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Pandemic-Induced Changes in Urban Consumption, Waste Generation, and Environmental Sustainability: A Case Study of Gwalior

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Abstract
The COVID-19 pandemic had a significant impact on the urban consumption patterns, waste generation dynamics, and environmental sustainability problems in cities around the world. This study aims to analyse the changes in the consumption pattern, biomedical waste generation, and environmental sustainability in the Gwalior district of Madhya Pradesh, India, due to the pandemic situation. A mixed geospatial and secondary data technique was used to access data from Google COVID-19 Community Mobility Reports, Government waste management reports, healthcare facility records, and spatial data in a Geographic Information System (GIS) environment. Spatial analysis to assess the spatial distribution and intensity of pandemic-related environmental pressures was carried out, including mapping of healthcare facilities, Kernel Density Estimation (KDE), identification of hotspots, environmental sustainability risk analysis, and priority zoning for waste management.

The results reveal significant changes in consumption habits in the cities both during and after the pandemic, along with the generation of increased healthcare-related waste and biomedical waste. Spatial analysis showed that the spatial distribution of waste generators and environmental risk were not uniform throughout the district, with the highest concentrations of waste and environmental risk being located in the north-central urban corridor where there were the greatest numbers of healthcare facilities and populations. Environmental sustainability risk mapping identified localized high- and very high-risk zones, where targeted interventions are needed. These results were used to create priority management zones for effective distribution of waste management resources and environmental monitoring. The study puts emphasis on the role of geospatial technologies in urban environmental planning and illustrates how the disruption of the pandemic can have a long-term impact on sustainability outcomes. The results offer important policy and managerial indications to improve waste management structures and strengthen urban resilience processes in the post-pandemic scenario.

Keywords: COVID-19 Pandemic; Urban Consumption; Biomedical Waste; Environmental Sustainability; GIS; Kernel Density Estimation; Waste Management; Hotspot Analysis; Gwalior; Urban Resilience.

1. Introduction

The global urban living environment, consumption behaviour, and environmental quality underwent tremendous changes under the impact of the COVID-19 pandemic. Due to lockdowns, restrictions on movement, and alterations in consumer needs and purchasing choices, people increased consumption of essential commodities, shopping online, and also demanded medicines and PPE, and so on. The reduction of transportation and industry for a short time led to an improvement in the urban environment. However, increased consumption of disposable packaging also made for a rise in urban waste problems, waste disposal challenges, and thus environmental and social problems (Rume and Islam, 2020; Bell et al., 2023).

During the pandemic, in general, people's consumption changed from luxurious goods or services to essential daily necessities, medicine, medical devices, medical masks, online foods, take-out foods, and bottled drinks. A considerable quantity of solid municipal, biomedical, and plastic wastes, including discarded masks, gloves, and other PPE, is expected to increase further. These generated wastes, if not disposed of properly, can cause new environment pollutions, health risks, and pose enormous challenges to the existing waste management systems in cities (Haque et al., 2021; Mahmoudnia et al., 2022; Yousefi et al., 2021; Chen et al., 2022; Ganesapillai et al., 2023).

In India, the consumption patterns of individuals as well as the quantity of generation of solid waste were affected during the pandemic, particularly in the urban regions due to dense population and medical care-related operations (Roy and Chaube, 2021; Tripathi et al., 2024). To implement and propose planning policies for sustainability and for managing waste generated by waste management activities, understanding the distribution of waste generated in spatial dimensions as well as environmental risk associated due to this distribution is important and useful with effective tools, such as the use of Geographic Information System (GIS), for the analysis and estimation of waste hot-spots and vulnerability assessment for evidence-based policy design (Ray et al., 2024; Banal and Abad, 2025). In this light, the paper analyzes spatial patterns of waste generation and environmental sustainability risk in the major urban center of Madhya Pradesh, India, the city of Gwalior, with changes observed during the period of pandemic due to the novel Covid 19 coronavirus pandemic, focusing on changes due to alterations in mobility, medical service delivery, and waste generation.

1.1 Research Objectives

i. To examine pandemic-induced changes in urban consumption patterns using mobility indicators and urban activity characteristics.
ii. To analyze the spatial distribution and concentration of pandemic-related waste generation in Gwalior using GIS techniques.
iii. To assess environmental sustainability risks associated with waste generation and identify priority zones for sustainable waste management.

1.2 Research Questions

RQ1: How did the COVID-19 pandemic alter urban consumption patterns in Gwalior?
RQ2: What are the spatial patterns and hotspots of pandemic-induced waste generation in Gwalior?
RQ3: How have waste generation patterns influenced environmental sustainability risks and priority intervention areas in Gwalior?

2. Literature Review

2.1 COVID-19 and Urban Consumption

Urban consumption patterns changed a lot during the COVID-19 pandemic, as a result of lockdowns, social distancing, and restrictions on mobility. The onset of the pandemic saw consumers spending more on online shopping, home delivery, healthcare products and essential goods, and less on recreation, travel and non-essentials. These behavioral shifts had impacts on the economic activities in cities as well as on the demand for goods and services (Kumar & Abdin, 2021; Kol et al., 2023). Urban mobility challenges and shifts in consumption patterns also impacted the spatial structure of urban consumption. Research indicates that higher reliance on packaged products, e-commerce, and health products led to more materials and reliance on disposable products. The effect of such changes on urban sustainability and resource management has been long-term, both in developed and developing countries (Hammad et al., 2023; Pacheco et al., 2024).

2.2 Pandemic-Induced Waste Generation

Due to the pandemic, urban municipal solid waste (MSW) and biomedical waste (BMDW) increased significantly throughout the world. The pandemic caused a significant rise in MSW and biomedical waste (BMDW) in urban areas globally. Healthcare-related waste was unprecedented given the extent to which masks, gloves, sanitizers, testing kits, and equipment are being used. The rising demand for household consumption and food delivery services, however, led to an increase in the amount of packaging and plastic waste (Haque et al., 2021; Sharma et al., 2020). Some studies have indicated that the operation of the waste management system was a big challenge during the pandemic period, such as the collection, segregation, transportation, and disposal of infectious waste. The surge in PPE and plastic waste led to worries about environmental pollution and the ability of local government bodies to process the rising amounts of waste efficiently (Yousefi et al., 2021; Olawade et al., 2024; Jakimiuk et al., 2025).

2.3 Environmental Sustainability Implications

It has been both positive and negative impacts on the environment due to COVID. In many areas, air quality and greenhouse gas emissions improved because of temporary decreases in industrial activity and in traffic. But all of this often resulted in a rise in medical waste, single-use plastics, and household waste created in the pandemic (Rupani et al., 2020; Loh et al., 2022). The disposal of PPE, biomedical waste, and plastic products can be harmful to terrestrial and aquatic ecosystems if not done properly. Research has identified the possible effects of waste generated by the pandemic on the quality of soil, water, biodiversity, and public health. Therefore, sustainable waste management is crucial to curb environmental degradation and strengthen the city's resilience in dealing with future crises (Chen et al., 2022; Behera et al., 2024; Bell et al., 2023).

2.4 GIS Applications in Waste Management and Sustainability Assessment

Geographic Information Systems (GIS) have been valuable tools to examine the spatial distribution of waste generation and environmental risk. GIS-based methods, like hotspot analysis, kernel density estimation, proximity analysis, and weighted overlay modelling, aid in the identification of vulnerable areas that could accumulate waste and cause environmental contamination. These strategies are helpful for evidence-based planning and decision-making regarding urban waste management (Banal & Abad, 2025; Ray et al., 2024).

In recent years, GIS has been used extensively in studies to monitor waste generation from pandemics and to evaluate environmental sustainability. Spatial analysis helps to incorporate all the demographic, infrastructural, and environmental factors into priority areas for interventions and waste management strategies. These approaches are especially useful in fast-urbanizing cities, where environmental challenges and waste production are not evenly distributed across the city (Islam et al., 2024; Mahadevia et al., 2025).

2.5 Research Gap

Previous research has widely investigated the effects of COVID-19 on consumption behavior, waste generation, and environmental sustainability. Most investigations are concerned with national or global assessments; however, little attention has been paid to spatial analysis at the city level that combines these dimensions in one. Moreover, the research on medium-sized cities of India is still limited in quantity and far behind the environmental challenges faced by them. Lacking in particular are GIS-based studies that link the changes in urban consumption caused by the pandemic with waste generation hotspots and environmental sustainability risks. To fill this gap, the present study uses GIS techniques to analyze the spatial distribution of waste generation due to the pandemic and associated environmental sustainability risks in Gwalior, which contributes to sustainable urban planning and waste management strategies.

3. Study Area

3.1 Geographic Setting

Gwalior is an important urban center in the north part of Madhya Pradesh, India. From a geographical point of view, the city is situated between 26°10′ – 26°16′ N latitude and 78°10′ – 78°18′ E longitude and is a significant administrative, commercial, and educational center of the region. The climate in the city is semi-arid, with hot summers, moderate monsoon rains, and mild winters. The high location value and constant urban growth have shaped a high population density and pressure on urban infrastructure and environmental resources.

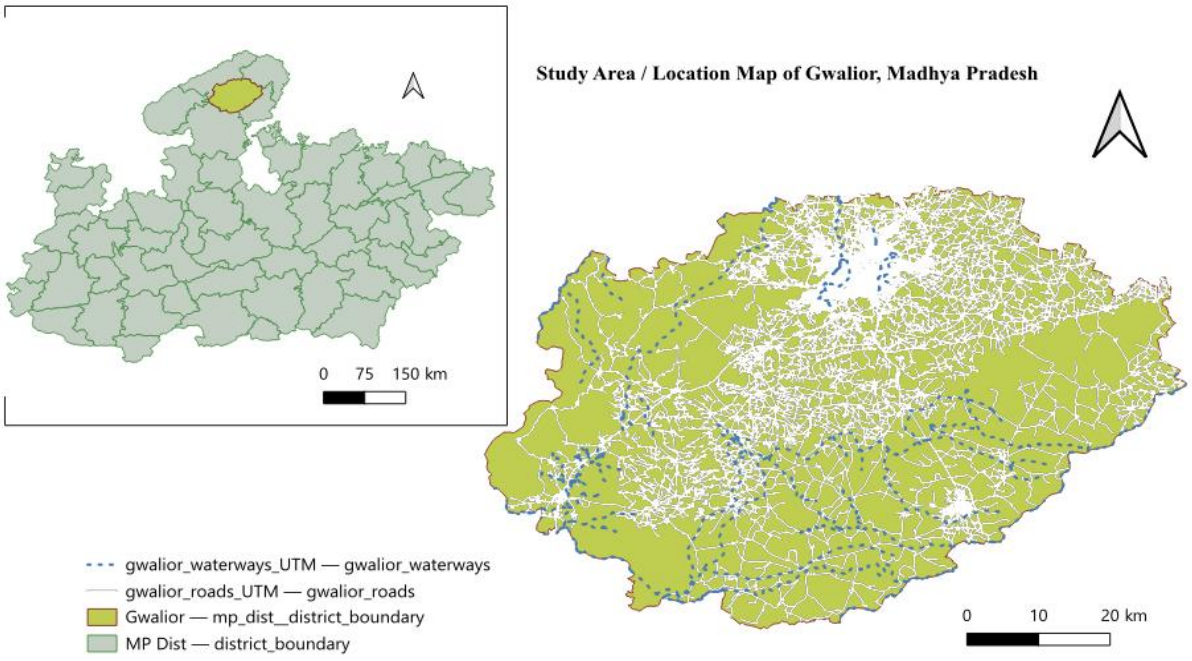

Figure 1: Study Area Map of Gwalior, Madhya Pradesh

The study area includes the city limits of Gwalior and the adjoining urbanized area. The city has a wide network of roads and various healthcare institutions, commercial buildings, residential neighborhoods, and public service utilities, which all contribute to patterns of waste production and the environment.

3.2 Demographic and Urban Characteristics

Population growth and urbanization have been steady in Gwalior in the last 20 years. The growth of residential developments, commercial areas, and health care centers has placed a growing demand on municipal services, such as waste collection and disposal. The high intensity of waste production and environmental management problems is found in the central urban areas due to population concentration.

The city is a regional health center, having several hospitals, clinics, diagnostic laboratories, medical institutions, etc. During the COVID-19 pandemic, there was a significant rise in health care-related waste, with corresponding rises in biomedical waste and municipal waste generation. The health care facility density and high-density residential settlements make Gwalior an ideal scenario to assess the environmental impacts of the pandemic.

3.3 Waste Management and Environmental Context

The main systems involved in the management of municipal solid waste in Gwalior are the collection, transport, and disposal systems of the local government. But the pandemic waste has added an extra burden to the already stretched waste management system due to the high volume of waste generated and the high rate of urbanization and consumption. During the COVID-19 period, the increased amount of healthcare waste, PPE disposal, and household waste has heightened concerns about environmental sustainability and public health. In the city, environmental vulnerability can be related to various aspects such as population density, transportation infrastructure, closeness to water, and spatial distribution of health services. These influences can impact the build-up of waste and possible environmental hazards. Thus, it is critical to conduct a GIS-based evaluation of waste generation hotspots and sustainability risk zones to pinpoint key areas where effective waste management interventions must be implemented, and sustainable urban planning is needed.

4. Materials and Methods

4.1 Research Design

The present work employs GIS-based spatial analysis for studying the impact of pandemic-derived changes in urban consumption behaviour, waste generation, and environmental sustainability in Gwalior City. Secondary data sources, mobility indicators, and geospatial data have been used to assess the spatial distribution patterns of waste and environmental risk factors in the study area. Geographic Information System (GIS) has been used for analyzing waste hotspots, vulnerability risk assessment of environmental risk factors, and delineating the area of concern for sustainable waste management.

4.2 Data Sources

In this study, spatial and non-spatial data were utilized, sourced from both governmental reports and available public online data along with published work. The following datasets were obtained: Administrative divisions (state, district and locality, and sub-locality), population of the study site (village and by type: male, female and children), health infrastructure points, road networks, natural streams and rivers network, administrative layer in shapefile of each biomedical waste generating area. Non-spatial

data sources include Google Community Mobility reports and literature survey data, including reported values for COVID-19-based waste generation and environmentally sustainable waste management strategies.

Table 1. Data Sources and Purpose

Dataset	Source	Purpose
Gwalior Boundary	Administrative GIS Data	Study area delineation
Population Raster (2020)	WorldPop/Census Data	Population risk assessment
Healthcare Facilities	GIS Database	Waste generation source identification
Road Network	Open GIS Data	Accessibility analysis
Waterways	GIS Database	Environmental vulnerability assessment
BMW Points	GIS Database	Hotspot analysis
Mobility Indicators	Google Mobility Report	Assessment of consumption changes
Literature and Reports	Published Sources	Interpretation and validation

4.3 GIS Database Preparation

The shapefiles were then standardized into the Gwalior municipal boundary by applying the same coordinate reference system and clipping. Data tables were standardized accordingly. The raster and vector layers were organized in QGIS and finalized for spatial modelling and risk modelling purposes.

4.4 Assessment of Urban Consumption Changes

Mobility Data: The Google Community Mobility Report data were utilized as mobility indicators of the urban consumption behavior changes caused by the pandemic. Specifically, those related to retail and recreation, grocery and pharmacy, workplaces, public transportation, and residential movement were employed to reflect urban consumption behavior changes during the pandemic and as supplementary evidence to evaluate resource consumption and waste generation during the pandemic period.

Table 2. Mobility Indicators Used for Assessing Urban Consumption

Indicator	Interpretation
Retail and Recreation	Consumer and shopping activity
Grocery and Pharmacy	Essential goods consumption
Public Transport	Urban mobility intensity
Workplaces	Economic activity level
Residential	Household-based consumption

4.5 Kernel Density Estimation (KDE)

Kernel Density Estimation (KDE) was utilized in identifying hotspots of waste generation caused by the pandemic. The biomedical waste was designated as input points that will serve as a foundation for a continuous density surface showing spatial variation in relative intensities of the generation. The hotspots provided insights on regions where extra monitoring and waste collection effort could be required.

4.6 Environmental Sustainability Risk Assessment

In this study, risks to environmental sustainability were evaluated by coupling together several spatial indicators - from land use and human presence, health facilities distribution, accessibility to roadways,

exposure to rivers, to waste-generating areas. Each index was re-coded into standardized risk categories from low to very high risk.

Table 3. Environmental Risk Assessment Criteria

Indicator	Risk Relevance
Population Density	Potential waste generation pressure
Healthcare Facilities	Biomedical waste generation
Road Accessibility	Waste transportation and accumulation
Waterway Proximity	Risk of environmental contamination
Waste Hotspots	Concentrated waste generation zones

4.7 Weighted Overlay Analysis

The study employed a weighted overlay technique to combine our identified indicators of environmental risk to create an Environmental Sustainability Risk Index. The weights were derived from an assessment of the relative importance of the identified environmental indicators to environmental vulnerability and waste generation. The classified output of the risk surface identified risk as Low, Moderate, High, and Very High. This output was then used to produce a series of prioritized areas or zones for sustainable waste management and environmental development within the city.

5. Results and Discussion

5.1 Pandemic-Induced Changes in Urban Consumption

The COVID-19 pandemic had a major impact on urban consumption patterns, affecting mobility behavior, the choice of purchases, and economic activities. Improved mobility, temporary closures of essential services, and heightened dependency on essential services altered the modes of urban residents' access to goods and services. Mobility indicators can offer valuable insights into these behavioral changes and what these mean for resource usage and waste.

An examination of mobility trends suggests significant shifts in mobility patterns for a variety of activity types. Greater mobility is seen in groceries and pharmacies, as well as a rise in demand for essential supplies and sanitation products. Likewise, the expansion of workplaces, retail, and public transport is indicative of the gradual return of urban economic functions during the recovery phase. Meanwhile, higher rates of residential mobility are associated with higher levels of household-based consumption and reliance on home delivery services, which led to higher levels of packaging waste generation and household waste. The results are similar to those of previous studies, suggesting that during the pandemic, the level of essential consumption increased, along with purchasing via the internet and increased consumption of disposable materials (Kumar & Abdin, 2021; Kol et al., 2023; Hammad et al., 2023).

Table 4. Pandemic-Induced Changes in Urban Consumption Indicators

Mobility Indicator	**Change from Baseline (%)**	**Consumption Interpretation**	**Environmental Implication**
Retail and Recreation	+22	Recovery of shopping and consumer activities	Increased packaging and commercial waste

Grocery and Pharmacy	+69	Increased purchase of essential and healthcare products	Higher plastic and household waste generation
Parks	+86	Increased use of public spaces during recovery	Growth in public waste generation
Public Transport	+39	Increased urban mobility and service access	Increased PPE and disposable waste
Workplaces	+50	Resumption of economic activities	Higher commercial waste production
Residential	+14	Continued home-based consumption	Increased household and packaging waste

Source: Compiled from Google Community Mobility Report (Madhya Pradesh, 2022)

Pandemic-driven shifts in purchasing and consuming habits observed also show trends towards increased usage of products related to healthcare, packaged products, and at-home services, which have been directly related to the increases in MSW and plastics production in various cities of the developing regions (Haque et al., 2021; Mahmoudnia et al., 2022). Moreover, increased usage of masks, gloves, sanitizers, and other PPE materials has resulted in increasing biomedical wastes and PPE wastes, thus further imposing on the waste management system to a great extent (Chen et al., 2022; Tripathi et al., 2024).

Therefore, it can be concluded from the results that pandemic-induced changes in the consumption practices have had short-term effects on individual behaviors but also had noticeable and unnoticeable environmental consequences on consumption. Also, the upward trend of disposable and packaged product usage was a prominent source of waste production in Gwalior city. Therefore, more stress should be placed on sustainable consumption habits and waste management systems in Gwalior city.

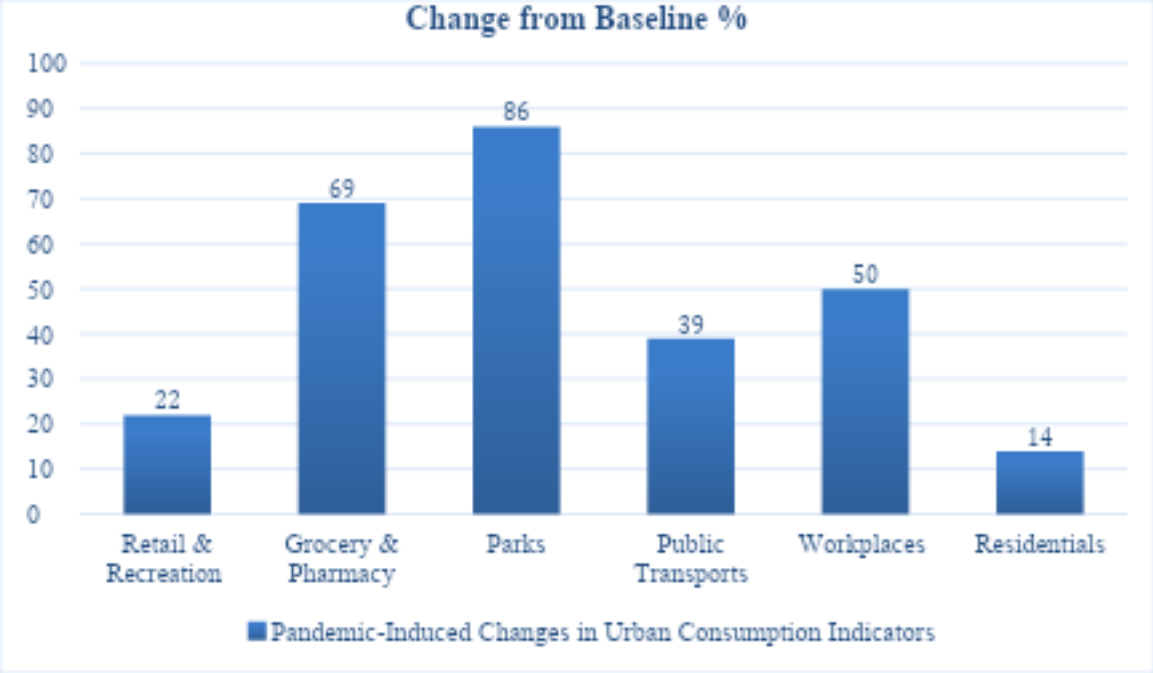

Figure 2: Pandemic-Induced Changes in Urban Consumption Indicators

Source: Compiled from Google Community Mobility Report (Madhya Pradesh, 2022)

5.2 Spatial Distribution of Pandemic-Related Waste Generation

Spatial patterns of COVID-19-related Biomedical waste generation in Gwalior: Spatial patterns. Biomedical waste is hazardous in nature; disposal methods are essential for sustainable environmental management. The geographical spread of healthcare services and biomedical waste-generating institutions contributes significant information about pandemic-associated waste. COVID testing centers, hospitals treating the pandemic, centers where vaccines were administered to patients, and other related medical facilities and patients were treated were prime sources of this waste; thus, a large amount of such waste, including masks, test kits, and other bio-medical equipment's including masks, was generated during COVID-19 in Gwalior, which is distributed primarily around urbanized areas.

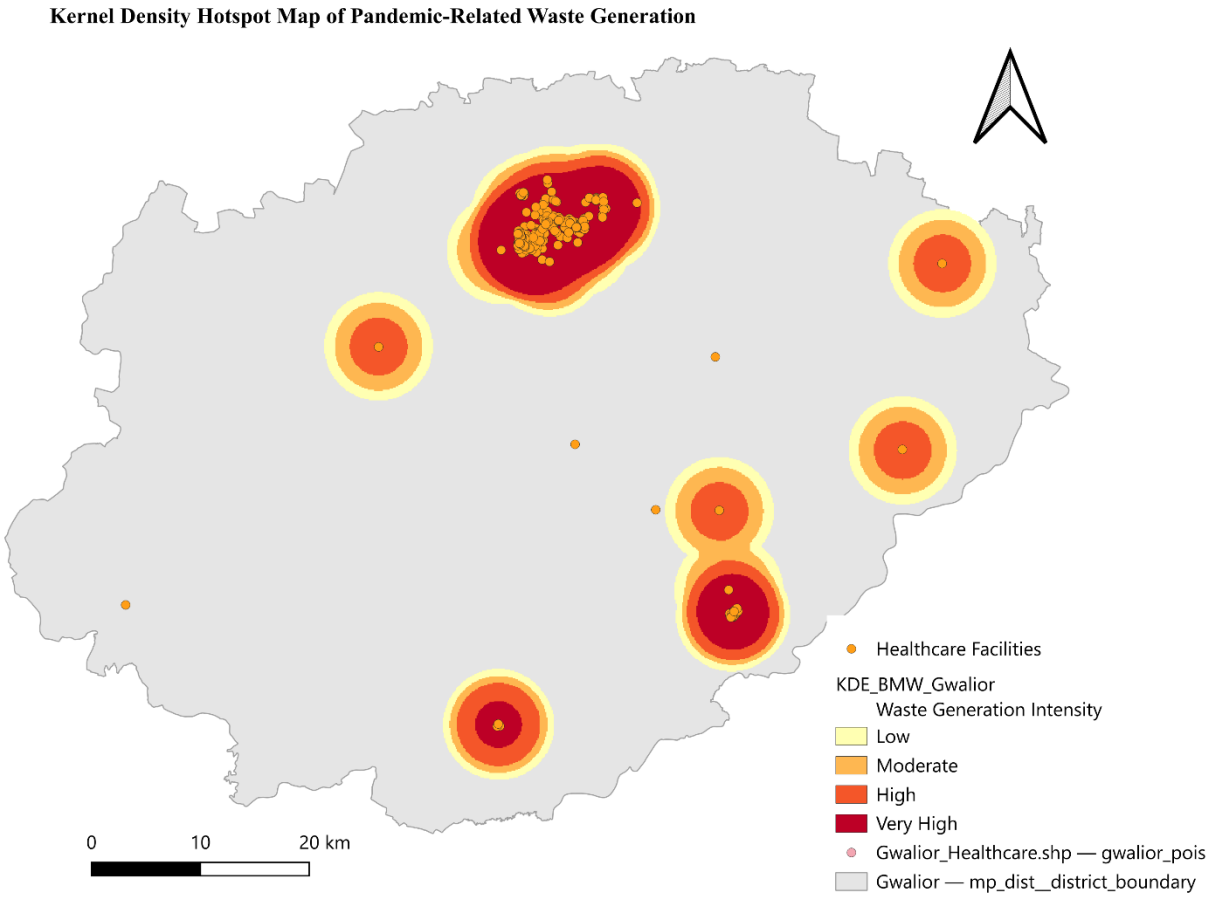

Figure 3: Kernel Density Hotspot Map of Pandemic-Related Waste Generation

Healthcare facilities were used as proxies to estimate the origin points of pandemic-induced biomedical waste in Gwalior city. The Kernel Density Estimation (KDE) method converts the distinct spatial attributes of healthcare facilities into a density surface that depicts spatial patterns of healthcare facility-based waste production concentration. In order to obtain an idea of where the bulk of the pandemic-induced waste management issues would likely reside, regions of high concentrations of pandemic-induced waste were computed. Similar works show increases in pandemic-induced medical equipment waste and PPE's generated during the COVID-19 period, particularly in urban areas with numerous health facilities (Sharma et al., 2020; Jakimiuk et al., 2025).

The KDE hotspot map shows an uneven spatial distribution of the waste generation intensity throughout Gwalior city, the largest and most prominent hotspot occurring in the north-central urban region, associated with clustered major health centers with a very high degree of potential waste generation intensity. Second-highest intensity centers are occurring in the eastern, southern, and western parts of the city district, associated with clusters of local health and service centers, while low-level intensity is appearing at the periphery and remote and underdeveloped zones (Figure 1). Pandemic-associated waste generation intensity was the highest in and around primary and high-order centers, and the need for a proper waste segregation and disposal strategy at the local level may be considered. (Parashar et al., 2022; Urban & Nakada, 2021)

Table 5. Waste Generation Hotspot Classification

Hotspot Class	Relative Intensity	Spatial Characteristics
Low	Minimal waste concentration	Peripheral and sparsely populated areas
Moderate	Moderate waste concentration	Residential and mixed-use zones
High	Significant waste concentration	Urban centers and healthcare clusters
Very High	Maximum waste concentration	Major healthcare and densely populated areas

The observed hotspot pattern indicates that healthcare infrastructure and population density were significant factors in the generation of pandemic-related waste. An increase in the use of health care products and single-use protective equipment was a significant source of waste in these areas. These results are echoed in other parts of the world, where it was found that healthcare facilities were one of the largest sources of waste in the pandemic (Haque et al., 2021; Yousefi et al., 2021).

Waste generation shows a strong spatial concentration, indicating that targeted waste management strategies are important. Enhanced waste collection and segregation, waste transportation, and treatment are needed to minimize environmental risks and public health risks in areas identified as high and very high hotspots. Moreover, hotspot mapping can be used as an effective spatial decision-support system for city managers who want to maximize waste management efficiency and enhance environmental sustainability in the context of the high rate of urbanization in cities.

5.3 Environmental Sustainability Risk Assessment

The environmental sustainability concerns on pandemic waste generation were approached using a combined approach with various spatial indicators such as population density, number of healthcare institutions per area, proximity to road networks, presence of waterways, and location of waste hotspots, which were considered in this approach due to their impacts on the rate of waste accumulation, environmental impact, and public health concerns. A composite Environmental Sustainability Risk Index was calculated from weighted overlay analysis of the above factors to predict the sensitive areas that need attention for immediate action.

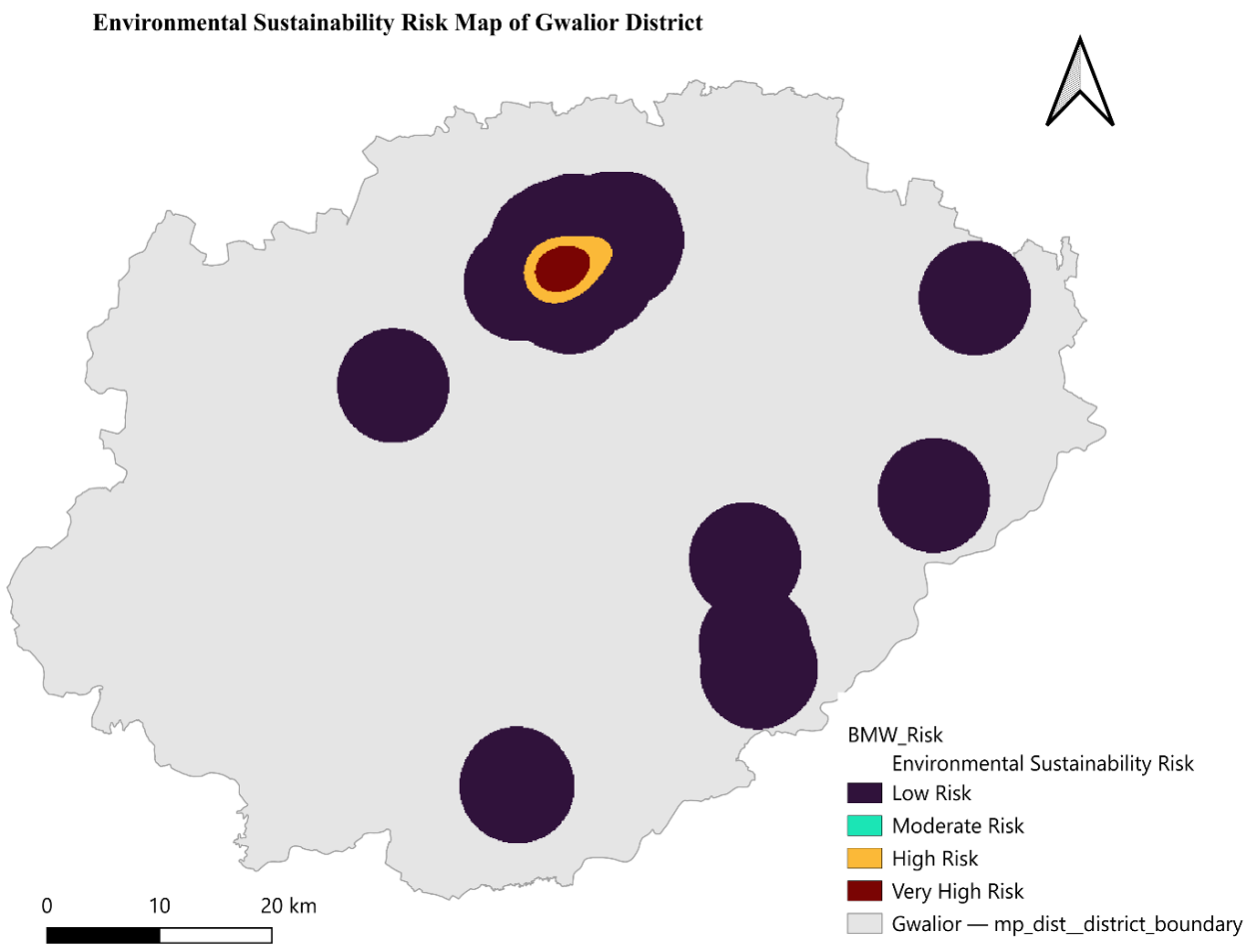

Figure 4: Environmental Sustainability Risk Map of Gwalior

Figure 4 depicts the environmental sustainability risk zones that result from biomedical waste generation intensity for Gwalior district. The very high environmental risk zone, where the biomedical waste generation intensity can be found in the north – northwestern urban part of the study region, where most of the healthcare units & biomedical sources are highly concentrated. The highly environmentally stressed zones are found in the south–south–eastern part along the secondary level of healthcare, whereas low- to moderately environmentally risky zones are found on outer / least urbanized peripheries of the study area. The spatial analysis shows that environment-stressed zones are not evenly spread out, and urban healthcare clusters are the most susceptible places of environment load caused by biomedical activities.

This risk map reveals a heterogeneous spatial distribution of environmental vulnerability in Gwalior. High and very high risk areas are mostly located in urban areas with high population density, where there is high healthcare activity and high waste generation intensity. These also show good links with the main transport routes that allow waste to be transported and stored. Conversely, the peripheral areas of the site tend to be low risk as there are fewer zones of waste production and a low population density.

This spatial correlation between population density and waste production shows that high-density regions have higher environmental impact as a result of higher consumption, waste production, and excessive use of resources. The urban population density was also found to be one of the key factors influencing municipal waste generation and environmental stress during the COVID-19 period in previous studies (Urban & Nakada, 2021; Islam et al., 2024). The results indicate that the environmental sustainability challenges are especially severe in urban areas with a high concentration of healthcare-related activities and commerce.

Waterways were also identified to be a key determinant of environmental vulnerability. Regions with high risk scores were those that were near drainage channels and water bodies where waste may enter the water. Improper disposal of biomedical waste, plastics, and PPE can lead to water contamination and ecological degradation, causing long-term environmental issues (Chen et al., 2022; Behera et al., 2024).

Table 4: Environmental Sustainability Risk Classification

Risk Class	Environmental Condition	Management Priority
Low	Limited environmental vulnerability	Routine monitoring
Moderate	Moderate environmental pressure	Preventive management
High	Significant environmental risk	Targeted intervention required
Very High	Severe environmental vulnerability	Immediate management priority

The analysis also shows that the healthcare environment is a key determinant of the environmental risk patterns. The pandemic further exacerbated environmental pressures in healthcare clusters, with massive amounts of biomedical waste being produced during the period of increased healthcare activities. These findings are in line with other studies focusing on pandemic healthcare waste and PPE disposal environmental issues (Mahmoudnia et al., 2022; Jakimiuk et al., 2025). The EWSR Map as a whole represents a spatial representation of the areas where the 4 factors of waste generation, population density, infrastructure access, and environmental sensitivity interact. The delineation of high-risk zones provides useful information for urban planners and municipal authorities who want to enhance municipal waste management systems, minimize environmental risks, and increase urban resilience in the event of future public health emergencies.

5.4 Priority Zones for Sustainable Waste Management

Identification of priority management zones is a key step towards waste management efficiency and reduction of environmental risk. The Environmental Sustainability Risk Index has categorized Gwalior into four categories: Low, Moderate, High, and Very High Priority Zones. The zones have been delineated in terms of environmental vulnerability and the need for waste management measures to enable interventions and better resource allocation.

Figure 5 shows the mapped priority of sustainable waste management interventions in Gwalior District. The areas prioritized as very high are primarily in the northernmost center of the urban nexus where biomass concentration, medical activities, and waste generation rates are extremely high. Secondary health centers have prioritized high and moderate regions, mostly situated in the urban transitional zone, as moderate, and peripheral areas have low priority levels, which shows the least environmental pressure. The map would practically guide the allocation of resources, including the waste collection system, management practices, environmental watch, etc. In critical parts of the study area.

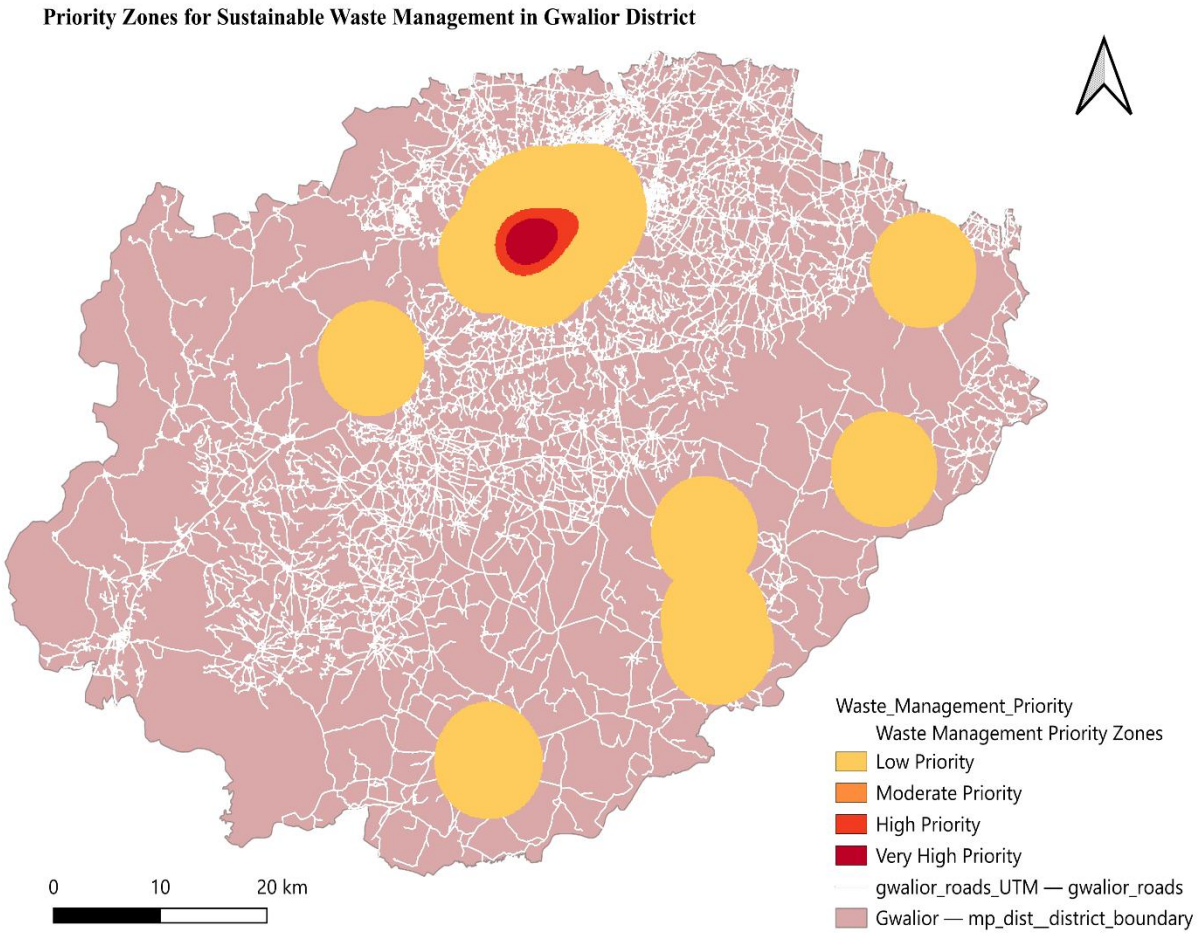

Figure 5: Priority Zones for Sustainable Waste Management in Gwalior

The spatial distribution of priority zones shows that the top priority zones are located in the clusters of urban density, healthcare, and zones of high waste generation. The areas have a high density of population, increased healthcare activity, high transportation connectivity, and close proximity to environmentally sensitive areas. Therefore, they need to be addressed right away in terms of waste collection, segregation, treatment, and disposal. The moderate-priority zones are mostly found in transitional urban zones where waste generation and environmental pressures are still considerable but not as high as in the main urban centers. Low-priority areas are typically located in areas with less population density and fewer waste sources. Environmental hazards in these areas are relatively low, but routine monitoring and preventive management are still important to prevent environmental degradation in the future.

Table 7. Recommended Waste Management Strategies by Priority Zone

Priority Zone	Characteristics	Recommended Management Strategy
Low	Low waste generation and environmental vulnerability	Routine monitoring and awareness programs
Moderate	Moderate waste generation and environmental pressure	Improved collection and segregation systems

High	Significant waste accumulation and environmental risk	Strengthened waste transportation and treatment infrastructure
Very High	Concentrated waste hotspots and severe environmental vulnerability	Immediate intervention, continuous monitoring, and advanced waste treatment facilities

Priority zones help to delineate practical guidance for sustainable urban waste management. Specialized investments should be targeted towards waste collection facilities, biomedical waste treatment systems, environmental monitoring, and public awareness campaigns in areas identified as high and very high priority. These specific actions can help to minimize the risks associated with the environment and optimize the performance of municipal waste management systems.

The results also indicate the ability of GIS-based spatial analysis to assist the process of evidence-based urban planning. Combining waste generation patterns with environmental vulnerability indicators can help decision-makers understand the areas they need to target and create location-specific management strategies. In the post-pandemic era, there are also other GIS-based solutions that have been suggested for strengthening the resilience and sustainability of cities (Mahadevia et al., 2025; Banal & Abad, 2025).

This study aims to synthesize the overall spatial prioritization framework that can be followed as a systematic approach to solve waste management issues during the pandemic and in order to be environmentally sustainable in Gwalior. This method can also be applied to other rapidly urbanizing cities with similar environmental and public health issues.

6. Discussion

6.1 Changes in Urban Consumption During the Pandemic

The results suggest that the COVID-19 pandemic significantly impacted consumption behaviors in urban markets, especially the reliance on essential products and services in the health and home sectors. Mobility indicators showed significant variations in retail, grocery, working, and residential activity, which represent the changes in consumer behavior during and after the restrictions imposed due to the pandemic. This is in line with the studies that noted an increase in the consumption of packaged food, health products, and home delivery services during the pandemic (Kumar & Abdin, 2021; Kol et al., 2023).

These consumption changes have environmental consequences as there is increased production of packaging materials, plastics, and single-use items. Moreover, previous research also found that the behavior change during the pandemic led to an increase in stress on the waste management systems in cities and changes in the composition of waste streams produced by cities (Hammad et al., 2023; Zhong et al., 2025). The present results thus support the notion that shifts in urban consumption are a key factor in environmental problems associated with the pandemic.

6.2 Spatial Patterns of Waste Generation

Hotspot analysis identified the areas of high waste generation due to COVID-19 in and around the densely populated areas and health care centers. The spatial concentrations suggest that the intensity of waste generation was driven by health care activities and population density at the start of the pandemic. Urbanization and the presence of a large healthcare sector have been linked to the generation of higher

biomedical waste in these studies, and this has been seen as a similar spatial pattern (Haque et al., 2021; Jakimiuk et al., 2025).

COVID-19 response activities like testing, treatment, vaccination, and the use of PPE also appear to have an environmental impact, as the number of hotspots is concentrated around healthcare facilities. As reported by Sharma et al. (2020) and Chand et al. (2021), the rise in biomedical-related activities resulted in the creation of new biomedical waste streams that needed specific management and disposal systems. The results highlight the need for spatially targeted interventions in waste management in urban areas.

6.3 Environmental Sustainability Risks and Priority Management Zones

The results of the environmental sustainability assessment indicated that the high-risk zones were mainly correlated with the areas of high population density, concentration of healthcare facilities, transportation accessibility, and intensity of waste hotspots. The GIS-based analyses integrated these variables into a unified picture of environmental vulnerability in the study area. Spatial methods have also been noted for their potential to pinpoint regions susceptible to high environmental risks from waste buildup and waste management deficiencies (Islam et al., 2024; Ray et al., 2024). Priority Management zones have practical implications for sustainable urban planning and environmental governance. High and very high priority areas need to have improved waste collection systems, better biomedical waste treatment units, and regular environmental monitoring. The findings are aligned with the recommendations of Bell et al. (2023) and Mahadevia et al. (2025) that urban management needs to be resilient and environmentally sustainable in the post-pandemic era. GIS-supported decision support systems can thus play a major role in enhancing urban environmental preparedness and sustainability for future public health challenges.

7. Policy Implications

The results of this research highlight the importance of boosting urban waste management systems in response to the environmental challenges arising from pandemic-induced consumption and waste changes. To push for waste segregation at source, optimize collection systems, and increase plant capacity for waste treatment, especially in high-risk and high-priority zones, municipal authorities need to focus on the aforementioned areas. Biomedical and PPE waste streams should be treated with special care to prevent environmental contamination and/or public health risks.

The combination of GIS-based monitoring and decision-support systems can help improve environmental management in urban areas and continuously identify waste hotspots and environmentally vulnerable areas. GIS-generated spatial information can be used to improve the efficiency of municipal waste management in the areas of resource allocation, route planning and optimization, infrastructure planning, and emergency preparedness.

Ensuring sustainable consumption practices and engaging the public are also vital to alleviating environmental pressures. Educational campaigns about the importance of proper waste management (including domestic and medical waste) and recycling, as well as reducing the use of single-use plastics, can help achieve sustainable development objectives. To build resilient and environmentally sustainable urban systems that can meet future public health challenges, the city, health care systems, environmental organizations, and the community must work together.

8. Conclusion

The COVID-19 pandemic has altered consumption, mobility, and waste generation patterns, causing new challenges to the environmental sustainability of cities globally. The research conducted using the district of Gwalior took a case study approach and analyzed the spatial implications of these changes in response to the pandemic by integrating mobility data, waste management data, healthcare infrastructure data, and spatial analysis with Geographic Information Systems (GIS). The research presents an in-depth analysis of the impact public health emergencies can have on urban environmental systems and resource management needs.

Study results showed that the impacts of the pandemic on consumption habits and healthcare needs increased biomedical and healthcare waste production, which further stressed the current waste management systems. Spatial analyses revealed that waste generation and environmental risks were not evenly spread throughout the district, but were instead clustered in certain areas of the city. Biomedical waste hotspots were detected using KDE related to large health care centers, while environmental sustainability risk mapping showed localized areas with high environmental pressure. Moreover, the identification of the waste management priority areas offers a tangible spatial approach to prioritize monitoring, infrastructure investment, and waste collection resources to the most at-risk areas.

The study highlights the importance of geospatial technologies for evidence-based environmental planning and sustainable urban management. The study provides a decision-support framework that integrates spatial risk assessment and prioritization of waste management, which can help policymakers, municipal decision-makers, and environmental agencies enhance preparedness for future public health emergencies. The results highlight that sustainable urban resilience is not achieved by only working on providing effective health responses, but also by having adaptive waste management systems that can respond to the effects of large-scale disruption on the environment. This research methodology could be applied in other fast-growing urban areas to enhance environmental sustainability and ensure a more resilient urban development after the pandemic.

References

1. Banal, R. G., & Abad, I. L. M. (2025). Tracking Coronavirus 2019 pandemic-related waste generation in urban waterways. Global Journal of Environmental Science & Management (GJESM), 11(3).
2. Behera, J. K., Mishra, P., Jena, A. K., Bhattacharya, M., & Behera, B. (2024). Understanding of environmental pollution and its anthropogenic impacts on biological resources during the COVID-19 period. Environmental Science and Pollution Research, 31(41), 54147-54162.
3. Bell, M. L., Pollitt, K. J., & Deziel, N. C. (2023). COVID-19 and the environment: the pandemic and beyond. Environmental Research Letters, 18(9), 092001.
4. Boccarossa, M., Lombardi, L., Tatàno, F., Folino, A., Spadi, V., Tuci, F., & Sirini, P. (2025). COVID-19 induced changes in residual municipal waste management in provincial territories of the Marche region (Italy): flow analysis and environmental assessment. Recycling, 10(2), 40.
5. Chen, Z., Zhang, W., Yang, H., Min, K., Jiang, J., Lu, D., ... & Jiang, G. (2022). A pandemic-induced environmental dilemma of disposable masks: solutions from the perspective of the life cycle. Environmental Science: Processes & Impacts, 24(5), 649-674.

6. COVID-19 Community Mobility report. (2022). COVID-19 Community Mobility Report. https://www.google.com/covid19/mobility/
7. Ganesapillai, M., Tiwari, A., Mehta, R., Sinha, A., Sarkar, I., Mondal, B., ... & Riar, A. (2023). Is the pandemic masking waste management?–A review on fallout of the COVID-19 viral contagion. Green Chemistry Letters and Reviews, 16(1), 2164224.
8. Hammad, H. M., Nauman, H. M. F., Abbas, F., Jawad, R., Farhad, W., Shahid, M., ... & Cerda, A. (2023). Impacts of COVID-19 pandemic on environment, society, and food security. Environmental Science and Pollution Research, 30(44), 99261-99272.
9. Haque, M. S., Sharif, S., Masnoon, A., & Rashid, E. (2021). SARS-CoV-2 pandemic-induced PPE and single-use plastic waste generation scenario. Waste Management & Research, 39(1_suppl), 3-17.
10. Islam, M. S., Rahman, M. N., Ritu, N. S., Rahman, M. S., & Sarker, M. N. I. (2024). Impact of COVID-19 on urban environment in developing countries: case study and environmental sustainability strategy in Bangladesh. Green Technologies and Sustainability, 2(2), 100074.
11. Jakimiuk, A., Koda, E., Goli, V. S. N. S., Podlasek, A., Winkler, J., Singh, Y., ... & Vaverková, M. D. (2025). COVID-19 pandemic-induced medical waste in the Anthropocene: Generation, management, and environmental impact. The Anthropocene Review, 12(2), 223-242.
12. Kol, O., Zimand-Sheiner, D., & Levy, S. (2023). A (local) apple a day: pandemic-induced changes in local food buying, a generational cohort perspective. European Journal of International Management, 19(1), 1-26.
13. Kumar, R., & Abdin, M. S. (2021). Impact of epidemics and pandemics on consumption pattern: evidence from Covid-19 pandemic in rural-urban India. Asian Journal of Economics and Banking, 5(1), 2-14.
14. Lee, H. H., & Huang, P. Y. (2023). Food waste and environmental sustainability of the hotel industry in Taiwan. Sustainability, 15(21), 15459.
15. Lenzen, M., Li, M., Malik, A., Pomponi, F., Sun, Y. Y., Wiedmann, T., ... & Yousefzadeh, M. (2020). Global socio-economic losses and environmental gains from the Coronavirus pandemic. PloS one, 15(7), e0235654.
16. Loh, H. C., Looi, I., Ch'ng, A. S. H., Goh, K. W., Ming, L. C., & Ang, K. H. (2022). Positive global environmental impacts of the COVID-19 pandemic lockdown: a review. GeoJournal, 87(5), 4425-4437.
17. Mahadevia, D., Delgado-Ramos, G. C., Barnes, J., Fitzgerald, J., Kamei, M., Lanza, K., ... & Rosenzweig, C. (2025). Learning from COVID-19 for Climate-Ready Urban Transformation. Elements in Climate Change and Cities.
18. Mahmoudnia, A., Mehrdadi, N., Kootenaei, F. G., Deiranloei, M. R., & Al-e-Ahmad, E. (2022). Increased personal protective equipment consumption during the COVID-19 pandemic: an emerging concern on the urban waste management and strategies to reduce the environmental impact. Journal of hazardous materials advances, 7, 100109.
19. Olawade, D. B., Wada, O. Z., Ore, O. T., David-Olawade, A. C., Esan, D. T., Egbewole, B. I., & Ling, J. (2024). Trends of solid waste generation during COVID-19 pandemic: A review. Waste Management Bulletin, 1(4), 93-103.
20. Pacheco, M., Madureira, H., & Monteiro, A. (2024). Examining post-pandemic urban transformations: a literature review on COVID-19's influence on urban design. Sustainability, 16(23), 10381.

21. Parashar, N., Hait, S., & Hussain, C. M. (2022). Implications of COVID-19 pandemic on waste management practices: Challenges, opportunities, and strategies towards sustainability. Advanced organic waste management, 473-490.
22. Paridhi, Sameer, & Pradhan, S. (2026). Sustainable Integrated Waste Management. Solid Waste Management: Challenges, Sustainability and Advancements, 49-91.
23. Ray, S., Ng, K. T. W., Mahmud, T. S., Richter, A., & Naghibalsadati, F. (2024). Quantification of construction and demolition waste disposal behaviors during COVID-19 using satellite imagery. Environmental and Sustainability Indicators, 24, 100502.
24. Roy, N., & Chaube, R. (2021). Environmental impact of COVID-19 pandemic in India. International Journal of Biological Innovations, 3(1).
25. Rume, T., & Islam, S. D. U. (2020). Environmental effects of COVID-19 pandemic and potential strategies of sustainability. Heliyon, 6(9).
26. Rupani, P. F., Nilashi, M., Abumalloh, R. A., Asadi, S., Samad, S., & Wang, S. (2020). Coronavirus pandemic (COVID-19) and its natural environmental impacts. International Journal of Environmental Science and Technology, 17(11), 4655-4666.
27. Sarbu, R., Alpopi, C., Burlacu, S., & Diaconu, S. (2021). Sustainable urban development in the context of globalization and the health crisis caused by the COVID-19 pandemic. In SHS Web of Conferences (Vol. 92, p. 01043). EDP Sciences.
28. Sharma, H. B., Vanapalli, K. R., Cheela, V. S., Ranjan, V. P., Jaglan, A. K., Dubey, B., ... & Bhattacharya, J. (2020). Challenges, opportunities, and innovations for effective solid waste management during and post COVID-19 pandemic. Resources, conservation and recycling, 162, 105052.
29. Tripathi, G. K., Khare, V., Bundela, P., Khiriya, P., Khare, P. S., Dixit, P., & Sundaramurthy, S. (2024). Impact of PPEs Waste Generation During COVID-19 Pandemic on the Environmental Sustainability and Its Economic Aspects in India and Worldwide. In Advanced Materials and Conversion Technologies for Personal Protective Equipment Used in the COVID-19 Pandemic (pp. 1-15). Singapore: Springer Nature Singapore.
30. Urban, R. C., & Nakada, L. Y. K. (2021). COVID-19 pandemic: Solid waste and environmental impacts in Brazil. Science of the Total Environment, 755, 142471.
31. Vanapalli, K. R., Sharma, H. B., Ranjan, V. P., Samal, B., Bhattacharya, J., Dubey, B. K., & Goel, S. (2021). Challenges and strategies for effective plastic waste management during and post COVID-19 pandemic. Science of the Total Environment, 750, 141514.
32. Wan, S., Nik-Bakht, M., Ng, K. T. W., Tian, X., An, C., Sun, H., & Yue, R. (2024). Insights into the urban municipal solid waste generation during the COVID-19 pandemic from machine learning analysis. Sustainable Cities and Society, 100, 105044.
33. Yousefi, M., Oskoei, V., Jonidi Jafari, A., Farzadkia, M., Hasham Firooz, M., Abdollahinejad, B., & Torkashvand, J. (2021). Municipal solid waste management during COVID-19 pandemic: effects and repercussions. Environmental Science and Pollution Research, 28(25), 32200-32209.
34. Zhong, Y., Hu, Y., Wang, L., Jiang, F., & Cui, S. (2025). The short-term impacts of the COVID-19 pandemic on takeaway dietary pattern, its environmental footprints, and nutritional quality. Journal of Environmental Management, 380, 124823.