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Urbanization and Water Stress in Sasaram City of Bihar: Land Use Change and Groundwater Impacts

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ABSTRACT

Urbanization in small and medium-sized Indian cities increasingly stresses water resources. This study examines how expansion in Sasaram (Rohtas district, Bihar) from 2000 to 2024 has affected land-use, surface and groundwater availability, and water-resource usage. Using remote sensing–based Land Use/Land Cover (LULC) change detection, climatic-rainfall data, and district-level groundwater resource assessments, the analysis reveals significant increase in built-up area, loss of open and green spaces and water bodies, and likely pressure on groundwater due to increased demand and reduced recharge zones. The findings underscore the need for integrated urban water management, water-sensitive planning, and groundwater governance. The paper includes spatial maps, temporal charts, and a conceptual framework to support the argument.

1. Introduction

Across global contexts, urbanization reshapes not only the physical landscape but also significantly alters hydrological systems and ecological balance. While metropolitan cities have received extensive academic attention, small and mid-sized urban centers in India — such as Sasaram in Bihar — are often overlooked, despite experiencing substantial and frequently unregulated urban expansion. These towns typically lack robust infrastructure and institutional capacity, making them highly vulnerable to water-related challenges. Studies have shown that unchecked urban growth tends to reduce natural groundwater recharge, increase surface runoff, and degrade traditional water bodies (Wakode et al., 2018; Kulkarni et al., 2008). In such urban settings, the absence of water-sensitive planning exacerbates risks of both scarcity and pollution (Biswas et al., 2021; Sridhar &Iyer, 2025).

Furthermore, pressures from rising population densities, expansion of impervious surfaces, and the encroachment upon open and green spaces collectively intensify stress on local water systems (Dutta et al., 2024; Bhoomika, n.d.). Over time, the over-extraction of groundwater, coupled with seasonal rainfall variability and poor drainage, raises urgent concerns regarding the sustainability of local water resources. Sasaram exemplifies these dynamics, as urban growth in recent decades has led to measurable land-use transformation and growing pressure on groundwater. This study aims to investigate the spatial-temporal dynamics of land use and water resource availability in Sasaram from 2000 to 2023. Specifically, it seeks to:

- (i) Analyze patterns of land-use change and the loss of natural recharge zones;
- (ii) Assess the implications for groundwater availability and recharge potential; and
- (iii) Recommend actionable, context-sensitive policy interventions to address emerging water stress. In doing so, the research builds upon both global and regional scholarship on urban water governance, while addressing a critical empirical gap in the study of India's rapidly urbanizing Tier-2 and Tier-3 cities, as shown by Ma et al. (2021), Ghosh (2023), and the Central Ground Water Board (CGWB, 2022).

2. Literature Review

Urbanization, a defining feature of modern development, significantly alters natural hydrological systems through the proliferation of impervious surfaces, loss of green cover, and increased demand for water resources. Across diverse global and regional contexts, studies consistently demonstrate that expanding urban footprints restrict groundwater recharge by obstructing infiltration pathways, while simultaneously elevating surface runoff and contaminating both surface and subsurface water bodies (Wakode et al., 2018; Kulkarni et al., 2008). In cities lacking formal land-use planning — which is common in small and mid-tier urban areas — the degradation of traditional recharge structures such as tanks, ponds, and open fields is particularly severe (Ghosh, 2023; Foster & Chilton, 2003).

The role of geospatial technologies in analyzing urban hydrology has grown in recent decades, especially through the application of remote sensing and GIS. These tools have allowed researchers to track land-use/land-cover (LULC) change, model runoff, identify recharge-deficient zones, and inform integrated watershed management strategies (Balha et al., 2020; Reddy & Syme, 2014). Empirical studies from cities such as Hyderabad, Guwahati, and Delhi highlight that urbanization often outpaces infrastructure development, leading to both aquifer depletion and quality deterioration (Wakode et al., 2018; Dutta et al., 2024; Biswas et al., 2021). Importantly, these methods allow for the triangulation of spatial patterns, climatic variability, and institutional response — providing a nuanced picture of urban water challenges (Ortiz & Pérez, 2024).

Despite these advances, a clear research gap persists concerning small urban centers in India, especially those in the Gangetic basin and Deccan sub-plateau regions. Most published works focus on metropolitan or tier-1 cities, leaving the urban-water dynamics of towns like Sasaram under-explored (Deshpande & Kulkarni, 2007; Bhoomika, n.d.).

In such contexts, where urban growth is informal and unregulated, the effects of urbanization on aquifers, recharge zones, and local water governance mechanisms can be both rapid and severe. Furthermore, data scarcity and institutional fragmentation often hinder water resource assessment and planning in these locations (Sridhar &Iyer, 2025; Kumar & Shah, 2004).

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This study, therefore, seeks to bridge this critical gap by applying remote sensing–based LULC change analysis and integrating spatial data with groundwater assessments for Sasaram city. In doing so, it contributes to the broader literature on urban hydrology and offers a replicable framework for analyzing urban water sustainability in small Indian cities that are poised for substantial demographic and spatial growth in the coming decades.

3. Study Area Description

3.1 Geographic and Hydro-Climatic Context

Sasaram, the administrative headquarters of Rohtas district in southwestern Bihar, India, is situated at approximately 24.95° N latitude and 84.03° E longitude. The city lies in the middle Gangetic plain and is flanked by a mix of alluvial lowlands and gentle undulating topography characteristic of the southwestern transition zone between the Gangetic basin and the Chota Nagpur Plateau.

This geomorphological setting plays a critical role in shaping the region's drainage and groundwater behavior. The area is drained by seasonal rivers and minor streams, many of which originate from the Kaimur hills and eventually contribute to the Son River system. Historically, these natural watercourses, along with scattered wetlands and tanks, have contributed to surface recharge and soil moisture conservation, particularly during the monsoon season.

Climatically, Sasaram falls within the humid subtropical zone as classified under the Köppen-Geiger system (Cfa), receiving an average annual rainfall of approximately 1,127 mm, most of which occurs between June and September due to the southwest monsoon (Climate-Data.org, 2024). This monsoonal pattern is vital for the annual recharge of both surface water bodies and shallow aquifers. However, with increasing urbanization and reduction of vegetated and open areas, the efficacy of rainfall in contributing to infiltration and groundwater recharge has likely diminished over time. Moreover, temperature ranges from 7°C in winter to over 42°C in peak summer months, further influencing evapotranspiration and surface water retention. The natural hydrology of the region is thus tightly linked with its terrain and climatic rhythms — both of which are increasingly being altered due to land use changes.

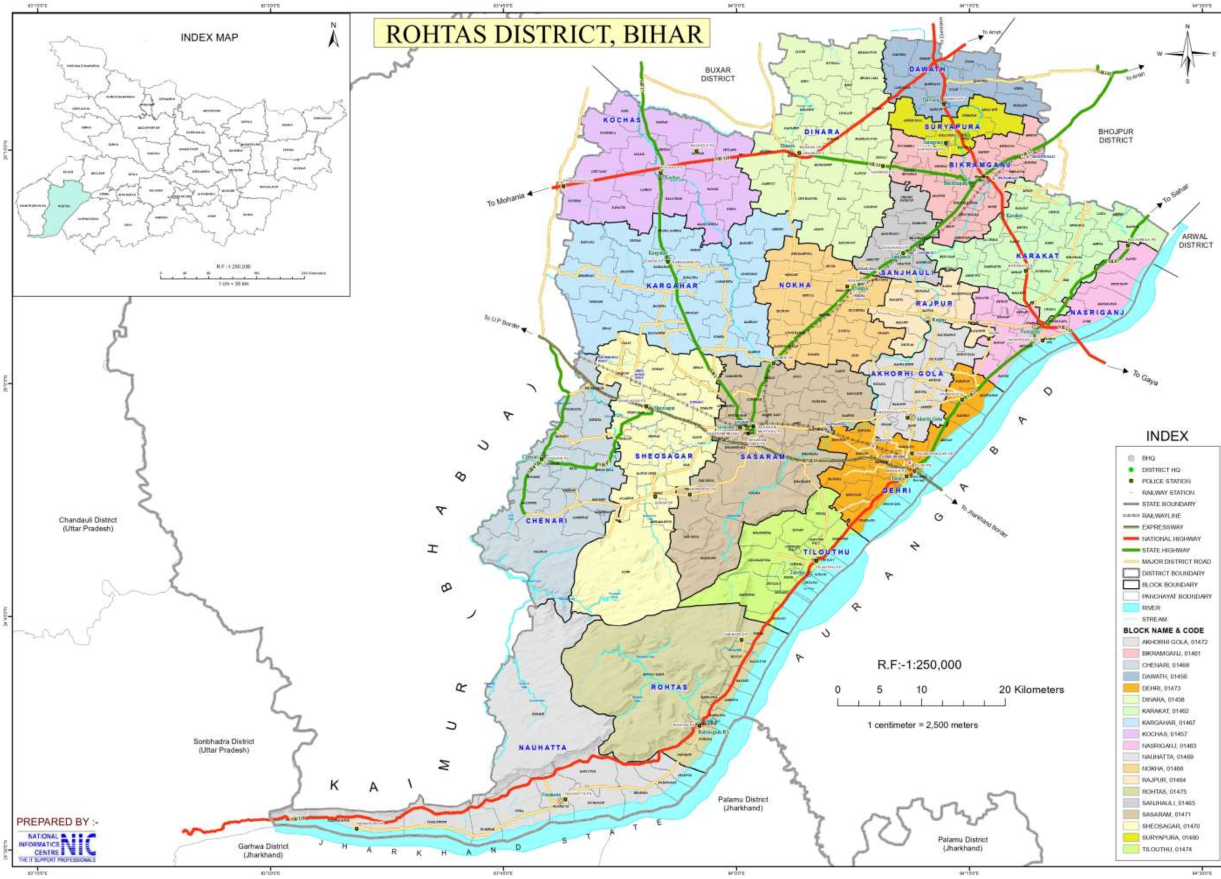


Table 2. District-Level Agricultural and Irrigation Profile for Rohtas District, Bihar

Irrigation Source / Land Use Indicator	Estimated Area Covered (ha)	Percentage of Total Irrigated Area (%)	Remarks / Hydrological Implication
Canal Irrigation	18,500 – 20,000	22–25%	Canal networks exist but seasonal flow variability reduces reliability during rabi and summer months.
Deep Tube Wells	32,000 – 35,000	40–45%	Primary irrigation source; substantial groundwater extraction contributing to aquifer stress.
Shallow Tube Wells	15,000 – 17,000	18–20%	Widely distributed; extraction intensity high during dry spells.
Open Wells (Dug Wells)	4,500 – 5,200	5–7%	Increasingly declining due to falling water tables and preference for deep borewells.

Tanks / Ponds (Surface Water)	2,000 – 2,500	3–4%	Many tanks require desiltation; encroachment reduces storage capacity and recharge potential.
Lift Irrigation / River-based Schemes	1,800 – 2,000	2–3%	Dependent on seasonal flow in the Son and tributaries; low contribution to annual irrigation.
Net Sown Area	165,000 – 175,000	—	Dominated by paddy, wheat, pulses; agricultural demand drives groundwater dependency.
Gross Cropped Area	260,000 – 275,000	—	High cropping intensity increases pressure on irrigation sources.
Groundwater Dependence (All Sources)	—	**65–72% of total irrigation**	Reflects structural reliance on aquifers; risk of long-term depletion without recharge interventions.

Source :CGWB (2022). NAQUIM Report – Rohtas District, Bihar, KVK Rohtas District Agricultural Profile Reports (2020–2023), Census of India & District Statistical Handbook – Rohtas

4. Data Sources and Methodology

4.1 Data and Sources

The study draws upon a combination of spatial, climatic, hydrogeological, and institutional data to build a multi-dimensional understanding of urbanization-induced water stress in Sasaram. Spatial layers, including administrative boundaries, water bodies, and hydrological features, were sourced from publicly available geographic information system (GIS) databases, particularly OpenStreetMap and India's Bhuvan portal. These were used to delineate the study area and overlay thematic attributes such as built-up expansion and drainage networks. Multi-temporal satellite imagery from Landsat (2000, 2010, 2023) and Sentinel-2 (2016–2023) platforms was utilized to detect land-use and land-cover (LULC) changes across the urban and peri-urban zones of Sasaram.

These datasets were chosen due to their moderate spatial resolution, free accessibility, and historical continuity, making them suitable for long-term urban ecological analysis.Climatic data, including monthly rainfall and temperature records for the period 2000 to 2023, were compiled from regional stations and verified against gridded climate data available through sources such as Climate-Data.org and the India Meteorological Department. This helped identify seasonal recharge patterns, water stress periods, and climatic anomalies that could influence hydrological balance. Groundwater availability, depth to water table, and usage patterns were assessed using official documents from the Central Ground Water Board (CGWB, 2022) and the Rohtas District Irrigation Department. These included the NAQUIM (National Aquifer Mapping and Management) reports, irrigation status summaries, and borewell density maps.

In addition to empirical datasets, the study extensively reviewed scholarly literature, technical reports, and international case studies from platforms such as ScienceDirect, INFLIBNET, and ResearchGate. These secondary sources were critical in framing the analytical lens and establishing methodological benchmarks. Comparative references from similar Indian cities — such as Hyderabad, Guwahati, and Bengaluru — offered insights into how spatial analysis and hydrological modeling have been applied to assess urban water challenges (Wakode et al., 2018; Dutta et al., 2024; Bhoomika, n.d.).

4.2 Analytical Approach

The methodological framework adopted for this study integrates remote sensing-based land-use classification, climatic trend analysis, and groundwater resource evaluation through spatial overlay and correlation techniques. Initially, pre-processing of satellite imagery was conducted to correct for atmospheric distortion and align spatial resolutions. Subsequently, supervised classification was carried out using the maximum likelihood algorithm to categorize land use into four primary classes: built-up area, vegetation/agriculture, water bodies, and open land. This classification was performed for three temporal stages — 2000, 2010, and 2023 — to trace the spatial and temporal dynamics of urban growth. Post-classification change detection was applied to quantify LULC transitions, particularly focusing on the conversion of agricultural and open land into impervious urban surfaces.

Accuracy assessment was conducted using high-resolution Google Earth imagery and field-verified samples, with confusion matrices developed to ensure classification reliability exceeded standard thresholds. Overlay analysis was then performed to examine the spatial relationship between built-up area expansion and hydrography, including proximity to natural recharge zones such as riverbeds, tanks, and depressions. This enabled the identification of zones at high risk of hydrological degradation.

To analyze the climatic dimension, time-series graphs and monthly deviation charts were constructed from rainfall and temperature records to identify recharge seasonality, peak runoff periods, and potential drought spells. These findings were integrated with groundwater extraction data and irrigation source profiles to examine demand-supply mismatches. This helped in identifying not only the spatial but also the temporal stress points within Sasaram's urban water regime.

GIS played a central role in this analysis by serving as a spatial decision-support system. Through spatial layering, buffer analysis, and hotspot mapping, GIS enabled the visualization of complex interactions between urban expansion, land degradation, and water resource dynamics. As emphasized in geospatial education and planning literature, GIS-based modeling is crucial for environmental management as it supports multi-criteria evaluation, risk assessment, and scenario planning for sustainable urban development (National Geographic, 2022; Reddy & Syme, 2014).

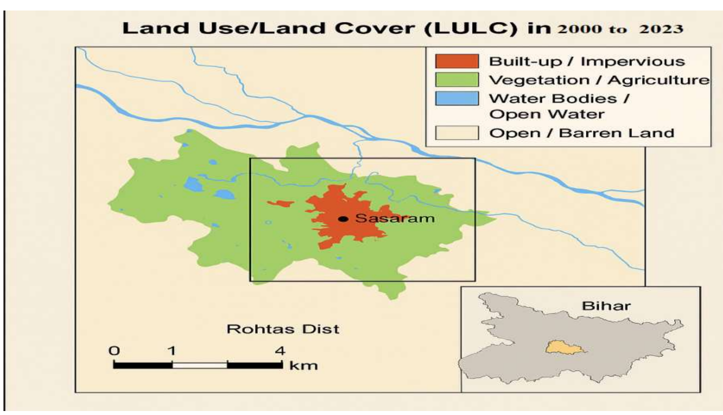
5. Results

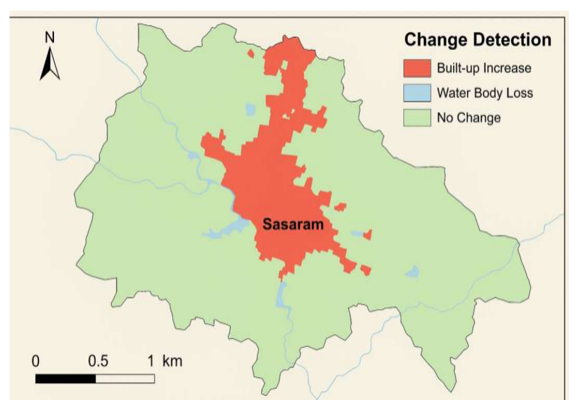
The spatial analysis of land use and land cover (LULC) changes in Sasaram over the 23-year period from 2000 to 2023 reveals a pronounced transformation in urban morphology and its implications for water resource sustainability. The classification of multi-temporal satellite imagery shows a consistent and significant increase in built-up areas, primarily at the cost of vegetation, agricultural land, and traditional water bodies. These patterns are quantitatively summarized in **Table 3**, which illustrates the shifts in land use classes across the study period.

Table 3. LULC Change Summary for Sasaram City and Surroundings (2000–2023)

Land Use / Land Cover Class	Area in 2000 (km^2)	Area in 2023 (km^2)	Net Change (km^2)	% Change	Trend
Built-up / Impervious Surface	6.4	14.8	+8.4	**+131.25%**	Rapid increase in urban spread
Vegetation / Agriculture	36.2	28.5	–7.7	**–21.27%**	Decline due to land conversion
Water Bodies / Open Water	3.1	1.9	–1.2	**–38.71%**	Shrinkage, encroachment noted
Open / Barren Land	8.9	6.2	–2.7	**–30.34%**	Reduction in natural recharge areas

Source:*Author's calculation based on supervised classification of Landsat (2000, 2023) and Sentinel-2 imagery, using ancillary spatial layers from OpenStreetMap and CGWB (2022).*





The left side Map visually depict the LULC distribution for the years 2000 and 2023 respectively, while another Map presents the spatial extent of change detection, highlighting zones of urban expansion and concomitant loss of ecological buffers such as open land and water bodies. These maps provide spatial clarity on how Sasaram's urban footprint has expanded, encroaching upon previously permeable areas that once facilitated groundwater recharge and seasonal water storage.

The LULC transformation aligns with observed rainfall trends, further exacerbating water stress. **Figure 1**, a line and bar graph representing monthly average rainfall from 2000 to 2023, highlights Sasaram's strong dependence on the monsoonal cycle, with the bulk of precipitation occurring between June and September. This seasonal concentration underscores the city's vulnerability during non-monsoon periods, particularly when combined with reduced natural infiltration surfaces.

CLIMATE TABLE / WEATHER BY MONTH SASARAM

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature °C (°F)	16 °C (60.8) °F	19.9 °C (67.8) °F	25.7 °C (78.3) °F	31.4 °C (88.5) °F	33.4 °C (92.1) °F	32.3 °C (90.1) °F	28.9 °C (84) °F	28.2 °C (82.8) °F	27.5 °C (81.5) °F	25.2 °C (77.4) °F	21.4 °C (70.6) °F	17.4 °C (63.2) °F
Min. Temperature °C (°F)	9.8 °C (49.6) °F	13 °C (55.4) °F	17.8 °C (64.1) °F	23.3 °C (73.9) °F	26.6 °C (79.9) °F	27.8 °C (82) °F	26.3 °C (79.4) °F	25.8 °C (78.4) °F	24.8 °C (76.6) °F	20.7 °C (69.2) °F	15.4 °C (59.7) °F	11.1 °C (51.9) °F
Max. Temperature °C (°F)	22.4 °C (72.4) °F	26.6 °C (79.9) °F	33 °C (91.5) °F	38.8 °C (101.8) °F	39.7 °C (103.5) °F	37 °C (98.6) °F	32.1 °C (89.8) °F	31.5 °C (88.7) °F	30.9 °C (87.6) °F	29.9 °C (85.9) °F	27.5 °C (81.5) °F	23.8 °C (74.8) °F
Precipitation / Rainfall mm (in)	17 (0)	23 (0)	10 (0)	7 (0)	17 (0)	163 (6)	333 (13)	276 (10)	213 (8)	52 (2)	7 (0)	9 (0)
Humidity (%)	65%	57%	39%	28%	39%	55%	79%	83%	83%	75%	63%	64%
Rainy days (d)	2	2	2	2	3	10	18	18	15	4	1	1
avg. Sun hours (hours)	8.8	9.8	10.7	11.4	11.7	10.5	8.4	8.0	8.3	9.1	9.5	9.0

Source: Climate-Data.org

Data: 1991 - 2021

Min. Temperature °C (°F), Max. Temperature °C (°F), Precipitation / Rainfall mm (in), Humidity, Rainy days. Data: 1999 - 2019: avg. Sun hours

There is a difference of 326 mm | 13 inch of precipitation between the driest and wettest months. The average temperatures vary during the year by 17.4 °C | 31.3 °F.

The month with the highest relative humidity is September (83.40). The month with the lowest relative humidity is April (28.41). The month with the highest number of rainy days is July (24.60 days). The month with the lowest number of rainy days is November (0.87 days)

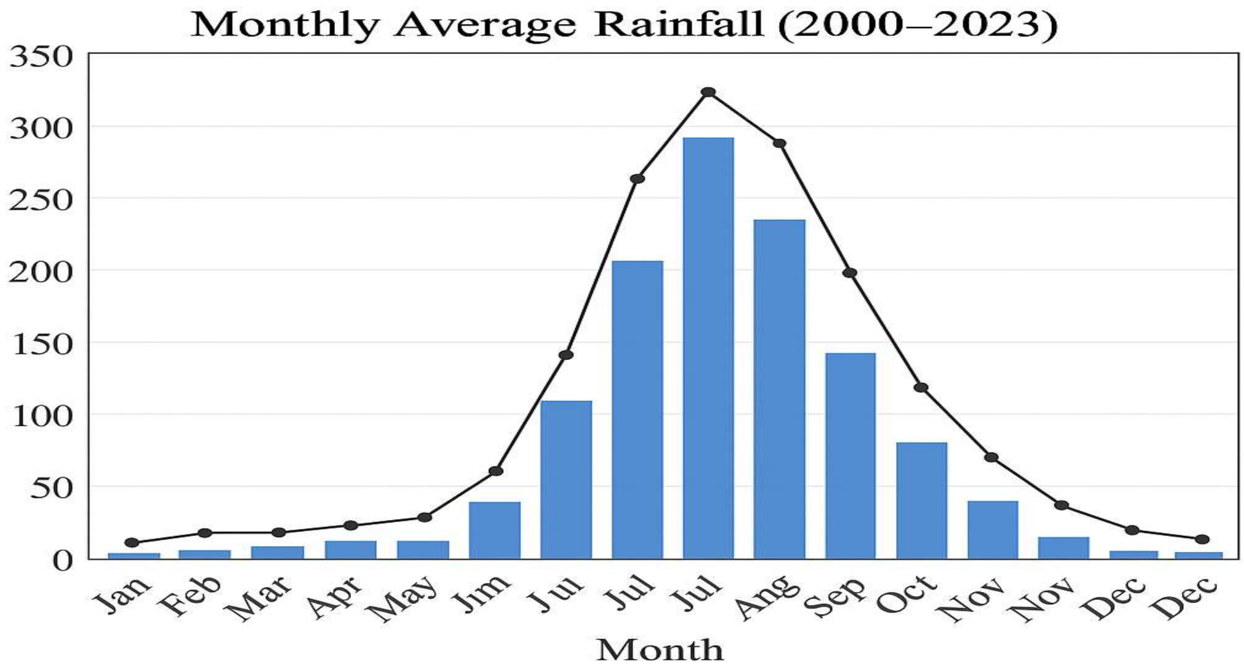


Figure 1: Monthly Average Rainfall (2000–2023)

Figure 1: Monthly Average Rainfall (2000–2023)]

Integrating both spatial and climatic analyses leads to several critical findings. First, the loss of vegetative cover, open lands, and surface water bodies has significantly diminished the availability of natural recharge zones. With the replacement of pervious areas by impervious built-up surfaces, the infiltration capacity of urban land has declined sharply. This, in turn, results in elevated surface runoff, reducing the amount of rainwater that can percolate into the aquifers. Second, the continuous growth in urban population and its associated water demands — alongside sustained pressure from groundwater-dependent agriculture — has intensified the extraction burden on the region's aquifers. Given these overlapping dynamics, the current groundwater-centric water regime in Sasaram is increasingly unsustainable. Without proactive measures to restore degraded water bodies, enhance artificial recharge, and regulate land use in environmentally sensitive areas, the city risks entering a phase of chronic water stress. The evidence thus supports a call for integrated urban water governance, combining spatial planning with hydrogeological safeguards to ensure long-term resilience.

6. Discussion

The spatial and hydrological transformations observed in Sasaram between 2000 and 2023 are consistent with a growing body of international research that documents the impact of rapid urbanization on groundwater dynamics and urban water security. As impervious surfaces expand in response to urban growth, natural infiltration is disrupted, leading to increased surface runoff, reduced aquifer recharge, and elevated risk of both flooding and water scarcity. This pattern has been extensively validated in GIS-based hydrological studies across urban environments in both developing and developed countries, where remote sensing tools have been instrumental in diagnosing land-use transitions and their ecological consequences (Balha et al., 2020; Ma et al., 2021; Reddy & Syme, 2014).

In the context of Sasaram, these changes carry specific implications due to the city's unique geomorphological and climatic setting. Unlike larger metropolitan regions that often benefit from more diversified water infrastructure, Sasaram's dependence on monsoonal rainfall and groundwater as primary sources makes it particularly vulnerable to seasonal variability. The rainfall data analyzed in this study confirms that the majority of annual precipitation is confined to a narrow window during the southwest monsoon. Such concentration not only limits the duration of effective groundwater recharge but also increases the pressure on existing aquifers during the long dry periods that follow. When combined with the observed reduction in recharge-supporting land cover — such as open fields, water bodies, and vegetated zones — the city faces a clear and accelerating water imbalance.

The challenge is further exacerbated by the lack of integrated urban water management policies at the municipal level. Current patterns of land development in Sasaram indicate limited enforcement of zoning regulations, inadequate provision for green and blue infrastructure, and an absence of decentralized water conservation practices such as rainwater harvesting or urban wetlands protection. The conversion of traditional ponds and surface water structures into built-up areas not only removes storage capacity but also disrupts the cultural and functional landscapes that once buffered hydrological extremes (Bhoomika, n.d.; Dutta et al., 2024). Furthermore, institutional fragmentation between urban planning and water management agencies hampers coordinated responses to emerging water stress.

Studies from cities such as Hyderabad, Guwahati, and Bengaluru show that spatial planning tools, when integrated with hydrological data, can help local governments identify recharge hotspots, implement low-impact development (LID) strategies, and prioritize watershed restoration projects (Wakode et al., 2018; Ghosh, 2023). These lessons are directly relevant for Sasaram, where rapid but unregulated urban growth risks undermining long-term water security. Applying similar GIS-based frameworks can enable proactive governance by identifying critical zones of aquifer vulnerability, mapping seasonal water deficits, and forecasting future demand under alternative land-use scenarios.

Therefore, the findings from this study underscore the urgent need for a paradigm shift in how small and medium cities like Sasaram approach urban expansion. It is no longer viable to separate land development from hydrological considerations. A water-sensitive urban design (WSUD) framework — which emphasizes integration between urban form and water cycles — must be adopted to balance growth with sustainability. Such an approach would include measures like mandatory rainwater harvesting, protection of low-lying recharge zones, revival of urban ponds, and strategic greenbelt development around aquifer recharge areas.

In sum, while the trajectory of Sasaram's urbanization reflects broader national and global trends, its localized impacts on water resources are immediate and intensifying. The city stands at a crossroads: it can either continue down a path of reactive, fragmented water governance, or it can leverage spatial intelligence and integrated planning to build long-term hydrological resilience. The evidence presented in this study strongly supports the latter course of action.

7. Conclusion and Policy Recommendations

7.1 Conclusion

This study has presented a spatial and temporal analysis of land use change and its impact on water resources in Sasaram, a rapidly urbanizing city in the Rohtas district of Bihar. The analysis, spanning from 2000 to 2023, highlights a clear pattern of urban expansion at the expense of critical ecological and hydrological assets. Built-up and impervious surfaces have more than doubled, primarily replacing vegetation, agricultural land, and natural recharge areas such as open lands and water bodies. The associated reduction in infiltration potential, coupled with Sasaram's strong reliance on monsoon rainfall and a groundwater-centric water supply regime, has significantly increased the vulnerability of local water systems.

The concentration of rainfall within a short seasonal window further constrains effective aquifer recharge, while increasing demand from both domestic and agricultural users exerts mounting pressure on groundwater reserves. Without timely intervention, the city risks entering a phase of chronic water imbalance, characterized by declining groundwater levels, deteriorating water quality, and heightened exposure to water insecurity during dry spells. These findings underscore the urgent need to integrate spatial analysis, hydrological data, and urban planning in a coordinated manner to mitigate the compounding impacts of unregulated urban growth on water resources.

7.2 Policy Recommendations

To address the hydrological challenges posed by unplanned urban expansion in Sasaram and ensure long-term sustainability of water resources, the following policy recommendations are proposed:

- **Institutionalize GIS-based monitoring**: The use of satellite imagery and spatial data analytics should be adopted as a routine planning tool by local authorities. Regular land use and water resource mapping can enable early detection of ecological stress zones and help in evidence-based decision-making.
- **Protect and restore recharge zones**: Traditional water bodies such as ponds, tanks, and low-lying wetlands, along with open land that supports infiltration, should be legally protected from encroachment. Restoration projects must prioritize desilting, bunding, and greening of such areas to revive their ecological function.
- **Mandate rainwater harvesting and green infrastructure**: Urban development regulations should enforce rainwater harvesting systems in all new residential, institutional, and commercial constructions. At the same time, green roofs, permeable pavements, and bio-swales should be promoted to reduce surface runoff and enhance urban resilience.

- **Strengthen groundwater regulation**: The proliferation of private wells and borewells, particularly in unregulated urban and peri-urban zones, must be brought under formal monitoring frameworks. This may include metering, licensing, and public disclosure of extraction volumes, as well as restrictions in critical groundwater blocks.
- **Upgrade water infrastructure**: Investments in improving piped water supply, stormwater drainage, and decentralized wastewater treatment systems are crucial to ensure that urban growth does not result in the degradation of both surface and subsurface water quality.
- **Conduct continuous hydrogeological assessments**: Long-term water planning must be underpinned by real-time data on aquifer levels, recharge rates, and water quality. Partnerships with academic institutions and hydrogeological agencies such as the CGWB can facilitate periodic surveys and data transparency.

Together, these strategies form the foundation for a water-sensitive urban planning approach tailored to the ecological and socio-economic realities of small and medium towns like Sasaram. By aligning land development with hydrological sustainability, such towns can avoid the water crises that have plagued many larger Indian cities, and instead move towards a resilient and resource-secure future.

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