in land use patterns (**Figure 5**). The data obtained from the field survey (out of 183 respondents) indicates fluctuations in the water table across different villages, with 67% of the respondents stating a decline, 12% of the respondents witnessing a rise and the remaining 21% experiencing no change. Villages like Kundli Garhi, Pitampura, Badmalik, Liwan, Rathdhana, Asawarpur, Rasoi, Badkhalsa, Barhi, Lalheri Khurd, Garhi Jhanjhra, Saidpur, Pipli, Jatheri, and Tanda are experiencing a decline in the water table. This decline is attributed to factors such as increased agricultural activities leading to excessive groundwater extraction for irrigation, urbanization resulting in the construction of buildings and roads that disrupt natural water flow patterns, and industrialization leading to the discharge of pollutants into water bodies, thereby reducing groundwater quality and quantity. Villages like Issepur Kheri and Butana Sangwan are experiencing a rise in the water table. The rise in the water table in these villages, like Issepur Kheri, is specifically due to waterlogging during the monsoon. This has primarily stemmed from the saucer-shaped physiography of the region, affecting natural drainage pathways and increasing waterlogging risk in surrounding rural areas.

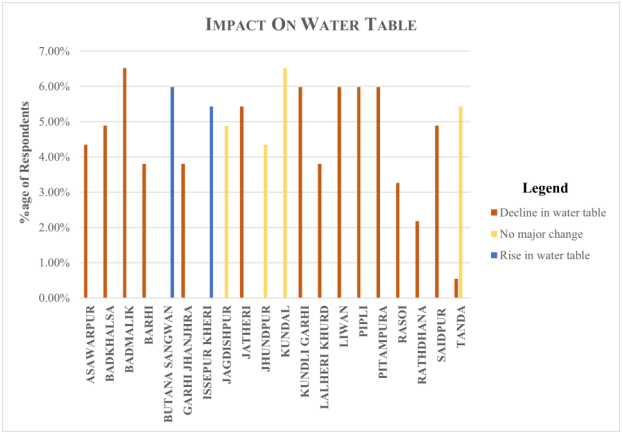


Figure 5. Impact of land use changes on the underground water table.

Source: Prepared by authors based on data obtained from the primary survey.

These disruptions in water quality and quantity due to industrialization and changes in land use in various villages can cast significant implications for food security. In villages where the water table is declining, such as Kundli Garhi and

Pitampura, excessive groundwater extraction for irrigation, urbanization, and industrial pollution can lead to reduced water availability, increased farming costs, and lower agricultural productivity, thus threatening food supply stability and increasing the risk of soil degradation.

3.5. Effects on Water Bodies

Land use changes have affected the status of Surface Water Bodies in the considered villages. As these areas undergo rapid development and urban expansion, natural water bodies such as ponds, lakes, andjohads are often filled in, drained, or encroached upon to make space for infrastructure, residential complexes, and industrial facilities. In Kundli Garhi, Pitampura, Badmalik, Liwan, and several other villages, natural water bodies have been transformed into waste dump yards due to pollution and encroachment. This indicates a severe degradation of environmental conditions, with once-vibrant water sources now contaminated and unusable, posing risks to both human health and the surrounding ecosystems. Furthermore, the disappearance of water bodies like ponds and Johads in villages like Rathdhana, Asawarpur, Rasoi, and others highlights the extent of land use changes and urbanization in these areas. These changes are likely driven by factors such as urban expansion, infrastructure development, and industrialization, which often prioritize economic growth over environmental conservation. The loss of these water bodies not only disrupts local ecosystems but also deprives communities of essential resources like clean water for drinking, irrigation, and recreational purposes. The contrast between villages like Kundal, Saidpur, Pipli, Tanda, Jhundpur, Jagdishpur, Issepur Kheri, Butana Sangwan, and Jatheri, where some ponds and Johads are still available despite pollution, suggests that there may be varying degrees of environmental resilience and community efforts to preserve these water bodies. However, the threat of pollution and disappearance looms large, depicting the urgent need for concerted action to protect and restore these vital natural resources (**Figure 6**).

The disappearance of surface water bodies has far-reaching consequences for both the environment and local communities. Ecologically, these water bodies play crucial roles in supporting biodiversity, regulating microclimates, and replenishing groundwater reserves. Their loss deprives ecosystems of vital habitats and disrupts ecological processes, leading to the decline of native species and ecological imbalances. Furthermore, surface water bodies often serve as sources of drinking water, irrigation, and recreation for nearby communities. The degradation and disappearance of surface water bodies due to urbanization and pollution significantly threaten food security. These water sources are essential for irrigation, livestock, and aquaculture, directly affecting agricultural productivity and food availability. The loss disrupts ecosystems, reducing biodiversity and ecosystem services vital for crop health. Thus, protecting and restoring these water bodies is crucial for sustaining food production, ensuring clean water access, and enhancing climate resilience, thus securing long-term food security and community well-being.

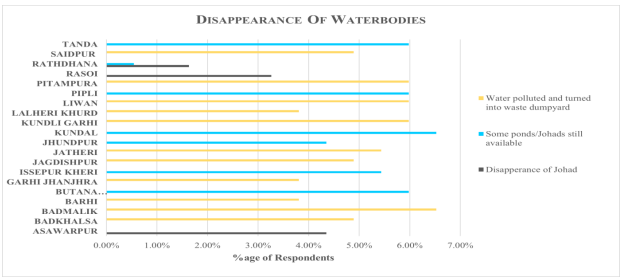


Figure 6. Disappearance of Surface Water Bodies due to land use transformation.

Source: Prepared by authors based on data obtained from the primary survey.

3.6. Impact of Air Pollution and Air Quality

The spatio-temporal variations in air pollutant concentrations across Sonipat district highlight the significant ecological impact of urbanization and land use changes. Over the years, the concentrations of SO_2, NO_2, and PM_{10} have escalated in key locations, such as Murthal and Kharkhoda, indicating a direct correlation with increased urban and industrial activities. For example, Murthal's PM_{10} levels surged from 193 $\mu g\ m^{-3}$ in 2000 to 212 $\mu g\ m^{-3}$ in 2024, while NO_2 levels in Kharkhoda rose sharply from 51 $\mu g\ m^{-3}$ to 89 $\mu g\ m^{-3}$ during the same period (**Table 3**). These rising pollutant levels have detrimental ecological implications, including reduced air quality, harmful impacts on vegetation, and disruptions in natural ecosystems. Elevated PM_{10} levels contribute to respiratory health issues and lower agricultural productivity by coating plant surfaces and inhibiting photosynthesis. Similarly, high NO_2 concentrations can lead to acid rain, further degrading soil and water quality.

Table 3. Spatio-temporal variations of annual average air pollutants conc. (ug m^{-3}) in Sonipat District, Haryana.

Year	Pollutants	Sonipat	Murthal	Mundlana	Kathura	Kharkhoda
	SO_2	10.0	20.0	8.0	5.0	3.0
2000	NO_2	18.0	23.0	18.0	5.0	51.0
	PM10	81.0	193.0	131.0	87.0	143.0
Annual average air pollutants conc. (ug m^{-3}) in 2000		36.3	78.7	52.3	32.3	65.7
	SO_2	12.0	23.0	9.5	5.4	3.5
2005	NO_2	22.0	28.0	20.0	6.8	55.0
	PM10	87.0	210.0	142.0	93.0	157.0
Annual average air pollutants conc. (ug m^{-3}) in 2005		40.3	87.0	57.2	35.1	71.8
	SO_2	15.0	24.0	10.0	6.5	4.5
2010	NO_2	27.0	34.0	23.0	8.5	62.0
	PM10	95.0	286.0	153.0	101.0	165.0
Annual average air pollutants conc. (ug m^{-3}) in 2010		45.7	114.7	62.0	38.7	77.2
	SO_2	15.5	27.0	11.0	7.0	8.0
2015	NO_2	74.0	26.0	27.0	9.0	75.0
	PM10	105.0	190.0	156.0	102.0	201.0
Annual average air pollutants conc. (ug m^{-3}) in 2015		64.8	81.0	64.7	39.3	94.7
	SO_2	12.0	12.5	9.0	5.0	4.5
2020	NO_2	35.0	14.0	19.0	5.0	44.0
	PM10	91.0	172.0	140.0	92.0	178.0
Annual average air pollutants conc. (ug m^{-3}) in 2020		46.0	66.2	56.0	34.0	75.5
	SO_2	16.5	29.5	13.0	8.5	10.0
2024	NO_2	86.0	38.0	40.0	15.4	89.0
	PM10	121.0	212.0	171.0	119.0	212.0
Annual average air pollutants conc. (ug m^{-3}) in 2024		74.5	93.2	74.7	47.6	103.7

Source: Prepared by authors based on database obtained from Central Pollution Control Board (CPCB).

3.7. Environmental Impact of Land Use Transformations in Villages of Sonipat District

The data also reflects the influence of temporary factors, such as the COVID-19 lockdown in 2020, which caused a noticeable dip in pollutant levels due to reduced human activity. For instance, the average annual concentration of SO_2 in Sonipat decreased to 12 µg m^{-3}, compared to 16.5 µg m^{-3} in 2024, illustrating the potential benefits of reduced emissions. This trend underscores the pressing need for sustainable urban development and stricter pollution control measures to mitigate the adverse ecological impacts in Sonipat district. Addressing these concerns is crucial for maintaining ecological balance and ensuring the long-term well-being of both human and natural systems. The spatio-temporal variations in air pollution levels, as illustrated in **Figure 7**, reflect the growing environmental implications of changing ecological conditions in Sonipat district between 2000 and 2024. Over time, air pollution has intensified in specific areas, largely driven by urbanization, industrialization, and expanding transportation networks. For example, by 2024, regions in eastern and central Sonipat exhibited annual average pollutant concentrations exceeding 100 µg m^{-3}, indicating severe air quality deterioration compared to the relatively safer levels observed in 2000.

High levels of PM_{10} and NO_2 contribute to poor air quality, impacting vegetation and soil health. Areas near industrial clusters like Murthal and Kharkhoda show a persistent rise in pollutant levels, leading to reduced agricultural yields and disrupted ecosystems. For instance, Murthal's average pollutant concentration rose from 78.7 µg m^{-3} in 2000 to 93.2 µg m^{-3} in 2024, indicating prolonged exposure to harmful pollutants.

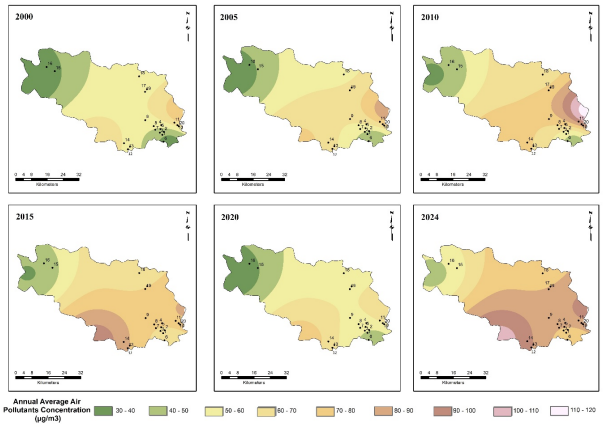


Figure 7. Spatio-temporal variations in pollutant levels in Sonipat District, 2000–2024.
Source: Prepared by authors based on database obtained from Central Pollution Control Board (CPCB).

Increased pollutants, coupled with reduced green cover, exacerbate urban heat islands in high-density urban areas. This effect is evident in regions like Kharkhoda, where pollutant concentrations, particularly NO_2, rose sharply from 51 μg m^{-3} in 2000 to 89 μg m^{-3} in 2024, contributing to higher localized temperatures.

In 2020, the COVID-19 lockdown temporarily reduced pollutant levels (e.g., PM_{10} in Sonipat decreased to 91 μg m^{-3} from 121 μg m^{-3} in 2024). This underscores the direct impact of reduced human activity on ecological recovery, highlighting the importance of sustainable development practices. Land use and land cover changes, coupled with a burgeoning secondary (manufacturing) sector in Sonipat District, have exerted profound and often detrimental impacts on the environmental conditions of villages. As these areas transition from predominantly rural to urban and industrial landscapes, the once-abundant natural habitats have undergone significant alteration or complete destruction. The increasing air pollution in Sonipat district, as depicted in **Figure 7**, underscores the pressing need for comprehensive mitigation strategies. These include promoting cleaner industrial practices, enhancing green infrastructure, and adopting sustainable land use policies to preserve ecological balance and ensure environmental sustainability.

3.8. Effects on Soil Fertility

Industrialization and intensive agricultural practices in Sonipat, including monoculture of wheat and rice and excessive use of chemical fertilizers, have significantly degraded soil health. Soil erosion, compaction, and contamination are common, with sedimentation in water bodies further harming water quality and aquatic ecosystems. High fertilizer application and the lack of fallow periods have caused nutrient imbalances, reduced microbial activity, and decreased soil fertility, directly impacting crop productivity and sustainability. Village-wise impact of land use changes on soil fertility is shown in **Figure 8**. This degradation not only threatens agricultural output but also heightens vulnerability to climate change, posing a severe risk to long-term food security.

The household survey outlined the status of common land across several villages, revealing diverse scenarios regarding land use post-sale. Villages like Kundli Garhi and Badmalik indicate a trend where common land has been acquired and sold, suggesting a shift towards private ownership or development. Conversely, villages like Pitampura utilize available common land for playgrounds and agriculture, emphasizing community-oriented uses. However, challenges emerge in villages like Lalheri Khurd, where common land is now a waste dump yard, highlighting potential environmental degradation. This varied landscape emphasizes the importance of understanding and regulating land transactions to ensure sustainable development, food security and community benefit. Last but not least, industrialization and urbanization have contributed significantly to air pollution in the villages.

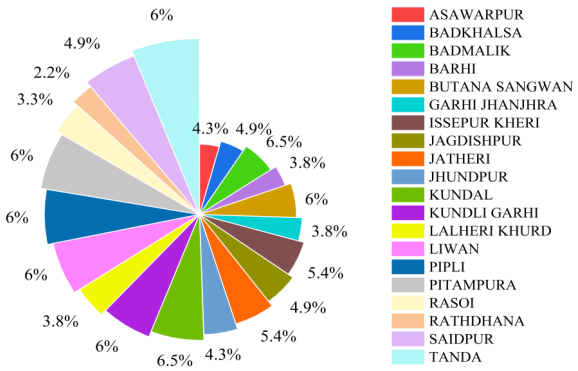


Figure 8. Village-wise impact of land use changes on soil fertility.
Source: Prepared by authors based on data obtained from the primary survey.

3.9. Effects of Increasing Pollution on Ecological Conditions

The data collected from the household survey suggests a significant increase in air pollution across several villages, accompanied by a general rise in overall pollution levels. **Figure 9**, through the use of a tree map, displays this phenomenon, where the entire diagram consists of the 183 respondents sampled for the primary survey. Among these, the size of the boxes in the tree map is directly proportional to the percentage of respondents (out of total) who have acknowledged a rise in pollution levels. Villages such as Kundli Garhi, Pitampura, Badmalik, Liwan, Rathdhana, Asawarpur, Rasoi, Badkhalsa, Barhi, Lalheri Khurd, Garhi Jhanjhra, Kundal, Saidpur, Pipli, Tanda, Jhundpur, Jagdishpur, Issepur Kheri, Butana Sangwan, and Jatheri have all experienced heightened air pollution, with all types of pollutants showing an increase, with relatively higher proportions in the villages of Badhmalik, Kundal, Butana Sangwan and Kundli Garhi. The consistent trend of increased air pollution across these villages raises concerns about the potential health and envi-

ronmental impacts on the residents and surrounding ecosystems. Elevated levels of pollutants like particulate matter, nitrogen oxides, sulfur dioxide, and volatile organic compounds can lead to environmental degradation. Furthermore, the data indicates a parallel increase in overall pollution levels, suggesting a broader environmental challenge beyond just air quality. This broader pollution encompasses various forms, including water contamination, soil degradation, and noise pollution, among others. Such widespread pollution poses significant threats to ecosystem and food health, biodiversity, and overall quality of life for residents in these areas.

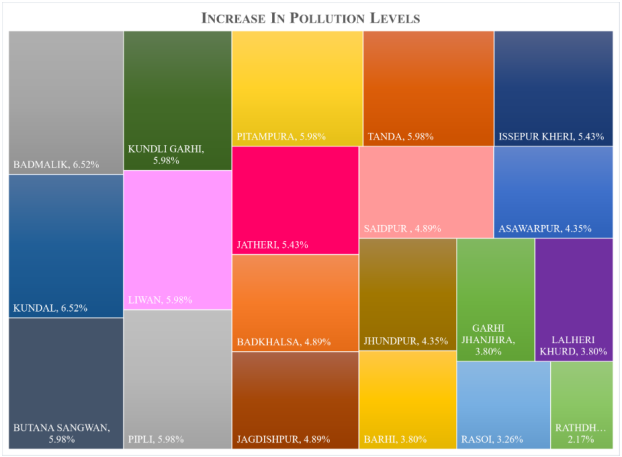


Figure 9. Tree Map showing the village wise increase in pollution levels.

Source: Prepared by authors based on data obtained from the primary survey.

The environmental degradation observed in the villages carries significant implications for both the local ecosystems and the well-being of the communities, with clear connections to land use and land cover changes, industrialization, and urbanization. The expansion of industrial and urban areas further accelerates environmental degradation through pollution, habitat destruction, resource depletion, health concerns and food insecurity. The degradation of natural resources also undermines agricultural productivity, exacerbating poverty and food insecurity in rural communities dependent on agriculture for their livelihoods.

3.10. Comprehending the Interplay of Ecological Conditions and Land Use Changes

Land use changes in the selected villages of Sonipat District, which has been used as a representation of the overall situation of the district, reveal that transformations in land use have mainly taken place due to land acquisition. Each village presents a unique distribution of land utilization, reflecting a mix of industrial, commercial, residential, educational, highway, railway, and agricultural zones. Initially, the villages were predominated by agricultural land use; however, post-land acquisition, they have undergone several transformations, as noted by the researcher through narratives from interviews conducted with the local population. For instance, villages like Kundli, Rasoi, Pitampura, and Barhi predominantly cater to industrial activities, while others like Badkhalsa, Rathdhana, and Liwan have a stronger emphasis on residential areas. Additionally, there are specialized zones such as Jagdishpur, Tanda, and Jhundpur designated as “Free Zones” with specific focuses like bulb manufacturing, water treatment, and agriculture. Saidpur and Kundal are oriented towards warehousing and industrial manufacturing, respectively. Villages like Pipli and Butana have allocations for infrastructure development such as highways, railways, and government colleges. Lastly, there are villages like Garhi-Jhanjhra and Lalheri Khurd that are entirely dedicated to specific purposes like cargo handling and industrial activities.

The alluvial diagram (**Figure 10**) illustrates the transformation of land use in Sonipat District, highlighting the dramatic shift from agricultural to industrial, commercial, and residential zones following land acquisition (LA). Before the acquisition, the majority of the land was utilized for agriculture, forming the backbone of local livelihoods and supporting the ecological balance of the region. However, post-acquisition, this agricultural land has been replaced by diverse uses such as industrial hubs, transportation infrastructure, and urban residential areas, signaling a transition towards urbanization and industrialization. One of the most significant ecological impacts is the loss of agricultural land. This change disrupts the natural ecosystem, leading to reduced biodiversity and altering soil and water dynamics. Agricultural activities, which once maintained the fertility and health of the soil, are now replaced by industrial and commercial establishments, potentially contributing to soil degradation and loss of vegetation cover. Furthermore, the shift in land use impacts water availability, as industrial and urban demands often overexploit groundwater resources, creating stress for nearby areas still reliant on agriculture.

The development of highways, railways, and other transportation infrastructure, while improving connectivity

and access, also brings ecological challenges. These projects fragment natural habitats, leading to a decline in native flora and fauna. Additionally, increased vehicular traffic results in higher emissions, further deteriorating air quality and contributing to climate change. Urbanization in the district has also introduced the risk of the urban heat island effect, where the replacement of green cover with concrete structures elevates local temperatures. Socio-economic conditions in Sonipat have been profoundly affected by these changes. While the transition from agriculture to industrial and commercial zones creates new economic opportunities, it also displaces traditional farming communities, forcing them to adapt to different livelihoods. For some, this shift may improve income levels, but for others, it leads to instability and challenges in adjusting to new economic activities. The influx of urban populations and the shift in land use patterns also alter traditional community structures, potentially leading to the erosion of cultural identities linked to agricultural practices.

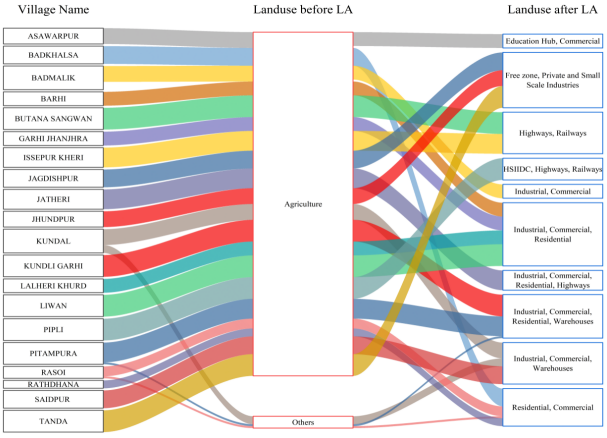


Figure 10. Alluvial diagram showing the transformation of land use before and after land acquisition.

Source: Prepared by authors based on data obtained from the primary survey.

The land-use transformation in Sonipat District reflects the broader challenges of rapid urbanization and industrial development. While these changes bring short-term economic benefits such as modernization, improved infrastructure, and job creation, they also pose long-term ecological and social risks. Loss of biodiversity, water resource stress, pollution, and cultural disruptions are critical issues that need to be addressed. Sustainable urban planning that balances development with ecological conservation and social equity is essential to mitigate the adverse impacts of this transition.

4. Suggestions for Mitigating Ecological Impacts

The rapid industrialization and urbanization in Sonipat District have significantly impacted the region's ecological conditions. Land use has shifted from predominantly agricultural to industrial, residential, and commercial zones, leading to severe environmental degradation. Air pollution has risen sharply, with increasing levels of pollutants such as PM10, NO_2, and SO_2, as shown in the data from 2000 to 2024. This pollution has disrupted local ecosystems, harming biodiversity and water quality. Soil degradation has worsened due to the overuse of chemical fertilizers, causing nutrient imbalances and reduced microbial activity, which has negatively affected agricultural productivity and sustainability. The transition from agriculture to industrial land use, particularly in villages like Kundli, Pitampura, and Badkhalsa, has led to reduced soil fertility and contamination of water bodies. The mitigating measures can be taken under the following heads:

- Sustainable Land Use: Prioritize the preservation of agricultural land through effective zoning and balanced land use, promoting green infrastructure to mitigate soil degradation and water contamination.
- Increase Green Spaces: Expand urban green spaces and forests to combat the urban heat island effect, improve air quality, and restore biodiversity.
- Sustainable Agriculture: Encourage practices like organic farming, crop rotation, and agroforestry to improve soil health and reduce fertilizer dependency.
- Pollution Control: Enforce stricter regulations on industrial emissions, waste management, and promote cleaner technologies to reduce pollution.
- Community Awareness: Educate communities on pollution and land degradation to foster local conservation efforts.
- Renewable Energy & Clean Industries: Promote renewable energy and cleaner industrial technologies to reduce pollution globally.
- Global Collaboration: Countries should work together on transnational environmental projects to share resources, knowledge, and best practices.
- Ecological Restoration: Invest in local and global ecological restoration programs for land rehabilitation, reforesta-

tion, and water conservation.

Additionally, the loss of agricultural land and the expansion of infrastructure such as highways and railways have fragmented natural habitats, contributing to biodiversity loss and water stress. Despite economic benefits like improved infrastructure and job creation, these changes pose long-term risks to the environment, food security, and community health. In summary, Sonipat's shift towards industrialization and urbanization has led to significant ecological changes, including increased pollution, soil degradation, and habitat loss. Sustainable development strategies that balance economic growth with environmental preservation are essential to mitigate these negative impacts.

Author Contributions

All authors equally contributed to the manuscript.

Funding

No funding was received for this research.

Institutional Review Board Statement

"The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of NAME OF INSTITUTE (protocol code XXX and date of approval)." for studies involving humans. The study did not require ethical approval as it did not involve humans or animals.

Informed Consent Statement

Not applicable, as the study did not involve humans.

Data Availability Statement

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

Acknowledgements

The authors are thankful to the Department of Geography, University of Delhi, and Ratan Tata Library (RTL) for providing the required positive environment to complete the study.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Mora, O., Le Mouël, C., de Lattre-Gasquet, M., et al., 2020. Exploring the future of land use and food security: A new set of global scenarios. PLOS ONE. 15(7), e0235597.

[2] Gardi, C., 2015. Land take and food security: Assessment of land take on the agricultural production in Europe. Journal of Environmental Planning and Management. 58(5), 898–912.

[3] Veenhuizen, R.V., Danso, G., 2007. Profitability and sustainability of urban and peri-urban agriculture. FAO: Rome, Italy. pp. 1–71.

[4] Altieri, M.A., Nicholls, C.I., 2017. The adaptation and mitigation potential of traditional agriculture in a changing climate. Climate Change. 140, 33–45.

[5] Cernea, M.M., 2000. Risks, safeguards and reconstruction: A model for population displacement and resettlement. Economic and Political Weekly. 35(41), 3659–3678.

[6] Singh, S., Venkateshmurthy, N.S., Brown, K.A., et al., 2023. Agricultural and socioeconomic factors associated with farmer household dietary diversity in India: A comparative study of Visakhapatnam and Sonipat. Sustainability. 15(4), 2873.

[7] Deng, J.S., Wang, K., Hong, Y., et al., 2009. Spatio-temporal dynamics and evolution of land use change and landscape pattern in response to rapid urbanization. Landscape and Urban Planning. 92(4), 187–198.

[8] Aggarwal, P.K., Rötter, R.P., Kalra, N., et al., 2001. Land use analysis and planning for sustainable food security: With an illustration for the state of Haryana, India. International Rice Research Institute (IRRI): New Delhi, India. pp. 1-153.

[9] Prakash, R., Dinesh, Kumar, S., 2021. Survey and mapping of groundwater quality of Sonipat block in Sonipat District of Haryana, India. Journal of Soil Salinity and Water Quality. 13(2), 221–227.

[10] Arunyawat, S., Shrestha, R.P., 2016. Assessing land use change and its impact on ecosystem services in northern Thailand. Sustainability. 8(8), 768.

[11] Tolessa, T., Senbeta, F., Kidane, M., 2017. The impact of land use/land cover change on ecosystem services in the central highlands of Ethiopia. Ecosystem Services. 23, 47–54.

[12] Musa, M.K., Odera, P.A., 2015. Land use land cover changes and their effects on food security. Kabarak

Journal of Research and Innovation. 3(1), 74-86.

[13] Agidew, A.-m.A., Singh, K.N., 2017. The implications of land use and land cover changes for rural household food insecurity in the northeastern highlands of Ethiopia: The case of the Teleyayen sub-watershed. Agriculture and Food Security. 6, 56.

[14] Obersteiner, M., Walsh, B., 2016. Assessing the land resource–food price nexus of the Sustainable Development Goals. Science Advances. 2(9), e1501499.

[15] Hinz, R., Sulser, T.B., Huefner, D., et al., 2020. Agricultural development and land use change in India: A scenario analysis of trade-offs between UN Sustainable Development Goals (SDGs). Earth's Future. 8(2), e2019EF001287.

[16] Das, B.S., Wani, S.P., Bendi, D.K., 2022. Soil health and its relationship with food security and human health to meet the sustainable development goals in India. Soil Security. 8, 100071.