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Municipal Solid Waste Management in Trans-Gomti Lucknow: An Environmental Perspective

Sanchita Misra[1*], Vikas Srivastava[2], Parah Salsabeel Jalal[3] and Ashhad Imam[4] and Atul[*5]

*[1,3]Research scholar, [4,*5]Assistant Professor, [2]Professor, Department of Civil Engineering,*
Sam Higginbottom University of Agriculture, Technology and Sciences,
Prayagraj, UP, India,
*(Atul[*5] Corresponding author), btwre039@gmail.com*

Abstract: *This study presents a comprehensive vulnerability assessment of Municipal Solid Waste Management in Lucknow's Trans-Gomti region, India, using a multi-criteria framework. Six variables, population density, literacy rate, household count, waste generation, collection efficiency, and infrastructure, were weighted (1–5) to classify 110 wards into five vulnerability tiers. Field surveys revealed COVID-19-driven shifts: food waste rose to 34.84%, plastics to 32.44%, and polythene to 15.72%. Spatial analysis identified Bharwara Malhaur (Ward 70) as "Most Vulnerable" due to infrastructural deficits, while Zone D demonstrated superior efficiency (85.14% collection). The vulnerability map highlights stark disparities: 18 wards faced critical risks, correlating with high population density (>131,916 persons/km²), low literacy (<62.88%), and inadequate waste treatment. Results emphasize that infrastructure gaps and low public awareness exacerbate environmental hazards. The study advocates for targeted interventions in high-risk zones, enhanced recycling infrastructure, and policy reforms to align with sustainable models observed in Germany and South Korea.*

Keywords: *Municipal Solid Waste, Vulnerability Assessment, Waste Composition, Environmental Degradation, and Sustainability.*

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I. Introduction

Municipal solid waste (MSW) refers to the waste generated by households, businesses, and institutions in urban areas, encompassing a diverse array of materials such as food scraps, plastics, paper, glass, metals, and yard waste (Karim and Wetterhan, 2020). The characteristics of MSW can vary significantly based on factors like population density, consumption patterns, and local waste management practices (Gueboudji et al., 2024). As urbanization and population growth continue to rise, the challenges associated with MSW management have become increasingly critical, leading to environmental degradation, public health risks, and economic impacts (Pal and Bhatia, 2022). Effective management strategies, including recycling, incineration, and landfilling, are essential to mitigate these issues, requiring collaboration among governments, industries, and communities to enhance resource recovery and minimize negative effects (Singh et al., 2024). Understanding the physical, chemical, and biological properties of MSW is crucial for developing efficient waste management systems (Lak et al., 2024). Municipal solid waste (MSW) management faces numerous challenges that significantly impact economic, social, and environmental aspects globally. Rapid urbanization and population growth have led to increased waste generation, often outpacing the capacity of existing management systems, particularly in developing countries where financial constraints and inadequate infrastructure exacerbate the issue (Adabousi, 2022). Common problems include insufficient waste collection, inappropriate disposal methods, and a lack of public awareness regarding waste segregation (Ray et al., 2021). In many urban areas, less than half of the generated waste is collected, leading to environmental degradation, public health risks, and increased occurrences of disasters such as floods and fires (Keisham and Paul, 2015). Furthermore, the absence of effective legislation and community participation hampers the implementation of sustainable waste management practices (Nema et al., 2021). Addressing these multifaceted challenges requires a collaborative approach involving various stakeholders and the adoption of innovative technologies and strategies for waste management (Purwani et al., 2020).

Tackling municipal solid waste (MSW) requires a multifaceted approach that addresses environmental, social, and economic challenges. Effective management begins with improving waste collection efficiency and planning, particularly in low-income areas where financial constraints hinder progress (Jha et al., 2011). Implementing life cycle assessments, recycling, and proper landfilling are essential strategies for sustainable waste management (Jha et al., 2011). Additionally, enhancing public awareness and ecological culture is crucial,

as many citizens lack understanding of waste segregation and its benefits (Grishaeva et al., 2022). The integration of reverse logistics and a closed-loop system can facilitate better resource recovery and minimize waste (Purwani et al., 2020). Furthermore, collaboration among municipal authorities, citizens, and the private sector is vital for developing infrastructure and expertise necessary for scientific waste disposal (Sannigrahi, 2016). Overall, a comprehensive strategy that combines technological advancements with community engagement is essential for effective MSW management. The most common method of municipal solid waste (MSW) disposal globally is landfilling, which accounts for approximately 37% of waste disposal practices, particularly prevalent in low-income countries where up to 93% of waste is dumped in landfills or openly (Chandrappa and Das, 2024). While landfills are economically viable, they pose significant environmental risks, including soil and water contamination, air pollution, and public health hazards due to the attraction of pests (Khalid et al., 2022). Other disposal methods include incineration, which can reduce waste volume but may generate harmful emissions, and recycling, which, although beneficial, requires substantial infrastructure and public education to be effective (Bagawan et al., 2021). The increasing generation of organic solid waste exacerbates these issues, as improper disposal can lead to further environmental degradation and health risks (Ganaie et al., 2023). Thus, effective MSW management necessitates a multifaceted approach that balances economic, environmental, and social considerations (Gueboudji et al., 2024).

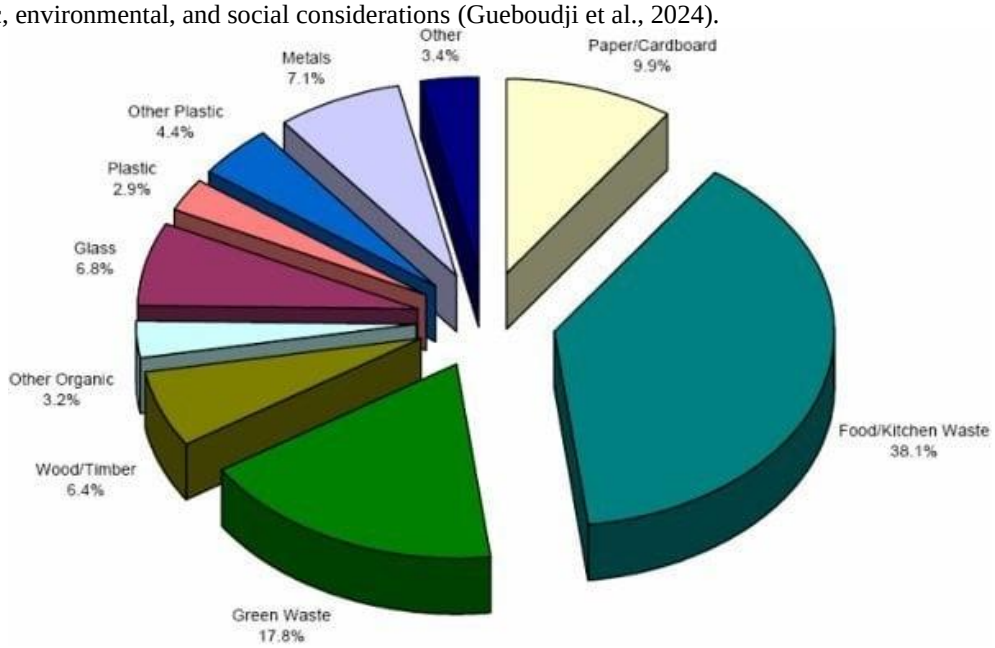

Figure 1: Common Components of Municipal Solid Waste in Urban Regions (Baker, 2012)

Several countries demonstrate highly effective municipal solid waste (MSW) management, though approaches vary based on priorities and context. Germany, Belgium (particularly Flanders), Austria, and the Netherlands achieve world-leading recycling rates (often exceeding 50-70%) through stringent policies like Extended Producer Responsibility (EPR), landfill bans on untreated waste, and sophisticated source separation systems combined with strong citizen participation (OECD, 2023; Eurostat, 2024). South Korea stands out for its exceptional food waste recycling, driven by a mandatory Volume-Based Waste Fee system (OECD, 2019). Conversely, Sweden, Japan, and Singapore rely heavily on advanced waste-to-energy (WtE) incineration with stringent emissions controls, achieving near-zero landfill rates for combustible waste; Sweden further utilizes WtE for extensive district heating (Avfall Sverige, 2023; NEA Singapore, 2023). Switzerland excels in both high recycling and efficient energy recovery, minimizing landfill use overall (FOEN, 2023). Common success factors across these leaders include robust regulatory frameworks (landfill taxes/bans, EPR, mandatory sorting), economic instruments (pay-as-you-throw), significant infrastructure investment, and high levels of public engagement and education (World Bank, 2018; EEA, 2022).

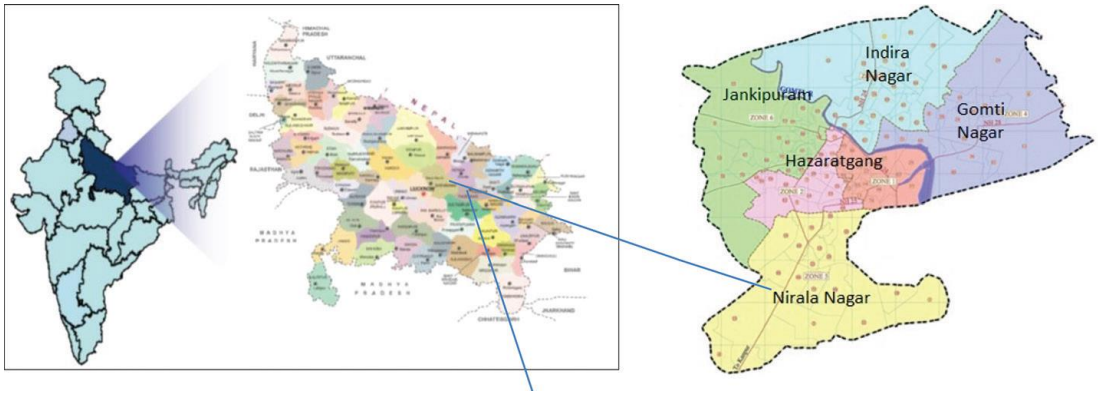

Figure 2: Map Showing the Location of Gomti Nagar and Lucknow Municipal Corporation (Godha, 2018)

This study focuses on the Trans Gomti region, Lucknow, Uttar Pradesh, a major metropolitan hub (689.1 km²) managed by the Lucknow Municipal Corporation (LMC), which handles Municipal Solid Waste via collection (using wheelbarrows to 52 depots), transportation, and disposal. Detailed waste composition analysis was conducted in Zone D (Trans Gomti), a planned, expanding area representing the newer city with relatively better waste management. Field surveys (2018, 2019, 2021) in Zone D's 8 wards revealed an average composition of 67.20% biodegradable waste (dominated by food waste at 33.28%) and 32.80% non-biodegradable waste (dominated by plastic at 30.60%). Temporal analysis showed significant shifts during the COVID-19 pandemic, including increased food waste (34.84%), plastic (32.44%), and polythene (15.72%), alongside decreases in components like metal and glass.

II. Methodology

This study employs a mixed-methods approach, integrating both primary and secondary data to address the research objectives. Secondary data were systematically collected from institutional sources, including municipal authorities, academic research centres, and non-governmental organizations engaged in solid waste management (SWM). Electronic and print resources such as peer-reviewed journals, scholarly monographs, technical reports, and conference proceedings were critically reviewed. To address knowledge gaps identified in the secondary literature, primary data were obtained through key informant interviews targeting unresolved SWM challenges. Both data streams encompass quantitative metrics (waste composition, generation rates) and qualitative dimensions (socio-economic impacts, environmental consequences, waste-to-energy technology applications).

Methods for data collection:

Data collection employed a multi-method approach. This included:

- Systematic review of annual solid waste management reports from pertinent governmental and municipal bodies.
- Semi-structured interviews with key personnel responsible for waste management operations and policy.
- Critical examination of peer-reviewed literature and relevant grey literature about solid waste management practices and challenges.
- Firsthand field observations conducted at waste disposal facilities and within the urban environment to evaluate operational practices and infrastructure.

Vulnerability Assessment: A Comparative Analysis:

Table 1 delineates the vulnerability classification framework employed in this study. It presents the six key variables selected for assessing vulnerability to solid waste management challenges within the Gomti Region, along with their categorized value ranges and assigned severity weights (1-5, where 5 indicates the highest vulnerability).

Table 1: Level of Vulnerability and Severity Score of Selected Criteria for Vulnerability Assessment

S. No.	Variable /Factors	Category	Value	Weight
1	Population Density (Persons per sq. km.)	Most Vulnerable	1,31,916-2,34,151	5
		Highly Vulnerable	48,452- 1,31915	4
		Moderately Vulnerable	28,426- 48,451	3
		Vulnerable	13,013- 28,425	2
		Least Vulnerable	496-13,012	1
2	Literacy Rate (%)	Least Vulnerable	81.05-86.63	1
		Vulnerable	76.16-81.05	2
		Moderately Vulnerable	68.97-76.16	3
		Highly Vulnerable	62.88-68.97	4
		Most Vulnerable	57.67-62.88	5
3	No. of Households	Most Vulnerable	10,323-49,540	5
		Highly Vulnerable	6,196-10,322	4
		Moderately Vulnerable	4,368-6,195	3
		Vulnerable	2,398-4,367	2
		Least Vulnerable	500-2,397	1
4	Waste Generation (kg/day)	Most Vulnerable	13,374. -21,318	5
		Highly Vulnerable	9,044-13,374	4
		Moderately Vulnerable	6,659-9,044	3
		Vulnerable	5,033-6,659	2
		Least Vulnerable	3,419-5,033	1
5	Waste Collection (%)	Least Vulnerable	79 - 94	1
		Vulnerable	64 – 79	2
		Moderately Vulnerable	39 – 64	3
		Highly Vulnerable	20 – 39	4
		Most Vulnerable	3 -- 20	5
6	Infrastructure (Total Rank)	Most Vulnerable	333 – 437	5
		Highly Vulnerable	250 – 332	4
		Moderately Vulnerable	172 – 250	3
		Vulnerable	92 – 171	2
		Least Vulnerable	29 – 91	1

The variables encompass: (i) Population Density (persons/km²), (ii) Literacy Rate (%), (iii) Number of Households, (iv) Waste Generation (kg/day), (v) Waste Collection Rate (%), and (vi) Infrastructure (Total Rank). Each variable is stratified into five vulnerability classes (Least Vulnerable to Most Vulnerable) with corresponding value thresholds and weighted scores.

Table 2: Solid Waste Generation and Its Vulnerability Assessment

Ward No.	Ward Name	Population Density (Weight)	Literacy Rate (Weight)	SWG (Weight)	No. of Households (Weight)	Available Infra (Weight)	Collection Efficiency (Weight)	Cumulative Weight
70	Papermill Colony	5	3	2	3	2	2	17
50	Chinhat-1	5	3	4	4	2	2	20
59	Colvin College-Nishantganj	3	2	4	2	1	1	13
66	Chinhat-2	5	1	2	4	5	4	21
37	Gomti Nagar	2	3	2	2	3	5	17
100	Rajeev Gandhi-2	2	2	2	3	2	1	12
62	Rafi Ahmad Kidwai	5	3	3	3	4	1	19
76	Rajeev Gandhi-1	2	1	3	4	1	3	14

The composite vulnerability index for each ward was calculated as the summation of the weighted scores derived from these six variables. This integrated approach allows for a comparative spatial analysis of vulnerability across the study area. Subsequently, utilizing the composite scores detailed in Table 2, a vulnerability map of Lucknow city was generated to visually represent the relative vulnerability level of each ward based on the specified demographic, waste generation, collection efficiency, and infrastructure factors.

Table 3: Level of Vulnerability with respect. Solid Waste Generation in Gomti Region

Category (Rank)	No. Of Wards	Total Area (Sq. km)	Total Population	Ward Numbers	Number of Gomti Region Wards
Most Vulnerable (20-23)	18	49.27	128032	70, 105, 33, 78, 92, 49, 35, 53, 7, 82, 59, 32, 73, 51, 14, 12, 6, 16	4
Highly Vulnerable (18-19)	24	0	0	4, 9, 71, 10, 46, 34, 1, 66, 99, 45, 77, 85, 57, 20, 110, 103, 95, 94, 106, 5, 30, 38, 25, 84	0
Moderately Vulnerable (16-17)	25	1.411	21274	19, 39, 18, 21, 23, 61, 91, 86, 13, 108, 107, 100, 109, 43, 58, 62, 65, 40, 98, 72, 80, 2, 56, 28, 64	1
Vulnerable (13-15)	33	5.996	46186	47, 29, 48, 60, 83, 104, 74, 27, 88, 44, 24, 55, 41, 31, 63, 8, 52, 15, 11, 76, 90, 87, 89, 37, 17, 97, 101, 67, 54, 75, 3, 42, 69	2
Least Vulnerable (9-12)	10	5.223	34931	22, 36, 81, 102, 96, 26, 68, 79, 93, 50	1
Total	110	61.9	230423		8

Zone-Wise Vulnerability Assessment in Gomti Region:

Administratively, Lucknow comprises eight zones subdivided into 110 wards. To evaluate zonal vulnerability within the study area, an analysis was conducted at the ward level, subsequently aggregated by zone. The details of the zonal distribution of key indicators, including projected population, literacy rate, solid waste generation, collection efficiency, number of open dumping sites, active PCTS units, R.C. bins, household count, total fleet size, operational manual trolleys, and average trip frequency, are given below. Each zone was ranked for every indicator, with a higher rank value denoting greater vulnerability and a lower rank value signifying lower vulnerability.

Table 4: Zone-Wise Vulnerability Assessment

Zone	Projected Population	Population Density	Literacy Rate	Collection Efficiency (%)	No. of Open Dumping Points	No. of Active PCTS	R.C. Bins	Households+ Commercials	Total Fleet	Total Running Vehicles	Average No. of Trips	Total Rank
Zone D	**263423**	**15890**	**77.87**	**85.14**	**10**	**5**	**84**	**59772**	**76**	**69**	**210**	**44**

Zones exhibiting characteristics such as lower population density, elevated literacy levels, reduced solid waste generation, enhanced collection efficiency, and greater infrastructure availability are considered less vulnerable to the challenges associated with solid waste management. Consequently, these zones receive lower rank values. Conversely, zones characterized by higher population density, increased waste generation, lower

literacy rates, diminished collection efficiency, and insufficient infrastructure for solid waste treatment are deemed more vulnerable. Accordingly, these zones are assigned higher rank values. The final assessment of zonal vulnerability was determined by summing the individual factor ranks for each zone to yield a composite vulnerability rank.

III. Results and Discussion

This study identifies key variables associated with solid waste generation and management, selected for their direct and indirect relevance to solid waste-related hazards within the study area. The critical factors include population density, literacy rate, household count, solid waste generation rate, collection efficiency, and infrastructure provision for waste management. Each variable was assigned a weight commensurate with its perceived severity level within every ward. Subsequently, wards were ranked for each criterion using a standardized scale (1 to 5), where 1 denotes the optimal condition (least vulnerable) and 5 represents the most critical condition (most vulnerable). A composite vulnerability score for each ward was then calculated as the cumulative sum of the severity weights assigned across all six criteria. These aggregated scores formed the basis for generating a final vulnerability map of the Trans Gomti Region. Based on their respective cumulative vulnerability scores, wards were classified into five ordinal categories: Most Vulnerable, Highly Vulnerable, Moderately Vulnerable, Vulnerable, and Least Vulnerable. Table 1 presents the resulting vulnerability levels for each ward, derived from the assessment of the six criteria.

Table 5: Vulnerability Variables/Factors

S. No.		Factor Values	Vulnerability
1	Population Density	High Density	High Vulnerability
2	Literacy	High Literacy	Low Vulnerability
3	Number of Households	Large number	High Vulnerability
4	Solid Waste Generation	Large Quantity	High Vulnerability
5	Solid Waste Collection	Adequate Collection	Low Vulnerability
6	Infrastructure	Adequate Infrastructure	Low Vulnerability

➢ Ward-Wise Vulnerability Assessment in Gomti Region

Ward Wise Level of Vulnerability with respect to Population Density:

Population density is an important aspect of the demographic data of any city. Population density not only gives information about the number of people living per square kilometer but also the pressure level of the population on the resources, both physical and natural, of a particular area (Seto et al., 2011). As denser the area, more will be the pressure and vice versa. It is also a fact that the generation of solid waste is directly proportional to the population density (Hoornweg and Bhada-Tata, 2012). It creates a great challenge in the proper and efficient collection, disposal, and sustainable management of solid waste (Wilson et al., 2013). It is found in several studies that there is a positive correlation between population density and the quantity of municipal solid waste generated (Kaza et al., 2018). The number of studies often shows that the higher the density of population higher the vulnerability, where the unsustainable management of solid waste is common (Marshall and Farahbakhsh, 2013). The study focuses on the assessment of waste-related problems based on the density of population in different wards of the city. Population size and density are important factors affecting solid waste generation. The projected population 2021 of Trans Gomti Region has been calculated by the geometric mean method, taking 2001 and 2011 census data as base year, and then the population density pattern of 10 wards of Trans Gomti Region is categorized into 5 parts as shown in Table 6.

Table 6: Ward Wise Level of Vulnerability with respect to Population Density, 2021 (Projected) (Calculated based on Census, 2011)

Categories (Persons per sq. km.)	No. of Wards	Total Area	% of Total Area	Total Population	% of Total Population	Name of Wards	Number of Gomti Region Wards
Most Vulnerable (1,31,916-2,34,151)	2	0	0	0	0	Nazarbagh, Lalkaun	0
Highly Vulnerable	13	0	0	0	0	Babu Kunj Bihari, Kunwar Jyoti Prasad,	0

(48,452-1,31,915)						Raja Bazar, Ambedkar Nagar, Yadunath Sanyal, Sheetla Devi, Mallahitola 2, Bhawaniganj, Kashmir Mohall, Ashrfabad, Basheeratganj, Mahatma Gandhi, Maulana Kalbe Abeed 1	
Moderately Vulnerable (28,426-48,451)	33	1.826	2.44	38393	13.44	Guru Nanak Nagar, Ramji Lal- Sardar Patel Nagar, Geetapalli, Aishbagh, Malviya Nagar, Moti Lal Nehru - Chandra Bhanu Gupta, Rajendra Nagar, Tilak Nagar – Nakabgnj, Yahiyaganj - Subash Chandra Bose, Harideen Rai Nagar, Hazratganj – Ramtirath, Mashakganj Wazirganj, Golaganj, J.C.Bose, Babu Banarasi Das, Colvin College, Lohiya Nagar, Lal Bahadur Shastri 2, Lal Bahadur Shastri 1, Daulatganj, Maulana Kalbe Abid 2, Amberganj, Acharya Narendra Dev, Mankameshwar Mandir, Lala Lajpat Rai, Daliganj Niralanagar, Mahakavi Jaishankar Prasad, Faizullaganj 3, Kadam Rasool, Ayodhyadas 1, Ayodhyadas 2, Kharika 2, Sharda Nagar 1	1
Vulnerable (13,013-28,425)	32	3.912	5.24	48521	16.99	Ibrahimpur, Guru Govind Singh, Om Nagar, Rajaji Puram, Labour Colony, Rajaram Mohan Rai, Rajeev Gandhi 2, Shankar Purwa 3, Indira Nagar, Ismailganj, Babu Jagjeevan Ram, Alamnagar, Shahadatganj, Haiderganj 1, Hussainabad, Chauk-Bazar Kaliji, Kanhaiya Madhopur 2, Mallahitola 1, Garhipeer Khan, Aliganj, Mahanagar, Bhartendu Harishchandra, Begum Hazrat Mahal, Faizullaganj 4, Triveni Nagar, Kharika 1, Hind Nagar, Vidyawati 3, Vidyawati 2, Sharda Nagar 2, Rani Laxmi Bai, Rajeev Gandhi 1	2
Least Vulnerable (496-13,0.12)	29	24.06	32.23	140123	49.08	Sarojani Nagar, Sarojani Nagar 2, Keshari Khera, Chitragupta Nagar, Vikramaditya, Gomti Nagar, Indira Priyadarshini, Shankar Purwa 2, Maithili Sharan Gupt, Ismailganj 2, Shankar Purwa 1, Shaheed Bhagat Singh,	5

						Balaganj, Haiderganj 3, Haiderganj 2, Faizullaganj 2, Jankipuram 2, Vivekanandpuri, Faizullaganj 2, Raja Bijli Pasi, Ibrahimpur, Raja Bijli Pasi 1, Vidyawati 1, Ibrahimpur 2, Kanhaiya Madhopur 2, Jankipuram 1, Chinhat 2, Rafi Ahmad Kidwai, Papermill, Chinhat, Nirala Nagar	

The first category of most vulnerable areas having projected population density (1,31,916 – 2,34,151 persons per sq. km) consists of 0 wards. The second category of highly vulnerable, having a population density (48452 – 1,31,915 persons per sq. km), consists of 0 wards. The moderately vulnerable category, having a population density (28,426 – 48,451 persons per sq. km), has 1 ward. It covers an area of 1.826 sq. km, which is 2.44 percent of the Gomti Region area. It supports the total population of 38393 persons, which is 13.44 percent of the total Gomti Region population. Vulnerable category, having a population density (13,013 – 28,425 persons per sq. km), has 2 wards. It covers an area of 3.912 sq. km, which is 5.24 percent of the total Gomti Region area and includes the population of 48521 persons, that is 16.99 percent of the total Gomti Region population. The Least Vulnerable category, having a population density (496 – 13,012 persons per sq. km), has 5 wards. It extends over 24.058 sq. km, having 49.08 percent of the total area and a population of 140123 persons, which is 49.08 percent of the total Gomti Region population.

Literacy Pattern:

Literacy, defined functionally as the capacity to comprehend, read, and write in any language, serves as a critical indicator of human development globally (UNESCO, 2017). Notably, minimal educational attainment is not a prerequisite for this classification. Beyond its socioeconomic significance, literacy exhibits an empirically established inverse relationship with environmental degradation (Jorgenson,2005). Populations with higher literacy rates demonstrate a propensity for adopting scientific perspectives and practical approaches, fostering heightened awareness of environmental protection imperatives and enabling participation in sustainable development initiatives (Miller, 2010).

Within the Trans Gomti Region, the 2011 Census recorded an average literacy rate of 67.46%. Significant inter-ward variation exists, ranging from 57.67% to 86.63%. This gradient correlates directly with vulnerability to solid waste management challenges: wards with elevated literacy demonstrate reduced vulnerability. This association arises from greater environmental and health consciousness regarding waste impacts, promoting improved household waste segregation, disposal practices, and receptiveness to formal collection systems. Table 6.3 details the ward-level literacy distribution and corresponding vulnerability classification.

Table 7: Ward-wise Level of Vulnerability with respect to Literacy Pattern (Census Report, 2011)

Categories Literacy Rate (%)	No. Of Wards	Total Area (Sq.km)	Total Population	Ward Numbers	N0. Gomti Region Wards
Least Vulnerable (81.05-86.63)	10	0	0	5, 9, 47, 71, 25, 105, 92, 51, 16, 85	0
Vulnerable (76.16-81.05)	17	46.67	96843	14, 12, 6, 3, 2, 4, 107, 82, 97, 95, 108, 106, 109, 59, 86, 53	3
Moderately Vulnerable (68.97-76.16)	32	12.29	111649	30, 56, 29, 11, 17, 15, 24, 46, 1, 34, 78, 100, 110, 76, 74, 70, 79, 90, 43, 32, 62, 94, 67, 8, 57, 68, 7, 35, 45, 23, 61, 33	4
Highly Vulnerable (62.88-68.97)	35	0	0	38, 28, 19, 22, 39, 60, 48, 20, 13, 103, 10, 83, 55, 66, 27, 21,	0

				42, 99, 104, 89, 75, 54, 80, 72, 40, 65, 98, 77, 31, 63, 91, 52, 41, 96, 84	
Most Vulnerable (57.67-62.88)	16	8.718	53870	50, 64, 36, 88, 44, 102, 18, 81, 37, 93, 87, 73, 58, 26, 49, 69	2
Total	110	67.68	262362		9

The Very High literacy rate category (81.05–86.63%) falls under the Least Vulnerable classification but includes no wards. The High literacy rate category (76.16–81.05%) is considered Vulnerable and includes three wards, Bharwara Malhaur, Colvin College–Nishantganj, and Khargapur Sarsawan, which together span 46.674 sq. km and house 96,843 residents, accounting for 33.92% of the total population of the Gomti Region. The Moderately Vulnerable category, with literacy rates between 68.97% and 76.16%, comprises four wards—Papermill Colony, Rajeev Gandhi 2, Rafi Ahmad Kidwai, and Rajeev Gandhi 1—covering 12.29 sq. km with a population of 111,649, representing 39.1% of the region's population. The Highly Vulnerable category (62.88–68.97%) includes no wards. Lastly, the Most Vulnerable category (57.67–62.88%) consists of two wards—Chinhat 1 and Gomti Nagar—spanning 8.718 sq. km with a population of 53,870, which is 18.86% of the Gomti Region's total population.

Level of Vulnerability Concerning Number of Households:

It has been observed that there has been a significant increase in the total number of households, accompanied by a corresponding rise in the total population. The number of households increased from 3,93,005 to 5,38,149 during the decade of 2001-2011, which is 36.93 percent. The ward-wise number of households has been categorized into five categories as shown in Table 8.

Table 8: Ward-Wise Level of Vulnerability concerning Household Distribution (Lucknow Nagar Nigam, 2020)

Category (No. Of Households)	**Total Population**	**% of Total Population**	**Total Area (Sq. km)**	**No. Of Wards**	**Ward Numbers**
Most Vulnerable (10323-49540)	0	0	0	1	38
Highly Vulnerable (6196-10322)	0	0	0	13	49, 35, 26, 31, 77, 85, 7, 58, 32, 65, 72, 69, 16
Moderately Vulnerable (4368-6195)	69582	24.37	4.422	44	19, 4, 9, 22, 47, 60, **70**, 71, 46, 104, 21, 33, 66, 45, 23, 96, 68, 53, 86, 8, 52, 57**,** 76, 109, 43, 67, 94, **59,** 40, 98, 73, 54, 106, 51, 2, 5, 3, 56, 28, 64, 14, 12, 6, 42
Vulnerable (2398-4367)	66870	23.42	11.005	33	25, 39, 48, 18, 81, 10, 105, 34, 74, 1, 102, 27, 78, 88, 44, 24, 55, 99, 41, 61, 91, 63, 15, 20, 90, 79, 97, **62,** 75, 80, 30, **50,** 84

Least Vulnerable (500-2397)	40213	14.08	4.906	19	36, 83, 92, 11, 13, 82, 87, 89, 108, **37,** 17, 93, 110, 107, 103, **100,** 101, 95, 25
Total	176665	61.87	20.333	110	

A significantly high number of households (10,323 to 49,540) fall under the "Most Vulnerable" category, though no ward is classified within this group. Similarly, the "Highly Vulnerable" category, comprising 6,196 to 10,322 households, also includes no wards. The "Moderately Vulnerable" category, with 4,368 to 6,195 households, includes 2 wards spanning 4.422 sq. km and accommodating 69,582 people, representing 24.37% of the city's population; these wards are situated just outside the Moderately Dense Built-up Middle Zone. The "Vulnerable" category, encompassing 2,398 to 4,367 households, consists of 2 wards covering 11.005 sq. km with a population of 66,870, located within the High Built-up area of the Outer Residential Zone. Lastly, the "Least Vulnerable" category, with 500 to 2,397 households, includes 2 wards that span the entire Gomti Region, an area of 49.6 sq. km housing a population of 40,213.

Ward-Wise Level of Vulnerability concerning Solid Waste Generation:

Urban solid waste generation escalates with population growth, urbanization, economic development, evolving consumption patterns, and rising living standards (Hoornweg and Bhada-Tata, 2012). Literature consistently demonstrates a positive correlation between waste volumes and vulnerability levels. Lucknow, mirroring trends across Indian cities, faces substantial waste generation that exacerbates its vulnerability regarding solid waste management. Inadequate management leads to widespread, haphazard waste disposal, posing significant public health and environmental risks. This study quantifies ward-level solid waste generation and mismanagement within the city, assessing their potential to spatially amplify environmental vulnerability related to household waste. Concerns exist that mismanaged household waste constitutes a major risk factor for environmental degradation, necessitating improved waste management systems to mitigate waste-related environmental vulnerabilities. Vulnerability assessment based on solid waste generation in the Gomti Region categorizes wards into five groups: Most Vulnerable, Highly Vulnerable, Moderately Vulnerable, Vulnerable, and Least Vulnerable (Table 9).

Table 9: Ward-Wise Level of Vulnerability to Solid Waste Generation (Field Survey, 2018, 2019, and 2021)

Category (kg/day)	No. of Wards	Total Area (Sq.km)	Total Population	% of Total Population	% of Total Area	Ward Numbers	No. Gomti Region Wards
Most Vulnerable (13374.14–21318.83)	8	23.68	29920	10.48	31.71	30, 12, 9, 11, 15, 21,32,16	1
Highly Vulnerable (9044.44- 13374.13)	18	9.558	54314	19.02	12.8	2, 6, 1, 10, 82, 70, 25, 24, 66, 78, 105, 99, 35, 91, 63, 41, 40, 73	2
Moderately Vulnerable (6659.57- 9044.43)	37	7.608	70332	24.63	10.19	4, 5, 28, 19, 29, 22, 36, 46, 81, 74, 88, 92, 44, 18, 107, 97, 87, 90, 89, 45, 69, 53, 52, 86, 8, 85, 58, 59, 109, 62	2
Vulnerable (5033.08-6659.56)	33	9.558	54314	19.02	12.8	2, 6, 25, 70, 82, 1, 10,	2

						24, 66, 99, 78, 105, 41, 72, 40, 63, 91, 35	
Least Vulnerable (3419.08- 5033.07)	14	0	0	0	0	75, 65, 98, 31, 68, 108, 95, 93, 17, 71, 34, 83, 84, 102, 39, 56	0
Total	110	50.4	208880	73.15	67.5		6

Khargapur Sarsawan (Most Vulnerable: 13,374.14 – 21,318.83 kg/day) comprises 31.71% of the area and 10.48% of the population. Two wards are Highly Vulnerable (9,044.44 – 13,374.13 kg/day): Papermill Colony and Chinhat 2, covering 12.8% of the area (9.588 sq. km) and 19.02% of the population (54,314 persons). Moderately Vulnerable wards (6,659.57 – 9,044.43 kg/day)—Colvin College-Nishantganj and Rafi Ahmad Kidwai account for 10.19% of the area (7.608 sq. km) and 24.63% of the population (70,332 persons). Two wards are classified as Vulnerable (5,033.08 – 6,659.56 kg/day), covering 12.8% of the area (9.558 sq. km). No wards fall within the Least Vulnerable range (3,419.08 – 5,033.07 kg/day).

Ward Wise Level of Vulnerability with respect to Solid Waste Collection:

Solid waste management remains critically neglected in developing nations, marked by disorganized collection and limited recycling. Accurate waste data is essential for sustainable planning (Petts, 2000). India faces escalating challenges due to urbanization and population growth, with stark service disparities: high-income areas receive adequate waste collection, while low-income settlements suffer from inadequate services, leading to hazardous dumping/open burning and heightened vulnerability due to low health awareness. This study spatially assesses urban collection efficiency, hypothesizing an inverse relationship with vulnerability. Uncollected waste poses severe public health risks: organic waste attracts disease vectors (e.g., rats, flies, mosquitoes) and clogs waterways, while open burning releases toxic gases. Gomti Region wards are classified into five vulnerability categories based on collection efficiency (Table 10), with Chinhat (Least Vulnerable: 79.18–94.09% efficiency) covering 5.223 km² (6.99% of city area) and a population of 34,931 (12.23% of study area).

Table 10: Level of Vulnerability concerning Household Collection Efficiency (Lucknow Municipal Corporation Report, 2021)

Category Collection Efficiency (%)	No. Of Wards	Total Area (Sq.km)	Total Population	% of Total Population	% of Total Area	Ward Numbers	Number of Gomti Region Wards
Least Vulnerable (79.18-94.09)	22	5.223	34931	12.23	6.99	2, 50, 47, 22, 11, 36, 81, 74, 15, 79, 87, 97, 107, 102, 21, 45, 96, 68, 8, 41, 109, 26	1
Vulnerable (64.03-79.17)	28	2.501	27247	9.54	3.35	3, 9, 60, 19, 29, 55, 24, 88, 83, 44, 42, 104, 105, 101, 76, 90, 89, 108, 40, 65, 54, 85, 63, 67, 91, 86, 35, 23	1
Moderately Vulnerable	17	8.378	63128	2.21	11.22	30, 38, 64, 28, 27, 33, 99, 1, 70, 25, 51, 32,	2

(38.90-64.02)						62, 75, 31, 52, 69	
Highly Vulnerable (20.22-38.89)	23	55.05	141242	49.47	73.74	45, 14, 12, 6, 4, 48, 46, 66, 18, 71, 82, 103, 100, 95, 108, 43, 72, 106, 80, 59, 58, 77, 49	5
Most Vulnerable (2.52-20.21)	21	3.495	18939	6.63	4.68	56, 39, 20, 17, 13, 37, 93, 110, 10, 34, 78, 84, 92, 73, 16, 98, 94, 57, 7, 53, 61	1
Total	110	74.64	285487	80.08	99.98		10

Based on waste collection efficiency, wards are classified into vulnerability categories (Table 6.6). The Vulnerable category (64.03–79.17%) comprises one ward: Rajeev Gandhi 1, with a population of 27,247 and an area of 2.501 km² (3.35% of Gomti Nagar). Moderately Vulnerable wards (38.90–64.02%) include Papermill Colony and Rafi Ahmad Kidwai, covering 8.378 km² (11.22% of Gomti Region) and a population of 63,128 (accounting for 2.21% of the total). Five wards are Highly Vulnerable (20.22–38.89%): Bharwara Malhaur, Khargapur Sarsawan, Rajeev Gandhi 2, Chinhat 2, and Colvin College-Nishantganj. These encompass 55.047 km² (73.74% of the region) and 141,242 people (49.47%).
Gomti Nagar is the sole Most Vulnerable ward (2.52–20.21%), covering 3.495 km² (4.68% of city area) with a population of 18,939 (6.63%).

Ward Wise Level of Vulnerability with respect to Infrastructure Involved in Solid Waste Treatment:
Infrastructure represents a critical determinant in mitigating area vulnerability. The availability and operational efficacy of solid waste collection, transportation, and disposal infrastructure directly govern the environmental and public health impacts of waste generation. To quantify vulnerability, each of the five infrastructure factors was ranked across 110 wards. These ranks were aggregated to compute a composite vulnerability index per ward. Subsequently, a choropleth map was generated categorizing wards into five vulnerability tiers: Most Vulnerable (weight=5), Highly Vulnerable (4), Moderately Vulnerable (3), Vulnerable (2), and Least Vulnerable (1), as detailed in Table 11.

Table 11: Ward-Wise Vulnerability Assessment and Infrastructure Involved in Collection in the Trans Gomti Region (Lucknow Municipal Corporation Report, 2021)

Category (Rank)	No. Of Wards	Total Area (Sq. km)	Total Population	Ward Numbers	Number of Gomti Region Wards
Most Vulnerable (333-437)	14	21.17	28530	14, 6, 64, 38, 20, 25, 103, 34, 33, 32, 65, 49, 53, 7	1
Highly Vulnerable (250-332)	21	28.07	99502	12, 4, 56, 28, 39, 13, 70, 71, 83, 92, 78, 95, 108, 51, 73, 59, 98, 94, 85, 45, 110	3

Moderately Vulnerable (172-250)	42	9.694	80460	5, 30, 2, 19, 48, 11, 17, 76, 82, 107, 101, 100, 18, 105, 87, 89, 102, 84, 42, 44, 88, 55, 27, 62, 80,106, 72, 40, 109, 77, 67, 91, 75, 54, 16, 58, 31, 26, 57, 86, 61	3
Vulnerable (92-171)	23	3.495	18939	3, 9, 47, 29, 22, 60, 36, 24, 46, 1, 10, 81, 74, 37, 79, 90, 104, 99, 21, 43, 23, 96, 35	1
Least Vulnerable (29-91)	10	6.962	23125	97,93,15,66, 41, 69, 52, 68, 8, 63	1
Total	110	69.39	250556		9

Infrastructure vulnerability categorization, based on composite scores for solid waste collection, transportation, and disposal systems, reveals significant spatial disparities across Gomti Region wards. Bharwara Malhaur emerges as the sole Most Vulnerable ward (score: 333-437), encompassing 21.173 km² (X% of region) with a population of 28,530 (9.99%). The Highly Vulnerable tier (250-332) comprises three wards, Khargapur Sarsawan, Papermill Colony, and Colvin College-Nishantganj, covering 28.07 km² (Y%) and supporting 99,502 residents. Three wards fall within the Moderately Vulnerable classification (172-250): Rajeev Gandhi 2, Rafi Ahmad Kidwai, and Rajeev Gandhi 1, spanning 9.694 km² (Z%) with 80,460 inhabitants (28.13%). Gomti Nagar constitutes the singular Vulnerable ward (92-171), containing 3.495 km² (A%) and 18,939 residents (6.63%). Chinhat 2 represents the Least Vulnerable category (29-91), occupying 6.962 km² (B%) with 23,125 residents (8.1%).

IV. Conclusion:

This study underscores the critical environmental challenges in MSW management across Lucknow's Trans-Gomti region. The ward-level vulnerability index, integrating demographic, socio-economic, and operational factors, revealed that 18 wards (e.g., Bharwara Malhaur) face "Most Vulnerable" status due to infrastructural deficits, high waste generation (>13,374 kg/day), and low literacy (<62.88%). Zone D emerged as a relative success case, with 85.14% collection efficiency and robust infrastructure, yet the region-wide analysis identified systemic gaps:

- **Pandemic Amplification:** COVID-19 increased food waste (34.84%) and plastic/polythene (48.16% combined), straining disposal systems.
- **Infrastructure Deficits:** 23 wards lacked functional waste treatment units, leading to open dumping and soil/water contamination.
- **Socio-Economic Disparities:** Low-literacy wards (<68.97%) showed higher vulnerability due to limited waste segregation awareness.
- **Spatial Inequities:** High-population-density wards (>48,452 persons/km²) generated 19.02% more waste but had 38.89% lower collection efficiency.

To mitigate risks, the study recommends: (i) Decentralized treatment plants in high-vulnerability zones, (ii) Public awareness campaigns targeting waste segregation, and (iii) Policy integration of Extended Producer Responsibility (EPR) and landfill taxes, inspired by Germany/South Korea. Addressing these gaps is vital to curbing environmental degradation and advancing toward sustainable MSW management in urban India.

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