Advances in Environmental Technology 11(1) 2025, 36-62.

Iranian Reasearch Organization for Science and Technology (IROST)

Advances in Environmental Technology

Journal home page: https://aet.irost.ir

Assessing vulnerability of a solid waste management system through GIS and the Rank Sum method: A case study of Durgapur city, India

Md Mainul Sk

Department of Geography, Faculty of Arts, Rajendra University, Balangir, Odisha, India.

ARTICLE INFO

Document Type:
Case Study

Article history:
Received 21 September 2024
Received in revised form 3 November 2024
Accepted 12 November 2024

Keywords:
Waste Hazard Vulnerability
GIS-based Analysis
Urban Solid Waste Management
Spatial Analysis
Durgapur

ABSTRACT

The present study aims to assess the vulnerability of the Durgapur Municipal Corporation (DMC) in West Bengal, India, to hazards associated with solid waste through a multi-criteria analysis method integrated with Geographic Information Systems (GIS). Durgapur, a rapidly urbanizing industrial city, faces significant challenges in managing the increasing volume of waste, leading to potential threats to the environment and public health. This study employed a Rank Sum (RS) method to weigh and assign importance to eleven critical factors influencing waste hazard vulnerability. Data was collected through field surveys and existing GIS databases, focusing on 43 wards within DMC. The factors were ranked based on their importance in contributing to vulnerability, with waste collection, waste generation, and frequency of waste collection identified as the most significant. Using Weighted Overlay Analysis (WOA), vulnerability maps were prepared to identify areas within DMC that were most at risk from inadequate waste management practices. The results revealed that approximately 12.15% of Durgapur's area, encompassing 15.19% of the population, falls under very high vulnerability zones, necessitating immediate intervention to improve waste management and reduce associated risks. The research highlights the significance of combining spatial analysis with multi-criteria decision-making techniques to identify and mitigate urban vulnerabilities. The results provide crucial insights for urban planners, policymakers, and municipal officials in developing and executing efficient waste management strategies.

1. Introduction

Solid waste is a common byproduct of human daily activities, and the mismanagement of waste, especially in the case of handling, sorting, collection, and disposal, can severely jeopardize environmental and public health [1]. Since the last century, the rate of solid waste generation has increased tenfold globally and is predicted to double by 2025 [2]. The amount of solid waste produced in cities often exceeds the pace of urban growth [3]. Several research studies have shown that rapid urbanization and lifestyle changes contribute significantly to waste generation and

*Corresponding author Tel.: +7432059295
E-mail: mainuls919@gmail.com
DOI: 10.22104/AET.2024.7053.1939

altered waste composition [4, 5]. Globally, approximately 2.01 billion metric tons of municipal solid waste (MSW) are generated annually, and this figure is expected to increase to 3.40 billion metric tons by 2050 [6]. Of this total waste, roughly 33-40% is disposed of improperly, either through open dumping or burning. In low-income countries, this figure can be as high as 93% [7]. The improper disposal of solid waste contaminates the soil, water, and air, posing significant risks to public health [8, 9].

An increase in solid waste generation in India has also accelerated due to rapid population growth, urbanization, industrialization, a booming economy, and an improved living standard [10]. India is grappling with a serious waste management crisis due to rapid population growth, urbanization, and economic development. Although approximately 80% of municipal solid waste (MSW) is collected in India, only a small portion (28%) is actually recycled or reused. Currently, the country produces nearly 70 million tonnes of MSW annually; if current trends persist, this figure may rise to around 165 million tonnes by 2030 and could potentially reach 436 million tonnes by 2050 [11]. Many urban local bodies in India still dispose of solid waste unscientifically, leading to environmental and public health problems that conflict with sustainable development goals [12]. Municipal solid waste is often collected and dumped in landfills without proper treatment, creating breeding grounds for pests [13]. Urban solid waste disposal has become a perennial problem, leading to environmental pollution and degradation [14]. Improvement in the socio-economic aspects of urban dwellers, as well as urbanization and industrialization in the cities of India, intensify the vulnerability related to waste management. Studies on Indian cities, such as Mumbai and Delhi, reveal the struggle with landfills and the environmental consequences of unscientific waste disposal [15,16]. These cases highlight the national scale of the waste management crisis, aggravated by urbanization and economic growth.

The fast-growing urbanized areas in developing countries are prone to environmental and socio-economic problems because of multiple factors [17, 18]. The excessive use of natural resources and the unprecedented production of municipal solid waste are significantly deteriorating the environment in urban areas [19]. Solid waste management is a pressing environmental issue, especially in rapidly growing cities like Durgapur, India [20]. Previous research has suggested that specific factors, such as open dumping sites, significantly worsen environmental conditions in Durgapur [21]. A large volume of solid waste is directed to the main landfill site; several illegal open dumping sites are found in every part of the city that mostly create waterlogging during rainy seasons due to blockage of drainage networks, becoming a breeding place for insect and rodent vectors proliferating severe diseases for the public. The amount of municipal solid waste produced in Durgapur has risen steadily. In 2020-2021, the city generated nearly 332 tons of waste per day, with approximately 43% being dumped in landfills and the remaining waste being disposed of haphazardly in open spaces, vacant lands, water bodies, drains, and other areas. This indicates that a significant portion of the waste is still not properly managed, making the environment vulnerable to potential hazards. Therefore, this study aims to assess the vulnerability linked to these waste disposal practices by utilizing GIS and Rank Sum methodology to create a detailed risk assessment map for the city.

Currently, the application of GIS technology helps to predict hazard levels and their potential impacts [22, 23]. Effective management of vulnerable areas requires detailed site-specific mapping. Accurate mapping of a particularly vulnerable area facilitates the success of management plans [24]. The application of GIS in mapping vulnerable areas could help minimize the risk and environmental problems related to solid waste mismanagement [25]. Generally, vulnerability assessment is concerned with identifying the most vulnerable-prone areas and evaluating the variations in vulnerability in different geographical areas or within a geographical unit that may experience similar problems [26]. The coping strategy for vulnerability among the city population is not the same in all sections of urban dwellers, but it depends on the capability of the population [27]. Areas with poor waste management practices face greater vulnerability compared to those with wellplanned systems. People in peripheral or slum areas are particularly at higher risk than those in the city center due to differences in waste management practices [28].

Vulnerability assessments are used to identify environmental impacts and highlight the sensitivity of systems at risk from various hazards [29]. These assessments are a relatively new and effective analytical tool that focuses on identifying stages of susceptibility and vulnerability, guiding actions to reduce risks and improve well-being [30]. They are particularly well-suited for environmental assessments because they ensure objectivity in decision-making and provide environmental profiles that can be used to prioritize and identify urgent actions [31]. Numerous studies have used GIS and multi-criteria decision analysis (MCDA) for vulnerability mapping and hazard analysis [32-34]. MCDA is a decision support method that aids in organizing, measuring, and assessing decision problems by analyzing multiple criteria using mathematical tools [35]. It involves constructing and clarifying judgments and forecasting problems by analyzing multiple criteria using mathematical tools and determining a set of alternatives and decision criteria [36]. It is especially useful for problems involving geographical data, referred to as spatial or geographical decision problems. MCDA has been recognized as a valuable tool for evaluating complex decision problems, which often include incommensurable data or criteria [37] and can be used to integrate geographical, spatial, environmental, and socio-economic objectives to arrive at optimal decisions [38].

The integration of MCDA tools with GIS has been widely applied in spatial modeling and assessing natural hazards. The Rank Sum weight method is a well-established technique in multi-criteria decision-making [39]. In this study, the effectiveness of GIS combined with ranking methods has been assessed to map areas vulnerable to waste-related issues in Durgapur city, West Bengal, India. The key objective of this research is to identify and categorize the most vulnerable areas based on various factors linked to improper solid waste management. By assessing vulnerability through GIS and Rank Sum methodology, this study contributes to the limited body of literature on the environmental risks associated with improper waste management in mid-sized Indian cities. Unlike previous studies that focused solely on waste quantity or disposal methods, this research integrates socio-economic and environmental data, providing a holistic view of vulnerability in waste management. The results of this analysis will be valuable for impact assessment and provide valuable insights for urban local bodies, town planners, researchers, and government authorities for more informed decision-making.

2. Materials and Methods

2.1 Description of the study area

Durgapur Municipal Corporation is an urban center located in the state of West Bengal, India (Figure 1). It is one of the major cities in the Paschim Bardhaman district, known for its industrial and urban development. DMC was chosen as the study area because of its significant challenges related to solid waste management and its varied urban characteristics, which provide a comprehensive context for vulnerability assessment. Durgapur is situated approximately 170 kilometers northwest of Kolkata, the state capital. It lies within the coordinates of 23° 33' N latitude and 87°19' E longitude. The total area of Durgapur Municipal Corporation is approximately 154.20 sq. km and is home to a population of 566,517. The city has a tropical wet and dry climate, marked by hot summers, moderate rainfall during the monsoon season, and mild winters, all of which impact its waste management practices.

Durgapur is a city characterized by a diverse urban landscape that includes residential, industrial, and commercial areas, as well as green spaces. Rapid urbanization and industrial expansion have led to increased waste production, revealing significant shortcomings in the waste management system. Notably, the city faces challenges related to waste collection, disposal methods, and overall management practices.

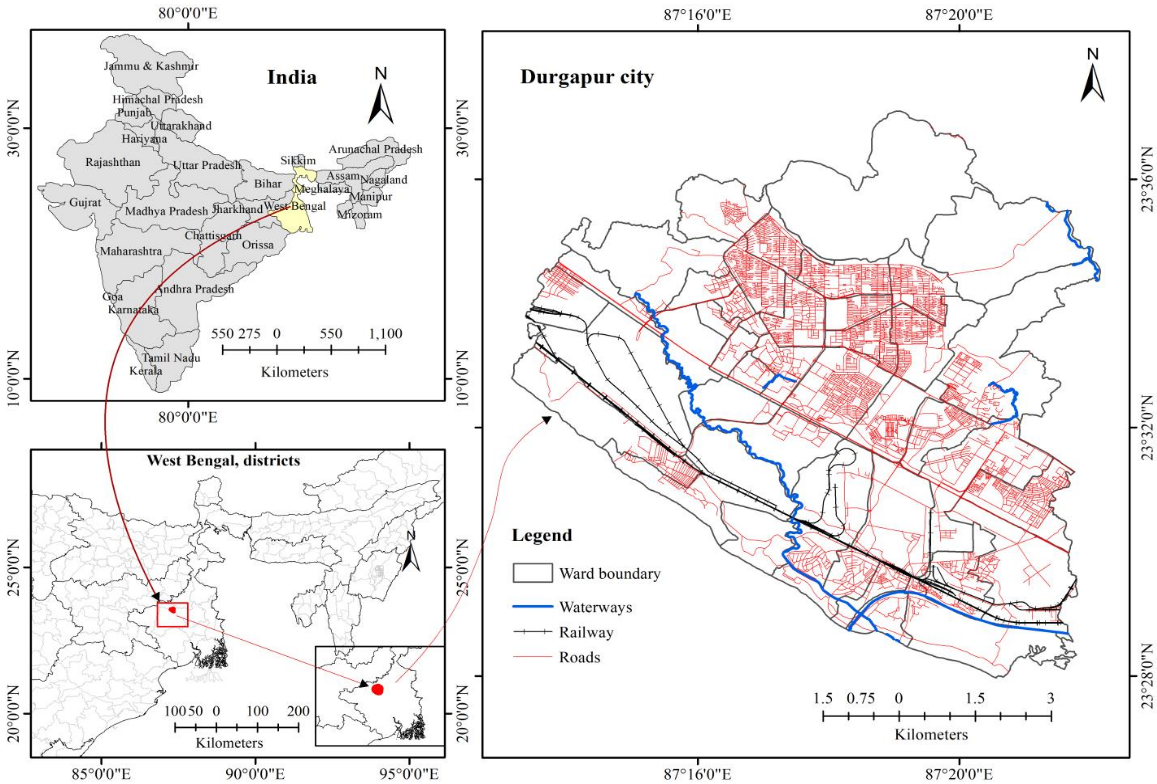

Fig. 1. Map of the study area.

2.2 Database

This study used GIS and the RS method to identify potentially vulnerable areas in Durgapur City, a rapidly urbanizing area with significant solid waste management challenges. GIS datasets of the study area, such as relative relief, slope, LULC, population density, literacy, population-bin ratio, waste disposal method, waste collection and frequency of waste collection, sweeper-population ratio, and waste generation, were collected from different sources.

Relative relief and slope data were obtained using the Shuttle Radar Topographic Mission (SRTM) Global Digital Elevation Model (DEM). The SRTM DEM was sourced from Remote Pixel (http://remotepixel.ca) in the Geographic Coordinate System (WGS84 datum). Landsat 8 imagery was used as the primary data source for Land Use and Land Cover (LULC) classification. For this classification, an unsupervised image classification method was employed. This approach allows for the automatic grouping of pixels based on their spectral signatures without the need for predefined training data, which is particularly useful for identifying distinct land cover types across diverse landscapes. Geometrically and radiometrically corrected satellite images from various time periods were downloaded from USGS Earth Explorer (http://earthexplorer.usgs.gov) in TIFF format (.tif) with a default UTM projection (Table 1). Images with 0% cloud cover were selected for download. A base map of the study area was prepared based on maps provided by the DMC. The projected population of Durgapur City was used for ward-wise distribution of the population. The city's literacy rate was collected ward-wise from the District Census Handbook for 2011. Other data related to vulnerability mapping, such as population-bin ratio, waste disposal method, waste collection, frequency of waste collection, sweeper population ratio (pop/sweeper), and waste generation, were collected from the Details Project Report (DPR) of DMC. The map digitization and analysis were performed within a GIS environment.

The RS method was used to assess each criterion, where a lower rank indicated lower vulnerability and vice versa. All Geographic Coordinate System

(WGS84) data were converted into Projected Coordinate Systems, specifically to the Universal Transverse Mercator (UTM) Zone 45N, and vector data were transformed into a raster format for the final vulnerability mapping in the study. The methodology used for this study is illustrated in Figure 2. The current practice of solid waste management by households and DMC and infrastructure availability in the area were considered as decision criteria.

Table 1. Data and source of collection.

Dataset	Source	Projection by default*	Data Type	Purpose of use
SRTM Global Digital Elevation Model (DEM)	Remote Pixel (http://remotepixel.ca)	Geographic Coordinate System (WGS84 datum)	Raster	Slope analysis, Relative relief
Landsat 8 (OLI & TIRS)	USGS Earth Explorer (http://earthexplorer.usgs.gov)	Projected Coordinate System (UTM_Zone_45N)	Raster	Land use classification
Population density	District Census handbook	Projected Coordinate System (UTM_Zone_45N)	Attribute	Distribution of population
Literacy	District Census handbook	Projected Coordinate System (UTM_Zone_45N)	Attribute	Distribution of literacy
Population Bin Ratio (pop/bin)	Details Project Report (DPR)-DMC	Projected Coordinate System (UTM_Zone_45N)	Attribute	Ward-wise distribution of population and bin
Waste disposal method	DMC Report	Projected Coordinate System (UTM_Zone_45N)	Attribute	Ward-wise practice of waste disposal
Waste collection	DMC report	Projected Coordinate System (UTM_Zone_45N)	Attribute	Evaluation of waste collection ward-wise
Frequency of waste collection	DMC	Projected Coordinate System (UTM_Zone_45N)	Attribute	Evaluation of waste collection frequency
Sweeper population ration (pop/sweeper)	DMC Report	Projected Coordinate System (UTM_Zone_45N)	Attribute	Ward-wise sweeper-population distribution
Waste generation	DMC Report	Projected Coordinate System (UTM_Zone_45N)	Attribute	Spatial pattern of waste generation

Note: * All Geographic Coordinate System (WGS84) were converted into Projected Coordinate System, ** the vector data types were converted into raster data for final vulnerability mapping

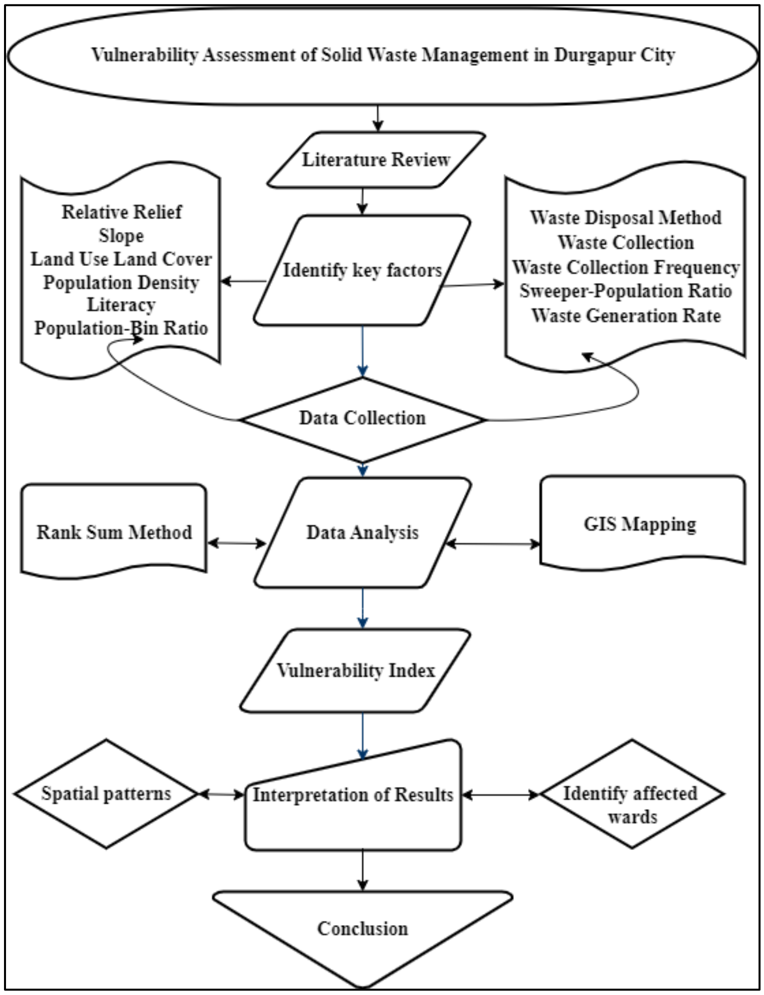

Fig. 2. Flow chart showing methodology applied in the present study.

2.4 Determination of decision criteria

2.4.1 Relative relief

Relative relief refers to the height variation within a specific area, calculated as the difference between the maximum and minimum elevation per grid. It is an important technique to represent the relief features without considering the sea level [42]. In this study, the area has been divided into one square kilometer grids, the smallest unit of the region. The elevation difference between the highest and lowest points in each grid has been calculated to analyze relative relief. The area's highest elevation is 124 meters, and the lowest is 56 meters, resulting in a total relative relief of 68 meters. The map shown in Figure 3 illustrates the distribution of relative relief in the study area, classified into five groups, ranging from below 32.37 meters to 50.75 meters and from 1.05 meters to 16.12 meters. These five different relative relief zones have been ranked according to their relief for the purpose of vulnerability mapping. The areas with a relative relief between 1.05-16.12 m were considered as very high vulnerable areas, covering 3.97% of the area of the city, and ranked 5; areas with relative relief between 32.36-50.75 m were considered as least vulnerable areas, covering 15.56% of the area of the city. It is hypothesized that the low relative relief areas of the city have a higher chance of vulnerability than the areas with high relative relief. The low-altitude areas of Durgapur are prone to waterlogging during the rainy season, particularly from June to September. This leads to waste accumulation, which degrades the urban environment. In several wards of Durgapur, heavy rainfall creates chaotic conditions, increasing the vulnerability of residents.

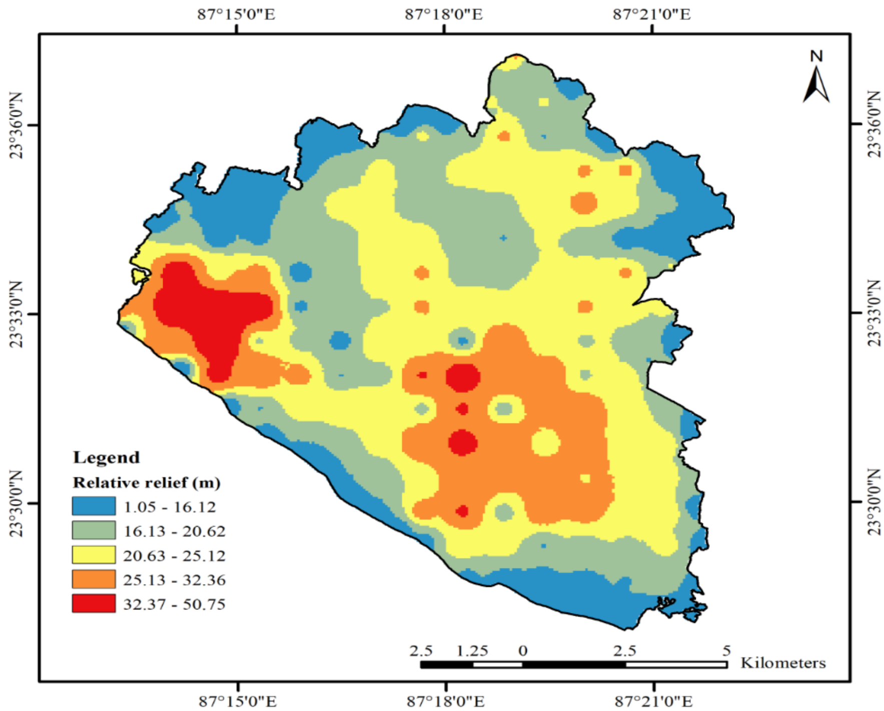

Fig. 3. Map of relative relief of the study area.

2.4.2 Slope

The slope is an important component of the complex landscape, which influences the pattern of the drainage system. The degree of slope in a geographical unit largely influences the surface runoff. Also, the slope is determined by the structure of the rocks and many other climatic and geographical factors. The slope in the study area ranged from over 1 degree to 65 degrees, and Figure 4 displays the distribution of these slope variations categorized into five groups for analysis. The analysis revealed that 30% of Durgapur City fell within the very high vulnerable areas, characterized by slopes ranging from 0 to 2.81 degrees. Areas with slopes between 2.81 and 5.36 degrees are classified as high vulnerable areas, encompassing 11.3% of the city. Furthermore, the moderately vulnerable areas, which had slopes between 5.36 and 8.94 degrees, accounted for 36.7% of the urban landscape. The low vulnerable areas, characterized by slopes from 8.94 to 15.33 degrees, covered 21.5% of the city; the regions with steeper slopes, ranging from 15.33 to 65.16 degrees, were classified as very low vulnerable areas, comprising 0.4% of Durgapur City. It was hypothesized that the areas with a less percentage of slope were more vulnerable than the areas with a higher percentage of slope. There is an inverse relationship between slope and vulnerability to solid waste. The areas at low slopes are suitable for the development of human settlements; they are also exposed to waste dumping, exacerbating the degree of vulnerability in the proximate settlements [43]. The areas located beside the Damodar River are characterized with low lying areas and a high chance of vulnerability.

2.4.3 Land use land cover

In this study, the Land Use and Land Cover (LULC) classification for the Durgapur area was undertaken to identify various land use types. LULC is classified into eight classes, viz., industrial zone, built-up area, settlement area, fallow land with vegetation, open space with vegetation, barren land, sparse vegetation, and swamp land (Figure 5). It was hypothesized that built-up and settlements were highly vulnerable areas because the waste management practice near the residential and built-up areas adversely affects the land values in terms of rents, selling price due to foul smell, dust, noise, stray animals, and unhygienic conditions [44, 45]. Indiscriminate dumping of solid waste around human environments also creates nuisance and aesthetic problems. Unscientific disposal of solid waste contaminates the surface and ground water through leaching of waste deposits. In developing countries, residents often experience severe environmental problems caused by inadequate solid waste disposal and collection systems [46].

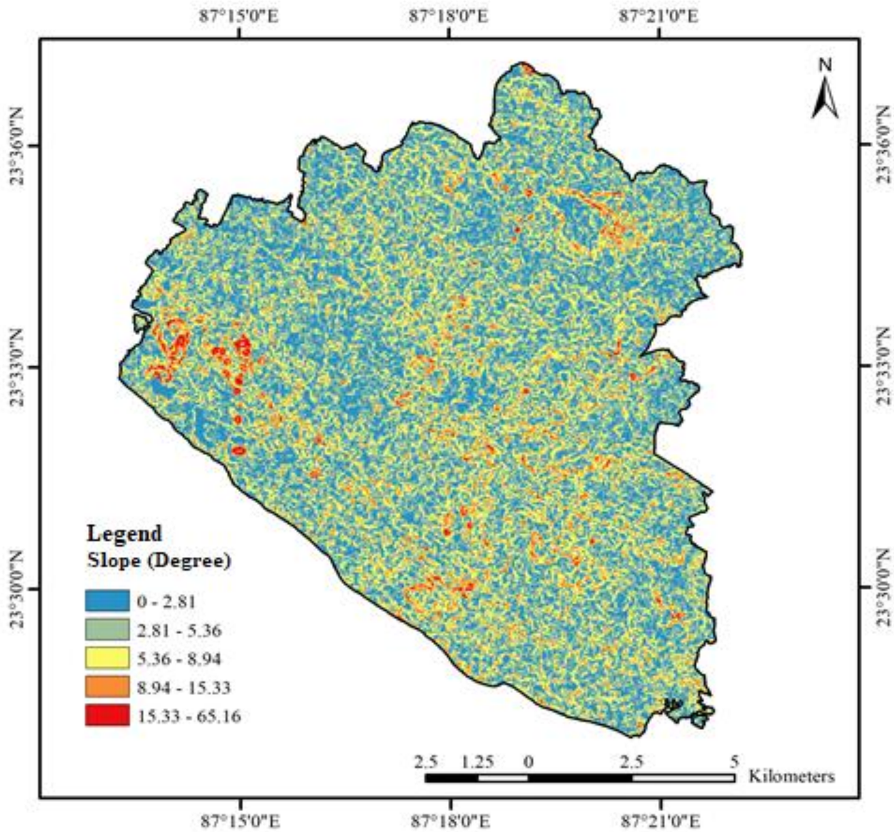

Fig. 4. Map of slope of the study area.

2.4.4 Population density

It has been found in several studies that there is a positive correlation between population density and the quantity of municipal solid waste generation [47, 48]. A large population and high population growth generate large volumes of waste. Therefore, managing this huge volume of waste requires proper infrastructure, economic resources, time, and effective administration to mitigate the adverse impacts on human health and the surrounding environment. In many cities in developing countries, solid waste management (SWM) is an overlooked area with inadequate waste collection, recycling, and disposal practices. Mismanagement of solid waste affects soil, water, and air, as well as the proliferation of microbial agents, malaria, cholera and other vector borne diseases [49]. The ward-wise population density data was obtained from the DPR provided by DMC. The vector data was converted into raster data, and finally, the map was prepared in a GIS environment (Figure 6).

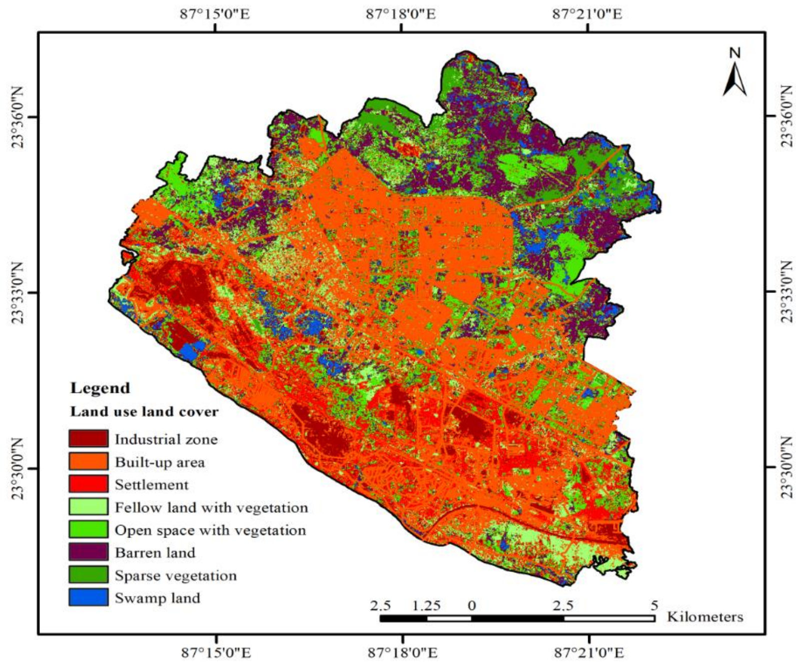

Fig. 5. Map of Land Use Land Cover of the study area.

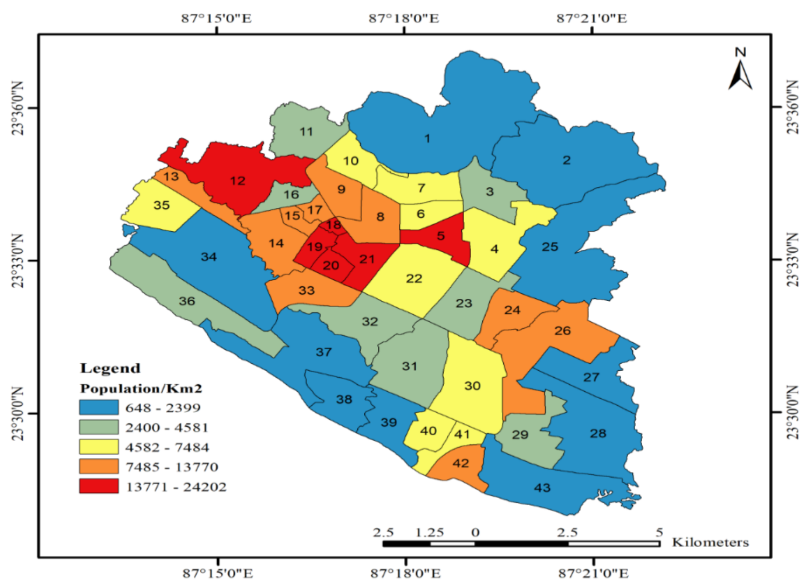

Fig. 6. Map of ward-wise population density in the study area (2016).

2.4.5 Literacy

Education increases the level of information and awareness among people regarding the benefits of reducing, reusing, and recycling waste; it has a direct relationship with public cooperation in solid waste management from separation of waste to disposal [50]. Research has highlighted the critical role of education in effective solid waste management practice. Educated individuals are generally more aware of the negative health and environmental consequences of poor waste disposal on health and the surrounding environment; thus, they practice positive waste management, promoting personal hygiene and a healthy environment [51, 52]. Therefore, education helps change human behavior and attitudes, improving the waste management practice of communities, which leads to a reduction of environmental pollution and waste related diseases. The literature proves that there is a positive relationship between education and solid waste management practice.

Another study found that a significant barrier to proper solid waste management in developing countries is the lack of education, awareness, and interest, resulting in poor community participation in decision-making processes [53]. Education and literacy act as a protective agent against environmental hazards related to waste problems, as they help people address exposure to vulnerability.

The study's analysis suggested that areas with higher literacy rates tend to show better solid waste management practices, as literate individuals are more aware of the adverse health and environmental impacts of improper waste disposal, which in turn promotes personal hygiene and a healthier environment. The ward-wise literacy rate of Durgapur City was obtained from the District Census Handbook (2011). The vector data was converted into a raster; finally, a ward-wise literacy rate map was prepared in a GIS environment (Figure 7).

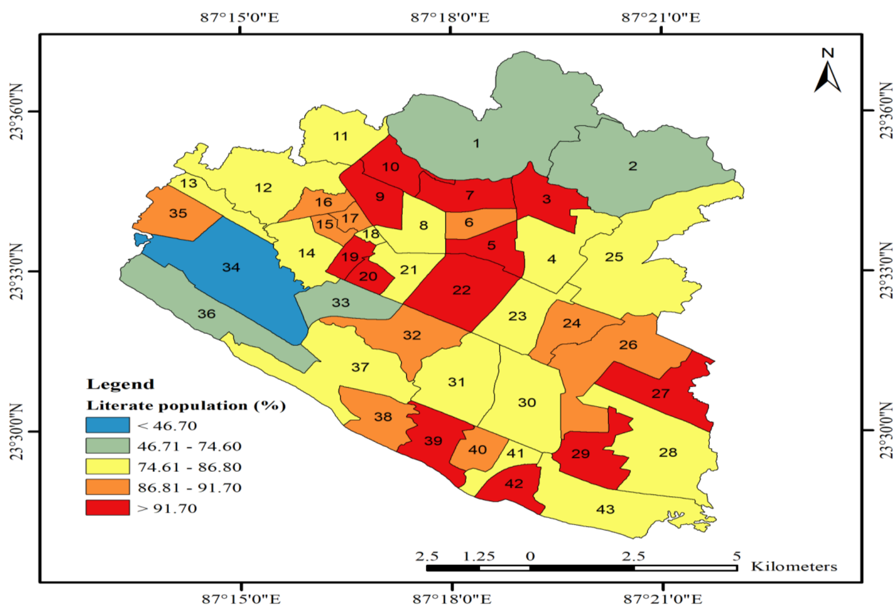

Fig. 7. Map of ward-wise literacy rate of the study area.

2.4.6 Population-waste bins ratio

The proper management practice of solid waste in a particular area is manifested by the optimum distribution of waste dustbins or collection points. Irrational and insufficient placement of dustbins coupled with mismanagement of waste, including the absence of regular dustbin waste collection and lacking awareness among the public regarding the proper usage of dustbins, cause diseases and environmental pollution [54]. The waste collection bins in different parts of the city have been hardly placed at optimum locations, leading to poor collection efficiency in Durgapur City. The collection of waste with an inadequate number of street dustbins is commonly observed in Durgapur. Dumping of waste in busy and important streets is common, leading to an unbearable nuisance to people. Presently, DMC collects approximately 67% of its generated waste, with the remaining dumped in dustbins or open places. This study was carried out to investigate the spatial distribution of dustbins across Durgapur, assessing how effectively these bins serve the population in different areas.

Additionally, the environmental pollution associated with these dustbins was examined, particularly focusing on issues such as waste overflow, odor, leachate generation, and the attraction of pests. These factors contribute to air and soil contamination, further impacting the health and quality of life of nearby residents. In order to conduct the study, the dustbin locations were identified through a GPS survey. The coordinate system, i.e., latitude and longitude, was recorded. Vulnerability assessment was carried out with respect to the number of dustbins and ward population. The wards with insufficient dustbins generally had the worst experience of waste management, while the situation was comparatively better in the wards with adequate provision of dustbin facilities. It was hypothesized that there was an inverse relationship between the number of dustbins placement and vulnerability. The higher the ratio between the population and bins, the higher the vulnerability and vice-versa. The number of dustbins and ward population ratio was categorized into five vulnerability groups: very high, high, medium, low, and very low vulnerability. The distributions of dustbins should be uniformly located to cover all classes of people in different parts of the city to ensure the holistic management of the waste. The placement of dustbins is concentrated in a particular place rather than uniformly distributed throughout the city. As a result, all the dustbins overflow with waste, leading to pollution of both the ground and air. As the garbage from the dustbins is collected in 15-day intervals, the situation becomes more complicated. Most of the dustbins in residential areas are located near the building, not at the far ends of colonies, which is another concern for residents. The population/dustbins ratio ward-wise data was collected from the DMC report and converted into raster data; finally, a map was prepared in a GIS environment (Figure 8).

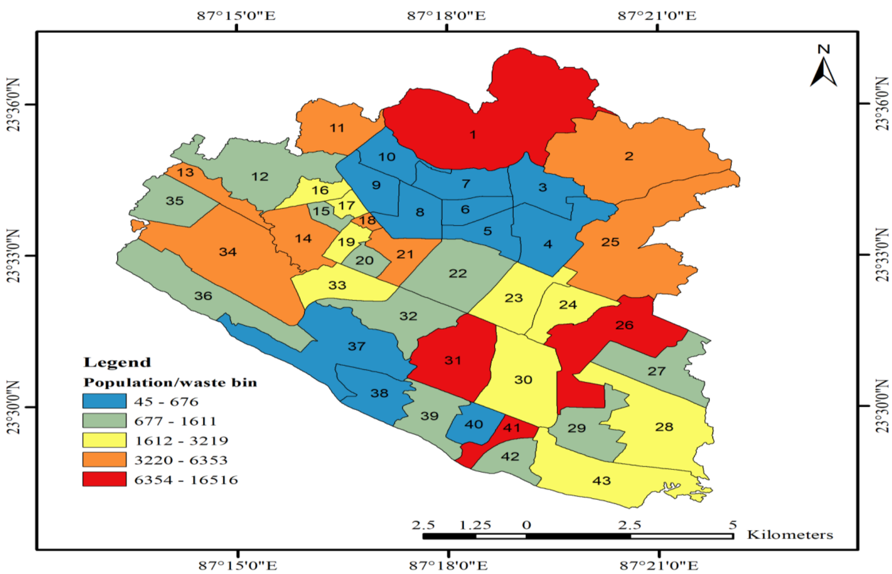

Fig. 8. Map of ward-wise population/bin ratio of the study area.

2.4.7 Waste disposal methods

Inappropriate selection of waste disposal methods in urban areas causes soil, ground water, and air pollution that adversely affects the environment and health of residents [55]. The literature on waste management clearly indicates that there is a link between inappropriate waste management and health problems due to the contamination of water and soil that exacerbates the proliferation of microbial agents, cholera, malaria, and vector-borne diseases [56]. Another study has also found congenital anomalies, low birth weight, and risk of cancer and respiratory diseases [57]. The practice of waste burying not only creates environmental pollution but is a significant waste of national wealth. Also, the burning of household waste releases suspended particles, toxic gasses, aerosols, and organic compounds [58]. Haphazard dumping of waste has significant health hazards, water pollution, soil degradation, and methane emissions [59]. The reckless disposal of waste into drains causes choking of sewers and drainage networks, leading to flooding and the contamination of ground and surface water. In many urban areas in developing countries, there is a loss of lives and properties due the negligence of proper waste disposal methods. Community dustbins certainly reduce the cost of collection and narrow the risk of health and environmental problems. However, irrational distribution and an inadequate number of community dustbins compelled residents to throw their generated waste into drains, gutters, open places, and roadsides. Open dustbins also release foul smells and attract flies, mosquitoes, and rodents in the absence of regular waste collection. In urban areas, dustbins are mostly open and cause poor sanitary conditions and health hazards to nearby residents and sanitary workers. The population in Durgapur City commonly practices burning, open dumping, drains, and dustbins for waste disposal. Burning waste is considered to have the maximum level of environmental hazards for people, followed by open dumping, drains, and dustbins practice. Figure 9 shows that 50% of households in Durgapur City dispose of their generated waste in dustbins, followed by open dumping (33.00%), burning of waste (8.7%), and drains (8.3%). The ward-wise waste disposal methods data were collected through personal discussions with DMC workers and converted into raster data; finally, a map was prepared in a GIS environment (Figure 9).

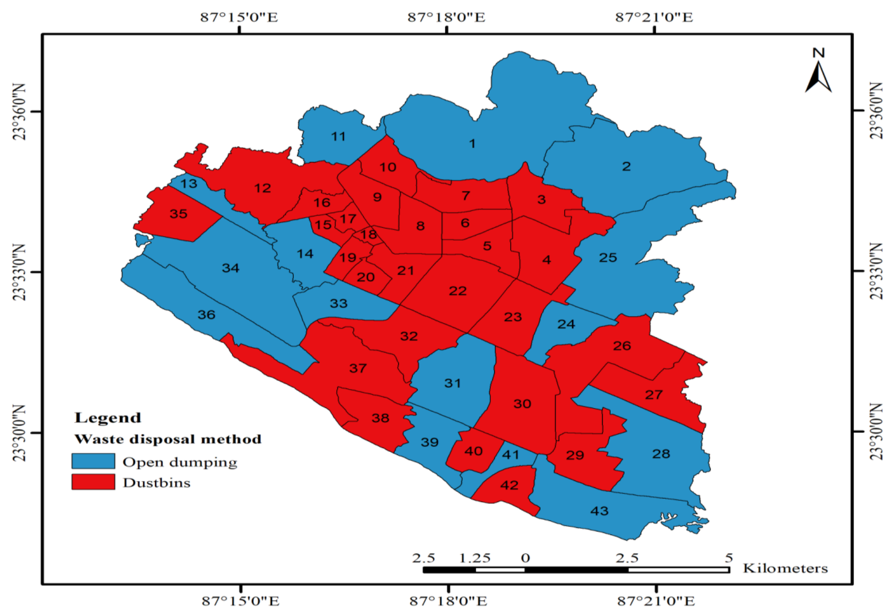

Fig. 9. Map of ward-wise solid waste disposal methods of the study area.

2.4.8 Waste collection

In developing countries, municipal solid waste management is the most neglected area, with the absence of organized waste collection and recycling practices. In Indian urban areas, the high-income families get better facilities for waste collection; on the other hand, low-income settlements get insufficient waste collection service and treatment facilities, leading to haphazard waste dumping and burning by households [60]. The insufficient collection of waste, coupled with the absence of awareness of health hazards regarding waste management among low-income settlements, make them more vulnerable. This study assessed the collection efficiency of waste in a spatial perspective in Durgapur City. It was hypothesized that the lesser the collection efficiency of waste, the higher the vulnerability and vice-versa. The uncollected and mismanaged waste is a public health hazard. The leftover or abandoned organic waste attracts disease vectors, and these wastes sometimes choke water bodies. The uncollected waste is also burned and releases toxic gas that adversely affects the local residents. All the wards in Durgapur City were categorized into five vulnerability categories based on waste collection efficiency.

The collection of waste in different wards is different for each ward of Durgapur City. Figure 10 shows the ward-wise collection efficiency of waste in the study area. The ward-wise waste collection data were obtained through personal discussions with DMC workers (2018) and converted into raster data; finally, a map was prepared in a GIS environment (Figure 10).

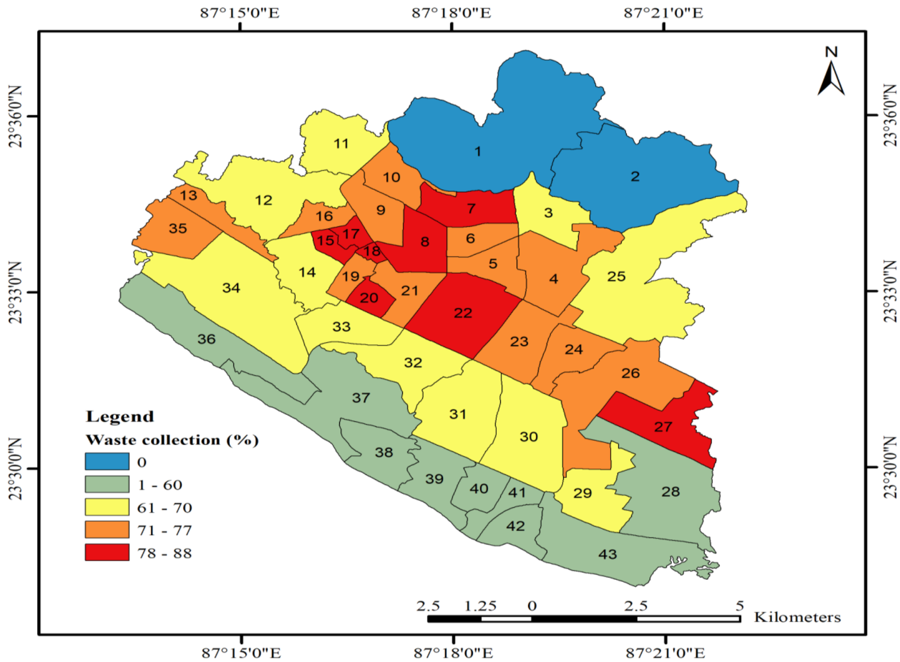

Fig. 10. Map of solid waste collection of the study area.

2.4.9 Frequency of waste collection

The primary responsibility for urban solid waste management in India lies with local authorities. However, urban areas in India often suffer from inefficient waste management systems. Inefficient and irregular waste collection operations by urban authorities resulted in dumping and heaps of garbage in many parts of the city. Poor collection or untimely collection of waste from dustbins in open places causes environmental, health, odor, and aesthetic problems in cities, as the MSW has a high proportion of biodegradable waste [61]. There are several constraints for mismanagement of waste, i.e., no proper record of waste generation in a spatial perspective, poor infrastructure and labor for waste collection, and an insufficient financial budget for waste management. In developing countries, a significant portion of solid waste is organic; hence, if it remains uncollected for a long time, it decomposes and causes a nuisance for the public. Waste collection practice in many wards of Durgapur is carried out fortnightly or on a monthly basis, while some areas are serviced weekly. So, the uncollected waste decomposes easily, attracting flies, rodents, and mosquitoes. It was hypothesized that the lesser the frequency of waste collection from wards, the higher the vulnerability. There was an inverse relationship between the frequency of waste collection and the degree of vulnerability in the city.

It was found that in many wards, the waste collection frequency interval ranges from a week to a month. It was considered that the total absence of waste collection in the area had the maximum level of environmental hazards for people, followed by monthly, fortnightly, and weekly intervals. Figure 11 shows that 42.63% of the waste in areas of the city is collected fortnightly by DMC, followed by 33.6% and 19.07% monthly and weekly, respectively. The ward-wise waste collection frequency data were collected from the DMC report and converted into raster data; finally, a map was prepared in a GIS environment.

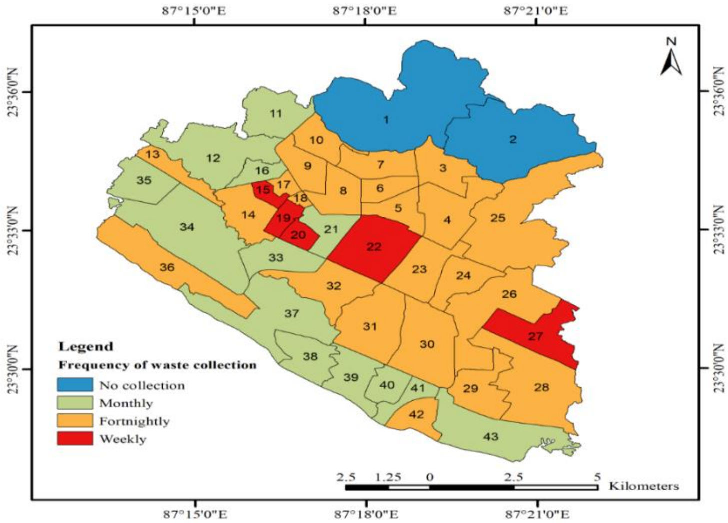

Fig. 11. Map of frequency of waste collection of the study area.

2.4.10 Sweeper-Population ratio

Sweepers play a significant role in the management of waste in urban areas. Adequate allotment of sweepers based on population density and road length helps in maintaining the health and hygiene of cities. However, there is no uniform yardstick or benchmark for street cleaning by urban local bodies. In India, street sweepers usually cover the roads that extend from 250 meters to 1 Km, and in some places, the length may be more than 3000 sq. meters. The allotment of sweepers in some places is based on the sweeper-population, which varies from 1:250 to 1:500 or more [62]. Inadequate allotment of sweepers, without concern for the population densities or numbers, results in irregular sweeping of roads. Due to the lack of adequate sweepers, urban places are swept on a weekly basis or twice a week. In Durgapur City, there is great variation in the sweeper-population ratio in different wards. An attempt was made to determine the population per sweeper. It was hypothesized that the higher the sweeper-population ratio, the higher the vulnerability and vice-versa. There is a positive relationship between the sweeper-population ratio and vulnerability. Based on the sweeper-population ratio, all 43 wards of the city were categorized into five vulnerability groups (Figure 12).

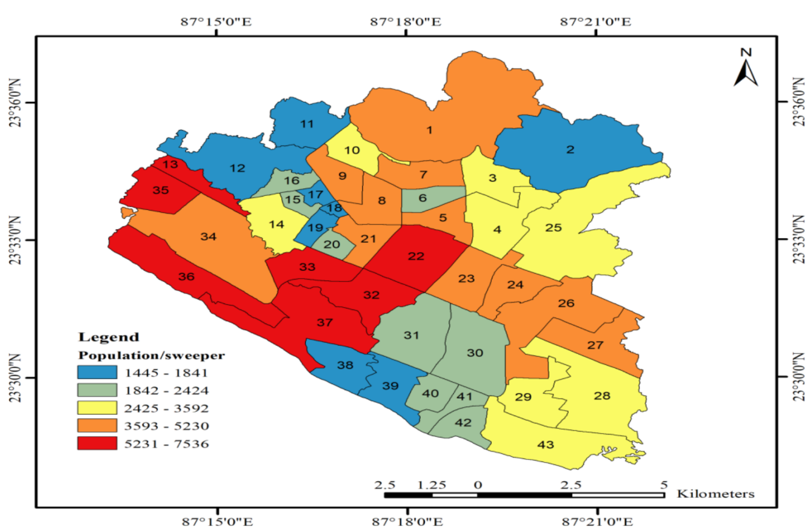

Fig. 12. Map of population/sweeper ratio of the study area.

2.4.11 Ward-wise waste generation

It is evident from the literature that there is positive correlation between the volume of waste generation and the level of vulnerability [63]. Durgapur city, like other cities in India, is experiencing a high quantity of waste generation that intensifies the vulnerability of the city linked to waste management problems. Insufficient management of solid waste leads to rampant littering of huge amounts of waste in a haphazard manner, posing risks to public health and the environment. It was considered that the large waste generating wards would experience a high risk of vulnerability related to waste hazard problems than the small waste generating wards. The vulnerability assessment of solid waste generation, categorized by the wards in DMC, was divided into five groups: very high vulnerable, high vulnerable, moderate vulnerable, low vulnerable, and very low vulnerable (Figure 13).

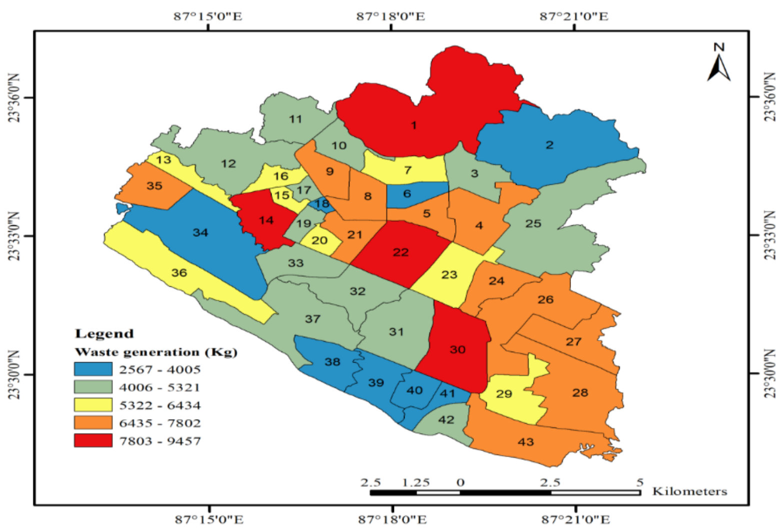

Fig. 13. Map of solid waste generation of the study area.

2.5 Rank Sum (RS) weight method

In order to create vulnerability maps and spatial analysis, different criteria related to waste management and infrastructure availability were chosen. Spatial maps were created in both feature and raster formats using various criteria. The selected vector or feature layers were transformed into raster layers (V2R) to assign rates and significance values. The Rank Sum weight method was applied, as it is a widely used tool in Multi-Criteria Decision Analysis (MCDA) for making complex decisions. In the RS technique, the weight is determined by normalizing individual ranks by dividing them by the total sum of ranks [64]. Decision-making in management studies is often influenced by multiple criteria, which may not hold equal importance in each case [65, 66]. Various methods have been documented in the literature to convert ranking orders into weights, including rank sum (RS), rank exponent (RE), rank reciprocal (RR), and rank order centroid (ROC) [64, 66, 67]. Among the different weighting methods proposed in the literature, rank-based approaches have been considered a good conciliation choice for several reasons: convert a criteria ranking order into numerical weights, ease of implementation, and the quality of the decision result [67]. Among different rank-order weighting methods, including RR, RS, and ROC, with the true weights based on a simulated expert's judgments without prior ranking, the use of Rank Sum was a good choice for the experts [68]. A comparative overview of different rank ordering weight methods was analysed. Several weighting methods were considered, including equal weight, rank sum, rank exponent, rank reciprocal, and centroid weights. Among these, the Rank Sum method was found to be the most suitable [64, 69-71]. These ranking methods were compared based on their accuracy in estimating weights under different conditions, such as varying numbers of criteria and decision-maker preferences structure, and the Rank Sum method was considered the best for estimating uniform weights [72].

Considering its importance and accuracy, Rank Sum was used in the present study to make a final decision on preparing the vulnerability assessment of solid waste management for Durgapur City. The first step in Rank Sum analysis involves defining decision criteria, which includes identifying the objective, selecting criteria/factors, choosing alternatives/sub-factors, normalizing the ranks, and making decisions based on the aggregated results. In the Rank Sum method, individual ranks are normalized by dividing them by the sum of all ranks. The equation for calculating weights is as follows (Eq. 1) [64-66, 73, 74].

$$Wj\ (RS) = \frac{n - rj + 1}{\sum_{k=1}^{n} n - rk + 1} = \frac{2n(n + 1 - rj)}{n(n+1)} \quad (1)$$

where *Wj* is the weight, n is the total number of criteria, *rj* is the rank of the j-th criterion, k is the index that iterates from 1 to n, and *rk is the rank of the k-th criterion*.

In the first phase of the study, the objective was to identify the areas that were most vulnerable to the issues related to municipal solid waste management. In the subsequent phase, weights were assigned to the selected factor based on the normalized sum to achieve the defined objective. For this study, eleven decision criteria were selected, viz., relative relief, slope, land use land cover, population density, literacy, population bin ratio (population/bin), waste disposal method, waste collection, frequency of waste collection, sweeper population ratio (population/sweeper), and waste generation. In the third phase, a waste management vulnerability map was prepared based on the weight of selected factors and alternatives. Finally, weighted overlay analysis (WOA) was used to classify the highest to least waste management vulnerability areas in Durgapur City. WOA is a method used to standardize various inputs on a common scale, allowing for a unified analysis of diverse factors [75].

Initially, the rank was applied to selected waste management-related factors based on their importance (Table 2). In this analysis, a ranking system was established where 1 represented the most critical factor, and 11 indicated the least important factor in terms of waste management vulnerability [73]. The RS method was then applied to calculate the Vulnerability Index (VI) by determining the respective weights of each chosen factor. These weights served as an index of sensitivity. Each selected factor was assigned a weight, and normalization was performed using the RS method, which is expressed as follows (Eq. 2):

$$RS = (n-R_i+1) \quad (2)$$

where *RS* is the rank sum, *n* is the number of factors under consideration (*1, 2, 3,.....n*), and R_i is the rank position of the factor or intensity of importance in decision making.

Table 2. The ranking scale to selected factors based on their importance in the vulnerability assessment of solid waste management.

Rank	Factors	Importance
1	Relative relief	10
2	Slope	11
3	LULC	9
4	Population density	8
5	Literacy	7
6	Population Bin Ratio (pop/bin)	5
7	Waste disposal method	6
8	Waste collection	1
9	Frequency of waste collection	3
10	Sweeper population ration (pop/sweeper)	4
11	Waste generation	2

Note: 1 was considered as the most important factor and 11 is least important factor in vulnerability mapping.

Each factor was weighted ‘n-Ri+1’ and then normalized by the sum weight ‘Wnj’. The normalized weight for each selected factor was assigned based on their relative significance, and the normalized weight was calculated by considering the following equation (Eq. 3):

$$W_{nj} = (n-R_i+1) \ / \ (\Sigma n-R_k+1) \quad (3)$$

where W_{nj} is the normalized weight, *n* is total no. of factors, R_k is the rank of factors, and R_i is the Intensity of importance.

The calculated weight or score for preparing the vulnerability map in a specific area was equal to the sum of each factor. The final waste management vulnerability map (WMVM) in Durgapur City was assessed from the following equation (Eq. 4):

$$WMVM = \Sigma\ (W_1nj * F_1 + W_2nj * F_2 + W_3nj * F_3\ W_nnj * F_n) \quad (4)$$

where *WMVM* is the waste management vulnerability map, $F_1, F_2, F_3, \ldots\ldots F_n$ are the selected factors, and $W_1nj, W_2nj, W_3nj, \ldots\ldots W_nnj$ are the normalized weight of each factor for vulnerability mapping.

2.4.1 Normalization of factors for vulnerability assessment of municipal solid waste management

While the numeric datasets were converted into raster pixels, some heterogeneity existed, which should be normalized for better results. Normalization is a process of removing heterogeneity from datasets and defining the objective of the study. In the present study, two formulas were used to normalize the selected factors used in the ward-wise vulnerability assessment of solid waste management in Durgapur City. Eq. 5 was used with datasets if the higher value of a factor was associated with higher vulnerability or vice versa. Eq. 6 was used if there was an inverse relation between the factors and vulnerability, i.e., a lower value of a factor was associated with higher vulnerability and vice versa.

$$Normalization = \left(\frac{F - F^{min}}{F^{max} - F^{min}}\right) \tag{5}$$

$$Normalization = \left(\frac{F^{max} - F}{F^{max} - F^{min}}\right) \tag{6}$$

where F is the un-normalised layer and F^{min} and F^{max} are the lowest and highest value of a particular factor, respectively. Details of the selected factors and their vulnerability are presented in Table 3.
The normalized maps of the selected factors are shown in Figure 14 (a-j).

Table 3. Value of each factor and vulnerability.

Sl. No	Factors	Factor value	Vulnerability
1	Relative relief	High value	Low vulnerability
2	Slope	High value	Low vulnerability
3	LULC	--	--
4	Population density	High density	High vulnerability
5	Literacy	High literacy	Low vulnerability
6	Population Bin Ratio	High value	High vulnerability
7	Waste disposal method	Open Dumping	High vulnerability
8	Waste collection	High value	Low vulnerability
9	Frequency of waste collection	No collection	High vulnerability
10	Sweeper population ration	High value	High vulnerability
11	Waste generation	High value	High vulnerability

Note: normalization is not possible for class categories

3. Results and Discussions

For the purpose of developing a vulnerability map for Durgapur City, eleven factors were selected and classified based on their influence in the decision-making process. These factors were grouped according to their significance in vulnerability assessment, with weights assigned according to expert views obtained from field observations. Each of the 11 factors was ranked on a scale of 1-11 based on their importance in vulnerability mapping. Using the RS approach, the normalized weights of all causative factors were computed. Risk scores were then assigned to 54 sub-factors, ranging from 1 (least importance) to 5 (very high importance), reflecting their relevance to waste hazard vulnerability (Table 4, 5).

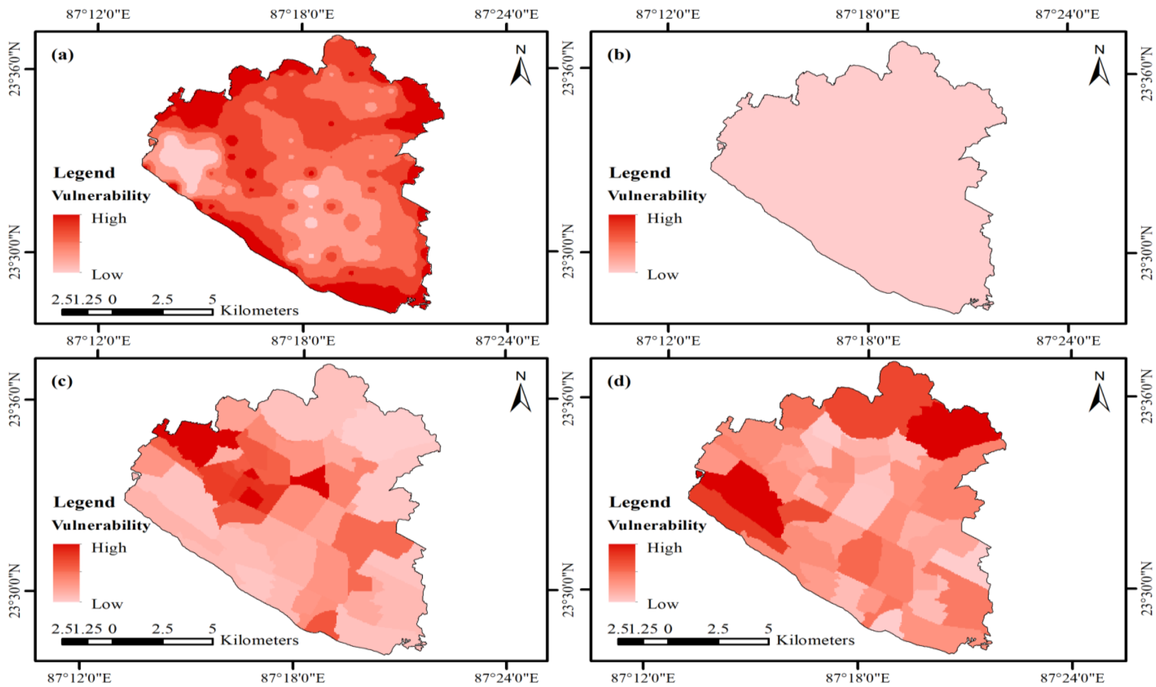

Fig. 14 (a-d). Normalized maps of relative relief (a), slope (b), population density (c), and literacy (d).

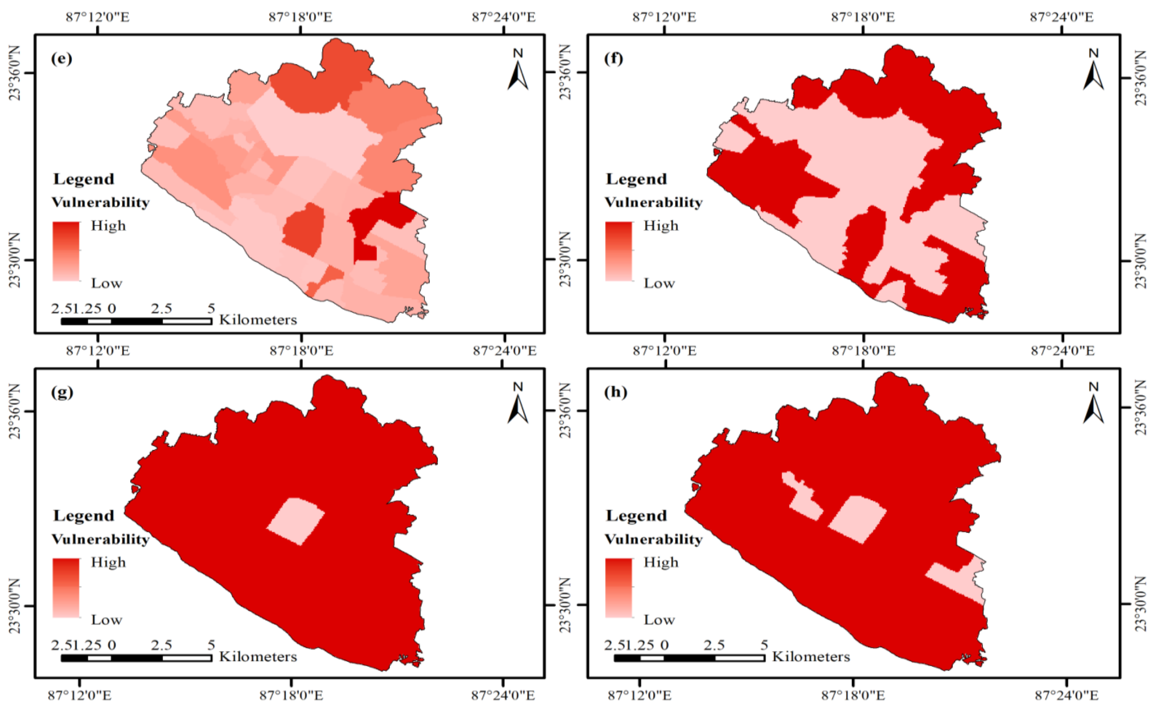

Fig. 14 (e-h). Normalized maps of Population Bin Ratio (e), Waste disposal method (f), Waste collection (g), and Frequency of waste collection (h).

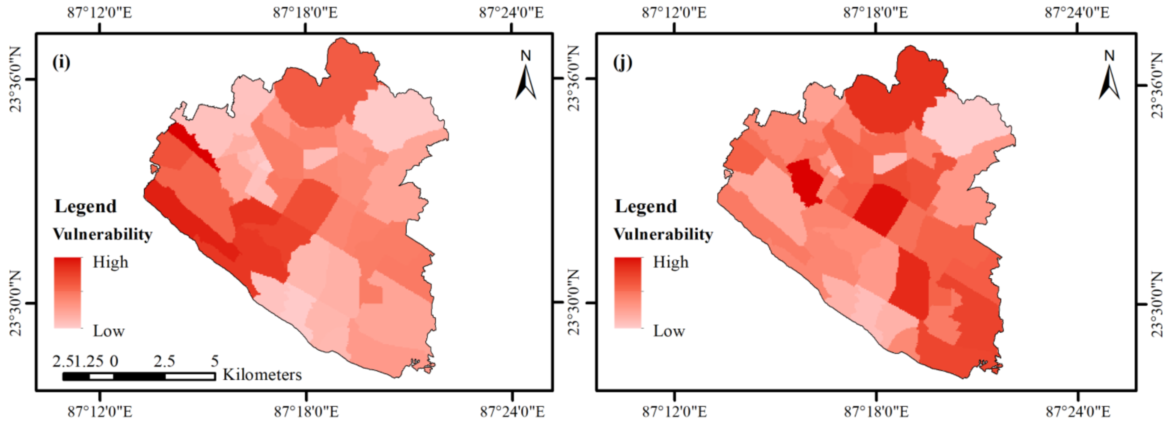

Fig. 14 (i-j). Normalized maps of sweeper-population ratio (i) and waste generation (j).

This study revealed that waste collection was the most significant factor influencing vulnerability in Durgapur, with the highest normalized weight of 0.1667. Given the essential role of waste collection in managing environmental quality, it is intuitive that this criterion significantly impacts vulnerability levels. Effective and frequent waste collection prevents the accumulation of waste, reducing exposure to pollutants and disease vectors. In contrast, wards with lower waste collection rates experienced higher vulnerability to environmental degradation and health risks. Waste generation was the second most important factor, with a normalized weight of 0.1515. Areas with high waste generation and inadequate waste management infrastructure were more prone to becoming vulnerable zones. The frequency of waste collection, sweeper population ratio, population bin ratio, and population density had an important contribution in vulnerability with the weights of 0.1364, 0.1212, 0.1061 and 0.0909 respectively; waste disposal methods also played a role in vulnerability. These elements highlight the role of service delivery and infrastructure in managing urban waste.

Slope, relative relief, LULC, population density, literacy, and waste disposal methods had comparatively low significance with low weights i.e., 0.0152, 0.0303, 0.0455, 0.0606, 0.0758 and 0.0909 respectively. This particular weight of each vulnerable factor was used for weight overlay analysis to identify the most vulnerable areas in Durgapur City. One of the key advantages of the Rank Sum approach was its ability to make optimal choices by ranking criteria and summing their values, which effectively met the needs of the analysis. The main purpose of employing multi-criteria analysis with the rank sum method was to explore the interrelationships among multiple factors and identify the most significant contributors to vulnerability associated with waste hazards in the area.

Table 4. Weight assigned to selected waste hazards related factors for mapping vulnerable areas.

Rk	Factor/Criteria	Ri	N- Ri +1	N- Rk + 1	Wnj
1	Relative relief	10	2	11	0.0303
2	Slope	11	1	10	0.0152
3	LULC	9	3	9	0.0455
4	Population density	8	4	8	0.0606
5	Literacy	7	5	7	0.0758
6	Population Bin Ratio (pop/bin)	5	7	6	0.1061
7	Waste disposal method	6	6	5	0.0909
8	Waste collection	1	11	4	0.1667
9	Frequency of waste collection	3	9	3	0.1364
10	Sweeper population ration (pop/sweeper)	4	8	2	0.1212
11	Waste generation	2	10	1	0.1515
				66	1.0000

Note: (1) Wnj= normalized weight, n= Total no of factors, Rk= Rank of factors and Ri= Intensity of importance; (2) Wnj= more or less than 1 is considered as inconsistence for decision making

Table 5. Risk Score of selected alternatives and weight of vulnerability (Goal: Vulnerability Assessment).

Criterion	Sub-criteria/alternatives	Risk Score	Normalized Weight	Weight (%)
Relative Relief (m)	1.05 - 16.12	5	0.030	3.03
	16.12 - 20.62	4		
	20.62 - 25.12	3		
	25.12 - 32.36	2		
	32.36 - 50.75	1		
Slope (degree)	0-2.81	5	0.015	1.51
	2.81-5.36	4		
	5.36-8.94	3		
	8.94-15.33	2		
	15.33-65.16	1		
Land Use Land Cover	Built-up	5	0.045	4.54
	Settlement	5		
	Industrial zone	4		
	Swamp land	2		
	Sparse vegetation	2		
	Fallow land with vegetation	1		
	Green space with vegetation	2		
	Barren land	1		
	Water bodies	3		
Population Density (per sq. km)	648-2399	1	0.061	6.06
	2399-4581	2		
	4581-7484	3		
	7484-13770	4		
	>13770	5		
Literacy rate (in percent)	≤ 46.7	5	0.076	7.57
	46.7-74.4	4		
	74.4-86.7	3		
	86.7-92.2	2		
	> 92.2	1		
Population-waste bins ratio	45-676	1	0.106	1.06
	676-1611	2		
	1611-3219	3		
	3219-6353	4		
	6353-16516	5		
Waste Disposal Methods	Open Dumping	2	0.091	9.09
	Dustbins	4		
Waste Collection (in percent)	0	5	0.167	16.66
	1- 60	4		
	61-70	3		
	71-77	2		
	78-88	1		
Frequency of waste collection	No Collection	5	0.136	13.63
	Monthly	4		
	Fortnightly	3		
	Weekly	2		
Sweeper-Population Ratio	1445-1841	1	0.121	12.12
	1842-2424	2		
	2425-3592	3		
	3593-5230	4		
	5231-7536	5		
Waste generation	2567-3561	1	0.152	15.15
	3561-4547	2		
	4547-6095	3		
	6095-7802	4		
	>7802	5		

Note: Level of vulnerability 5=Very High Vulnerability, 4= High Vulnerability, 3=Medium Vulnerability, 2= Low Vulnerability, and 1= Very Low Vulnerability

Successively, in order to identify vulnerable areas based on the selected factors, the relative importance of each factor was assigned to the corresponding map layers, and a weighted overlay analysis was conducted. Weighted overlay is a technique that applies a common measurement scale to different inputs for integrated analysis. Hence, in this study, the weighted overlay analysis (WOA) of each layer, such as relative relief, slope, LULC, population density, literacy, population-bin ratio, waste disposal method, waste collection, and frequency of waste collection, sweeper-population ratio, and waste generation, was engaged based on their derived weight. The weight of all the waste-related hazard factors was given to each thematic layer, and the WOA function was run, shaping the final vulnerable areas in Durgapur City. The results revealed that waste collection, waste generation, frequency of waste collection, sweeper-to-population ratio (pop/sweeper), population-to-bin ratio (pop/bin), and population density are significant factors contributing to vulnerability related to waste hazards in areas of Durgapur. Along with slope, relative relief, LULC, population density, and literacy, the waste disposal method also played a significant role in the vulnerability of waste-related hazards from a large to a small extent. The very high vulnerable areas are found in 12.15% of the areas of the city that witnessed high waste generation, minimum waste collection, less frequency of waste collection, less use of dustbins, and a high population/sweeper ratio.

In this context, an effort was made to combine the waste-related hazard factors with spatial analysis to assign the most vulnerable areas in Durgapur City using RS and GIS. The Rank Sum method, a decision-making technique, was employed to assess vulnerability to waste-related hazards. This method has gained widespread acceptance in GIS environments for spatial analysis due to its ability to assign consistent spatial weights. Concerning the task of vulnerability mapping, the result placed or categorized areas with respect to their waste hazard levels, greater vulnerable areas associated with ward numbers 1, 13, 14, 21, and 26. Therefore, it is recommended that these areas should implement improved waste management practices. Thus, the final vulnerable map was prepared, and the level of vulnerability was categorized into five classes (Figure 15).

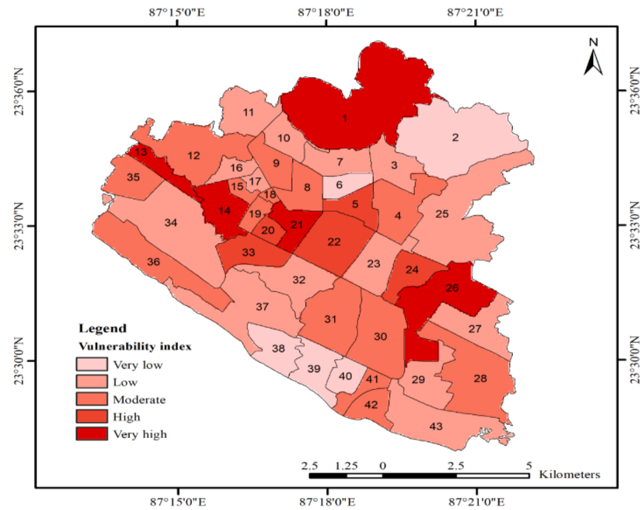

Fig. 15. Mapping of vulnerable areas in the study area.

Table 7 elaborates on the combination of selected factors, as stated earlier. The vulnerable map (Figure 15) of Durgapur City, prepared by combining RS and GIS, shows that there was a significant spatial variation in the level of vulnerability in DMC. The results revealed that the very high vulnerable areas were mainly found in wards 1, 13, 14, 21, and 26, where there was high waste generation, low percent of waste collection, high interval of waste collection frequency, open dumping of waste disposal, high sweeper-population ratio, and high population-waste bin ratio. These areas geographically featured low relative relief and less percentage of slope area. Table 6 shows that approximately 12.15% of the area came under the very high vulnerable index, which consisted of 15.19% of the population of the city. Five other wards, including 5, 20, 22, 24, and 33, were spread over 5.35% of the area, falling under a high vulnerable index consisting of 14.18% of the population in the city. These wards are located in the core part of the city. These areas are also geographically featured with low relative relief and less percentage of sloppy areas. The problems associated with solid waste in these areas include densely populated areas, high waste generation, high sweeper-population ratio, and population-bin ratio; also, the open dumping of waste disposal method is practiced.

Table 7. Durgapur City: Level of vulnerability.

Level of Vulnerability	Area (in percent)	Population-2016 (in percent)	Solid waste (%)	Total number of wards	Ward numbers
Very High	12.15	15.19	15.19	5	1, 13, 14, 21, 26
High	5.35	14.18	14.18	5	5, 20, 22, 24, 33
Medium	22.16	33.16	33.16	14	4, 8, 9, 12, 15, 18, 19, 28, 30, 31, 35, 36, 41, 42
Low	45.72	30.96	30.96	14	3, 7, 10, 11, 16, 17, 23, 25, 27, 29, 32, 34, 37, 43
Very Low	14.61	6.50	6.50	5	2, 6, 38, 39, 40
Total	100.00	100.00	100.00	43	

Source: Calculated by the researcher on the basis of data obtained from DMC

Another 14 wards, including 4, 8, 9, 12, 15, 18, 19, 28, 30, 31, 35, 36, 41, and 42, came under moderately vulnerable areas that cover 22.16% of the area of the city comprising 33.16% of the city's population. Generally, in these areas, there was high waste generation, densely populated areas, low percentage of waste collection, open dumping of waste, and high population-sweeper and high population-bins ratios that caused problems related to waste management. Approximately 45.72% of the city fell under a low vulnerable area, consisting of 30.96% of the population. Fourteen wards were considered low vulnerable areas: 3, 7, 10, 11, 16, 17, 23, 25, 27, 29, 32, 34, 37, and 43. These areas were geographically characterized by high relative relief and sloppy areas. These areas were generally less densely populated zones, having a high percent of literacy among people, a high percent of waste collection by DMC vehicles, and practice using dustbins for waste disposal, leading to better waste management. Ward numbers 2, 6, 38, 39, and 40 came under very low vulnerable areas that covered 14.61% of the area, consisting of 6.50% of the population of the city. Geographically, these wards featured high relative relief and sloppy areas. These wards were characterized by less population density, high literacy rates, and better availability of dustbins.

4. Conclusion

This study examined the spatial distribution of waste management vulnerabilities in Durgapur City, applying a multi-criteria decision-making approach integrated with GIS. The findings showed that 12.15% of the city's area, primarily in wards 1, 13, 14, 21, and 26, was categorized as highly vulnerable due to high waste generation, low collection efficiency, unscientific waste disposal, and inadequate infrastructure, which increased the risks of environmental degradation and public health issues. Another 5.35% of the city, mainly in the densely populated central wards, also faced significant vulnerability due to similar waste management challenges and geographical constraints. The findings also highlighted that waste generation and collection, along with demographic factors, such as population density and sweeper-to-population ratio, were the most critical determinants of vulnerability in the city. The application of the Rank Sum method effectively identified these key factors, while the weighted overlay analysis spatially delineated the areas that were most at risk.

This study provides a crucial framework for urban planners and policymakers in Durgapur to prioritize interventions. Immediate attention should be directed towards enhancing waste collection efficiency, optimizing the distribution of waste bins, and implementing public awareness campaigns in the most vulnerable wards. Additionally, improving infrastructure and waste management practices in these areas is indispensable to mitigate the identified environmental and public health risks. Overall, the integration of the Rank Sum method with GIS in this study has proven to be a robust tool for vulnerability assessment, offering essential insights for future urban planning and sustainable waste management practices in Durgapur. This approach could be a valuable model for other urban areas facing similar challenges, contributing to the broader goal of building resilient and sustainable cities.

Funding

No funding was received to assist in this research.

Declaration of competing interest

The author declared no conflict of interest.

References

[1] Chandel, A. S., Weto, A. E., & Bekele, D. (2024). Geospatial technology for selecting suitable sites for solid waste disposal: a case study of Shone town, central Ethiopia. Urban, Planning and Transport Research, 12(1), 2302531. https://doi.org/10.1080/21650020.2024.2302531

[2] Awasthi, M. K., Sarsaiya, S., Chen, H., Wang, Q., Wang, M., Awasthi, S. K., & Zhang, Z. (2019). Global status of waste-to-energy technology. In Current developments in biotechnology and bioengineering (pp. 31-52). Elsevier. https://doi.org/10.1016/B978-0-444-64083-3.00003-8

[3] Chen, Y. C. (2018). Effects of urbanization on municipal solid waste composition. Waste management, 79, 828-836. https://doi.org/10.1016/j.wasman.2018.04.017

[4] Ouda, O. K., Raza, S. A., Nizami, A. S., Rehan, M., Al-Waked, R., & Korres, N. E. (2016). Waste to energy potential: A case study of Saudi Arabia. Renewable and Sustainable Energy Reviews, 61, 328–340. https://doi.org/10.1016/j.rser.2016.04.005

[5] Voukkali, I., Papamichael, I., Loizia, P., & Zorpas, A. A. (2024). Urbanization and solid waste production: Prospects and challenges. Environmental Science and Pollution Research, 31(12), 17678-17689. https://doi.org/10.1007/s11356-023-27670-2

[6] Chandrappa, R., & Das, D. B. (2024). Waste quantities and characteristics. In Solid Waste Management: Principles and Practice (pp. 47-87). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-50442-6_2

[7] Ameen, M., Anwar-Ul-Haq, M., Sohail, M. I., Akmal, F., & Siddiqui, A. (2023). Mismanagement of Waste in Developing Countries. In Waste Problems and Management in Developing Countries (pp. 31-72). Apple Academic Press.

[8] Mor, S., & Ravindra, K. (2023). Municipal solid waste landfills in lower-and middle-income countries: Environmental impacts, challenges and sustainable management practices. Process Safety and Environmental Protection, 174, 510-530. https://doi.org/10.1016/j.psep.2023.04.014

[9] Ouda, O. K., Cekirge, H. M., & Raza, S. A. (2013). An assessment of the potential contribution from waste-to-energy facilities to electricity demand in Saudi Arabia. Energy Conversion and Management, 75, 402–406. https://doi.org/10.1016/j.enconman.2013.06.056

[10] Sukanya, R., & Tantia, V. (2023). Urbanization and the impact on economic development. In New Perspectives and Possibilities in Strategic Management in the 21st Century: Between Tradition and Modernity (pp. 369-408). IGI Global. https://doi.org/10.4018/978-1-6684-9261-1.ch019

[11] Meena, M. D., Dotaniya, M. L., Meena, B. L., Rai, P. K., Antil, R. S., Meena, H. S., ... & Meena, R. B. (2023). Municipal solid waste: Opportunities, challenges and management policies in India: A review. Waste Management Bulletin, 1(1), 4-18. https://doi.org/10.1016/j.wmb.2023.04.001

[12] Choudhary, M., Singh, D., Parihar, M., Choudhary, K. B., Nogia, M., Samal, S. K., & Mishra, R. (2024). Impact of municipal solid waste on the environment, soil, and human health. In Waste Management for Sustainable and Restored Agricultural Soil (pp. 33-58). Academic Press. https://doi.org/10.1016/B978-0-443-18486-4.00011-7

[13] Sk, M. M., Ali, S. A., & Ahmad, A. (2020). Optimal sanitary landfill site selection for solid waste disposal in Durgapur city using geographic information system and multi-criteria evaluation technique. KN-Journal of Cartography and Geographic Information, 70, 163-180. https://doi.org/10.1007/s42489-020-00052-1

[14] Ali, S. A., Parvin, F., Al-Ansari, N., Pham, Q. B., Ahmad, A., Raj, M. S., & Thai, V. N. (2021). Sanitary landfill site selection by integrating AHP and FTOPSIS with GIS: a case study of Memari Municipality, India. Environmental Science and Pollution Research, 28, 7528-7550. https://doi.org/10.1007/s11356-020-11004-7

[15] Sharma, S., & Parthasarathy, D. (2018). Urban ecologies in transition: Contestations around waste in Mumbai. In J. Mukherjee (Ed.),

Sustainable Urbanization in India, in Exploring Urban Change in South Asia (pp. 207–223). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-10-4932-3_11

[16] Velpandian, T., Kumari, S., Jain, S., Gupta, P., Biswal, S., Mathur, P., & Gupta, Y. K. (2018). Un-segregated waste disposal: An alarming threat of antimicrobials in surface and groundwater sources in Delhi. Environmental Science and Pollution Research, 25(29), 29518–29528. https://doi.org/10.1007/s11356-018-2927-9

[17] Ghobadi, M. (2024). Environmental capability assessment for MSW landfill site using geographic information system and multi-criteria evaluation. Advances in Environmental Technology, 10(1), 29–40. https://doi.org/10.22104/aet.2023.6210.1712

[18] Manguri, S. B. H., Omer, B., Ahmed, A., Hamad, S., Mawlood, S., & Majid, A. (2024). Optimization of municipal solid waste landfill site selection by geospatial analysis in the Ranya District of Iraq. Advances in Environmental Technology, 10(3), 218–236. https://doi.org/10.22104/aet.2024.6676.1823

[19] Sk, M. M., Qamar, S., & Sethy, T. (2023). Solid Waste Management In Indian Perspectives: A Comprehensive Review. Humanities and Social Science Studie, 12(1), 35-45. https://www.researchgate.net/publication/373737929

[20] Sk, M. M. (2023). Spatial Analysis of Solid Waste Generation Patterns In A Fast-Growing Industrial City-Durgapur, India. Journal of Emerging Technologies and Innovative Research, 10(7), e245-253. https://www.researchgate.net/publication/373173198

[21] Banerjee, U. S., & Gupta, S. (2013). Impact of industrial waste effluents on river Damodar adjacent to Durgapur industrial complex, West Bengal, India. Environmental Monitoring and Assessment, 185(3), 2083–2094. https://doi.org/10.1007/s10661-012-2690-1

[22] Tsatsaris, A., Kalogeropoulos, K., Stathopoulos, N., Louka, P., Tsanakas, K., Tsesmelis, D. E., & Chalkias, C. (2021). Geoinformation technologies in support of environmental hazards monitoring under climate change: An extensive review. ISPRS International Journal of Geo-Information, 10(2), 94. https://doi.org/10.3390/ijgi10020094

[23] Daud, M., Ugliotti, F. M., & Osello, A. (2024). Comprehensive analysis of the use of Web-GIS for natural hazard management: A systematic review. Sustainability, 16(10), 4238. https://doi.org/10.3390/su16104238

[24] Ali, S. A., Khatun, R., Ahmad, A., & Ahmad, S. N. (2020). Assessment of cyclone vulnerability, hazard evaluation and mitigation capacity for analyzing cyclone risk using GIS technique: A study on Sundarban biosphere reserve, India. Earth Systems and Environment, 4, 71-92. https://doi.org/10.1007/s41748-019-00140-x

[25] Bilgilioglu, S. S., Gezgin, C., Orhan, O., & Karakus, P. (2022). A GIS-based multi-criteria decision-making method for the selection of potential municipal solid waste disposal sites in Mersin, Turkey. Environmental Science and Pollution Research, 1-17. https://doi.org/10.1007/s11356-021-15859-2

[26] Parvin, F., Ali, S. A., Calka, B., Bielecka, E., Linh, N. T. T., & Pham, Q. B. (2022). Urban flood vulnerability assessment in a densely urbanized city using multi-factor analysis and machine learning algorithms. Theoretical and Applied Climatology, 149(1), 639-659. https://doi.org/10.1007/s00704-022-04068-7

[27] Chisty, M. A., & Rahman, M. M. (2020). Coping capacity assessment of urban fire disaster: An exploratory study on ward no: 30 of Old Dhaka area. International Journal of Disaster Risk Reduction, 51, 101878. https://doi.org/10.1016/j.ijdrr.2020.101878

[28] Mihai, F. C., Gündoğdu, S., Markley, L. A., Olivelli, A., Khan, F. R., Gwinnett, C., & Molinos-Senante, M. (2021). Plastic pollution, waste management issues, and circular economy opportunities in rural communities. Sustainability, 14(1), 20. https://doi.org/10.3390/su14010020

[29] Diaz-Sarachaga, J. M., & Jato-Espino, D. (2020). Analysis of vulnerability assessment frameworks and methodologies in urban areas. Natural Hazards, 100(1), 437-457. https://doi.org/10.1007/s11069-019-03805-y

[30] Shockley, K. (2023). Two faces of vulnerability: Distinguishing susceptibility to harm and system resilience in climate adaptation. Wiley Interdisciplinary Reviews: Climate Change, 14(6), e856. https://doi.org/10.1002/wcc.856

[31] Shah, M. A. R., Renaud, F. G., Anderson, C. C., Wild, A., Domeneghetti, A., Polderman, A., &

Zixuan, W. (2020). A review of hydro-meteorological hazard, vulnerability, and risk assessment frameworks and indicators in the context of nature-based solutions. International journal of disaster risk reduction, 50, 101728. https://doi.org/10.1016/j.ijdrr.2020.101728

[32] Asfaw, H., Karuppannan, S., Erduno, T., Almohamad, H., Dughairi, A. A. A., Al-Mutiry, M., & Abdo, H. G. (2022). Evaluation of vulnerability status of the infection risk to COVID-19 using geographic information systems (GIS) and multi-criteria decision analysis (MCDA): a case study of Addis Ababa City, Ethiopia. International Journal of Environmental Research and Public Health, 19(13), 7811. https://doi.org/10.3390/ijerph19137811

[33] Bhuyan, M. J., Deka, N., & Saikia, A. (2024). Micro‐spatial flood risk assessment in Nagaon district, Assam (India) using GIS‐based multi‐criteria decision analysis (MCDA) and analytical hierarchy process (AHP). Risk Analysis, 44(4), 817-832. https://doi.org/10.1111/risa.14191

[34] Duan, C., Zhang, J., Chen, Y., Lang, Q., Zhang, Y., Wu, C., & Zhang, Z. (2022). Comprehensive risk assessment of urban waterlogging disaster based on MCDA-GIS integration: The case study of Changchun, China. Remote Sensing, 14(13), 3101. https://doi.org/10.3390/rs14133101

[35] Cinelli, M., Kadziński, M., Miebs, G., Gonzalez, M., & Słowiński, R. (2022). Recommending multiple criteria decision analysis methods with a new taxonomy-based decision support system. European Journal of Operational Research, 302(2), 633-651. https://doi.org/10.1016/j.ejor.2022.01.011

[36] Basílio, M. P., Pereira, V., Costa, H. G., Santos, M., & Ghosh, A. (2022). A systematic review of the applications of multi-criteria decision aid methods (1977–2022). Electronics, 11(11), 1720. https://doi.org/10.3390/electronics11111720

[37] Beaudrie, C., Corbett, C. J., Lewandowski, T. A., Malloy, T., & Zhou, X. (2021). Evaluating the application of decision analysis methods in simulated alternatives assessment case studies: Potential benefits and challenges of using MCDA. Integrated environmental assessment and management, 17(1), 27-41. https://doi.org/10.1002/ieam.4316

[38] Ustaoglu, E., Sisman, S., & Aydınoglu, A. C. (2021). Determining agricultural suitable land in peri-urban geography using GIS and Multi Criteria Decision Analysis (MCDA) techniques. Ecological Modelling, 455, 109610. https://doi.org/10.1016/j.ecolmodel.2021.109610

[39] Hatefi, M. A. (2024). A new method for weighting decision making attributes: an application in high-tech selection in oil and gas industry. Soft Computing, 28(1), 281-303. https://doi.org/10.1007/s00500-023-09282-7

[40] Zardari, N. H., Ahmed, K., Shirazi, S. M., & Yusop, Z. B. (2014). Weighting methods and their effects on multi-criteria decision making model outcomes in water resources management. Springer. https://doi.org/10.1007/978-3-319-12586-2

[41] Ding, Y., Fu, Y., Lai, K. K., & Leung, W. K. J. (2018). Using ranked weights and acceptability analysis to construct composite indicators: A case study of Regional Sustainable Society Index. Social Indicators Research, 139(3), 871–885. https://doi.org/10.1007/s11205-017-1765-3

[42] Kumar, R., Khaira, J. K., Ahmed, R., Devrani, R., & Deshmukh, B. (2024). Land degradation vulnerability mapping using geospatial techniques: a case study of Nandakini River basin, NW Himalaya, India. International Journal of River Basin Management, 1-16. https://doi.org/10.1080/15715124.2024.2396141

[43] Iacoboaea, C., Luca, O., Șercăianu, M., Aldea, M., Păunescu, M., & Popescu, A. L. (2024). Towards Sustainable Modes for Remote Monitoring in Waste Management: A Study of Marginalized Urban Areas in Romania. Sustainability, 16(6), 2400. https://doi.org/10.3390/su16062400

[44] Mainul, S. K., Ahmad, A., & Ali, S. A. (2019). Integrating public-private participation for sustainable solid waste management in Durgapur City: West Bengal. The Geographer, 66(2), 57-66.

[45] Bhattarai, K., Conway, D., Bhattarai, K., & Conway, D. (2021). Urban growth. Contemporary Environmental Problems in Nepal: Geographic Perspectives, 201-334. https://doi.org/10.1007/978-3-030-50168-6_4

[46] Abubakar, I. R., Maniruzzaman, K. M., Dano, U. L., AlShihri, F. S., AlShammari, M. S., Ahmed, S. M. S., & Alrawaf, T. I. (2022). Environmental sustainability impacts of solid waste management practices in the global

South. International journal of environmental research and public health, 19(19), 12717. https://doi.org/10.3390/ijerph191912717

[47] Zambrano-Monserrate, M. A., Ruano, M. A., & Ormeño-Candelario, V. (2021). Determinants of municipal solid waste: a global analysis by countries' income level. Environmental Science and Pollution Research, 28, 62421-62430. https://doi.org/10.1007/s11356-021-15167-9

[48] Araiza-Aguilar, J. A., Rojas-Valencia, M. N., & Aguilar-Vera, R. A. (2020). Forecast generation model of municipal solid waste using multiple linear regression. Global Journal of Environmental Science and Management, 6(1), 1-14. https://doi.org/10.22034/GJESM.2020.01.01

[49] de Titto, E., & Savino, A. (2024). Human Health Impact of Municipal Solid Waste Mismanagement: A Review. Advances in Environmental and Engineering Research, 5(2), 1-37. http://dx.doi.org/10.21926/aeer.2402014

[50] Debrah, J. K., Vidal, D. G., & Dinis, M. A. P. (2021). Raising awareness on solid waste management through formal education for sustainability: A developing countries evidence review. Recycling, 6(1), 6. https://doi.org/10.3390/recycling6010006

[51] Salem, M., Raab, K., & Wagner, R. (2020). Solid waste management: The disposal behavior of poor people living in Gaza Strip refugee camps. Resources, Conservation and Recycling, 153, 104550. https://doi.org/10.1016/j.resconrec.2019.104550

[52] Akmal, T., & Jamil, F. (2021). Assessing health damages from improper disposal of solid waste in metropolitan Islamabad–Rawalpindi, Pakistan. Sustainability, 13(5), 2717. https://doi.org/10.3390/su13052717

[53] Olukanni, D. O., Pius-Imue, F. B., & Joseph, S. O. (2020). Public perception of solid waste management practices in Nigeria: Ogun State experience. Recycling, 5(2), 8. https://doi.org/10.3390/recycling5020008

[54] kwun Omang, D. I., John, G. E., Inah, S. A., & Bisong, J. O. (2021). Public health implication of solid waste generated by households in Bekwarra Local Government area. African Health Sciences, 21(3), 1467-1473. https://doi.org/10.4314/ahs.v21i3.58

[55] Siddiqua, A., Hahladakis, J. N., & Al-Attiya, W. A. K. (2022). An overview of the environmental pollution and health effects associated with waste landfilling and open dumping. Environmental Science and Pollution Research, 29(39), 58514-58536. https://doi.org/10.1007/s11356-022-21578-z

[56] Domenico, B., Alice, D. P. B., Lorenza, L., La Torre, G., Cocchiara, R. A., Sestili, C., ... & La Torre, G. (2022). The impact of environmental alterations on human microbiota and infectious diseases. In Environmental Alteration Leads to Human Disease: A Planetary Health Approach (pp. 209-227). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-83160-8_10

[57] Vinti, G., Bauza, V., Clasen, T., Medlicott, K., Tudor, T., Zurbrügg, C., & Vaccari, M. (2021). Municipal solid waste management and adverse health outcomes: A systematic review. International journal of environmental research and public health, 18(8), 4331. https://doi.org/10.3390/ijerph18084331

[58] Chavan, D., Arya, S., & Kumar, S. (2022). Open dumping of organic waste: Associated fire, environmental pollution and health hazards. In Advanced organic waste management (pp. 15-31). Elsevier. https://doi.org/10.1016/B978-0-323-85792-5.00014-9

[59] Mainul, S. (2019). Challenges in the management of single-use plastic carrier bags in Aligarh City: A study on sellers and consumer attitude. International Journal of Research in Social Sciences, 9(7), 732-750. https://www.researchgate.net/profile/Md-Sk-7/publication/372440858

[60] Shahab, S., & Anjum, M. (2022). Solid waste management scenario in india and illegal dump detection using deep learning: an AI approach towards the sustainable waste management. Sustainability, 14(23), 15896. https://doi.org/10.3390/su142315896

[61] Jasrotia, A., & Soloman, P. E. (2021). Environment Hazards from Municipal Solid Waste of Urban Space: A Global Perspective. Urban Growth and Environmental Issues in India, 269-286. https://doi.org/10.1007/978-981-16-4273-9_17

[62] Keshava, D. S. (2006). Urbanization and Solid Waste Management in Bangalore: Growth, Options and Challenges. Keshava SR (2006),"Urbanization and solid waste management in Bangalore: growth option and challenges" in Environmental Issues of

Development, edit, Ganesh Kawadia and Kanhaiya Ahuja, 225-241. The Associated Publishers, New Delhi, ISBN 81-8429-038-1.

[63] Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2012). Social vulnerability to environmental hazards. In Hazards vulnerability and environmental justice (pp. 143-160). Routledge. https://dx.doi.org/10.2139/ssrn.4338413

[64] Stillwell, W. G., Seaver, D. A., & Edwards, W. (1981). A comparison of weight approximation techniques in multiattribute utility decision making. Organizational behavior and human performance, 28(1), 62-77. https://doi.org/10.1016/0030-5073(81)90015-5

[65] Hwang, C. L., & Lin, M. J. (2012). Group decision making under multiple criteria: methods and applications (Vol. 281). Springer Science & Business Media.

[66] Malczewski, J. (2006). GIS-based multicriteria decision analysis: a survey of the literature. International journal of geographical information science, 20(7), 703-726. https://doi.org/10.1080/13658810600661508

[67] Sureeyatanapas, P. (2016). Comparison of rank-based weighting methods for multi-criteria decision making. Engineering and Applied Science Research, 43, 376-379. https://ph01.tci-thaijo.org/index.php/easr/article/view/70803

[68] Saeid, M., Abd Ghani, A. A., & Selamat, H. (2008). Rank-order weighting of web attributes for website evaluation (Doctoral dissertation, Universiti Putra Malaysia). https://core.ac.uk/download/pdf/42994132.pdf

[69] Solymosi, T., & Dombi, J. (1986). A method for determining the weights of criteria: the centralized weights. European journal of operational research, 26(1), 35-41. https://doi.org/10.1016/0377-2217(86)90157-8

[70] Barron, F. H., & Barrett, B. E. (1996). Decision quality using ranked attribute weights. Management science, 42(11), 1515-1523. https://doi.org/10.1287/mnsc.42.11.1515

[71] Youn, S., Ahn, J. H., & Park, K. (2008, April). Entrance detection of a moving object using intensity average variation of subtraction images. In 2008 International Conference on Smart Manufacturing Application (pp. 459-464). IEEE. https://doi.org/10.1109/ICSMA.2008.4505600

[72] Rassem, H. H., Nour, A. H., & Yunus, R. M. (2016). Techniques for extraction of essential oils from plants: a review. Australian Journal of Basic and Applied Sciences, 10(16), 117-127. https://www.ajbasweb.com/old/ajbas/2016/November/117-127.pdf

[73] Zeleňáková, M., Gaňová, L., & Kuzevičová, Ž. (2011). Using ranking method and geographical information system for evaluation flood vulnerable areas in eastern Slovakia. Journal of Landscape Management, 2(2), 21-25.

[74] Roszkowska, E. (2013). Rank ordering criteria weighting methods–a comparative overview. Optimum. Studia Ekonomiczne, 5 (65), 14-33. https://doi.org/10.15290/ose.2013.05.65.02

[75] Xiao, Y., Yi, S., & Tang, Z. (2017). Integrated flood hazard assessment based on spatial ordered weighted averaging method considering spatial heterogeneity of risk preference. Science of the Total Environment, 599–600, 1034–1046. https://doi.org/10.1016/j.scitotenv.2017.04.218

How to cite this paper:

SK, M. M. (2025). Assessing vulnerability of a solid waste management system through GIS and the rank sum method: a case study of Durgapur city, India. Advances in Environmental Technology, 11(1), 36-62. DOI: 10.22104/AET.2024.7053.1939