Research Article

Spatial–temporal variations and forecasting analysis of municipal solid waste in the mountainous city of north-western Himalayas

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Abstract
Municipal solid waste management is a growing problem faced by several municipalities and has become a global issue, particularly in mountainous cities of developing countries. This study focuses on the existing pattern of municipal solid waste management (MSWM) and challenges in the mountainous city of Srinagar, Kashmir, India. The study aims at analysing the municipal solid waste composition, spatio-temporal variations of municipal solid waste generated and its management by using ArcGIS mapping software. The annual results of MSW composition revealed high organic waste (53.40%), followed by recyclable (16.79%) and inert waste (23.40%), respectively. Further, the ANOVA statistical analysis in SPSS software was utilized to evaluate the seasonal variations between two seasons (i.e. winter and summer). The results showed a significance between the type of MSW and the season in which MSW was generated ($p = 0.001$). Further, the GIS-based spatial maps were generated, viz. ward-wise location, population density, municipal solid waste generation, wastebin density and spatial distribution of open waste points with illegal dumpsites. The spatial map findings showed high-density of MSW generation between (30.04 and 35.65) Mt day^{-1} in administrative wards of (4, 6, 7, 16, 20, 21, 22 and 23), due to high population density. Furthermore, the forecast trend of MSW generation between 2020 and 2030 was evaluated in Minitab software. Based on forecasted findings, a total of 216,82,10 Mt MS will be generated during the next decade (i.e. 2020–2030). This high-quantity trend of MSW generation indicates that extra pressure will be on the existing MSW system. However, the problems of MSW management can be mitigated by implementing the integrated waste management plan.

Keywords Municipal solid waste (MSW) · Mountainous · Population · Spatial · Geographical information system (GIS) · Forecasting

1 Introduction

Globally, every country faces environmental problems in assorted forms. Municipal solid waste management (MSWM) is the most challenging environmental problem for each municipality of the world. Also, municipal waste management has become an emergent threat on the agenda of global sustainability to the United Nations due to the population explosion [1]. The world population is 7.3 billion and will increase in the coming decades to 9 billion, and around 80% of this raising population will be settled in the cities [2], while the MSW generation is increasing around various nations due to many factors, such as urbanization, consumption patterns and growth of population, respectively [3]. Nearly 2.01 billion tonnes of waste is produced around the world annually, and 3.40 billion tonnes is expected growth by the year 2050 [4].

However, the global scenario shows waste collection rates in African countries is 44%, while in Europe, Central Asia and North America, around 90% of the waste is

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collected, respectively [4]. The waste collection is dependent on the budget system of an MSW managing body of the particular region, mostly the government of developing countries lacks resources, while developed nations have enough fund for the waste collection system. Mainly, waste is produced in or around cities, and inappropriate waste collection has an immense threat to public health and the surroundings [5]. MSW management solutions vary from region to region, for factors, such as different socio-economic conditions and demography. However, the scenario of MSW generation is different, as we shift from low-altitude to high-altitude regions, like the mountains face several challenges in the form of low temperatures, remoteness, prone to natural hazards, difficult topography and hapless socio-economic circumstances, respectively [6]. These factors may juxtapose additional challenges to the mountainous regions, such as difficulties while collecting and transporting MSW, the building of recycling centres and identification of suitable waste landfills. The remoteness and hilly terrain in mountainous areas having roundabout routes to avoid steep areas increases the distance to vehicles from collection points. Further, the elevation difference in the mountains can increase time travel and fuel will be more to cover a particular area or distance [7]. While another major issue is the suitability of landfills, due to the natural slope, it is difficult to find the landfill area for dumping.

Mountains play a substantive role by providing enough services like energy, food, water and other important natural products to the inhabitants of mountains and downstream areas. Moreover, 22% of the world's land surface is covered by mountains and is home to 13% of the global population [8]. Moreover, the literature has shown that the Himalayan region faces many environmental problems and has an impact on the mountain ecosystem [5]. The beauty and the placid environment in the Indian Himalayan region have been always an origin of attraction to every natural lover [9] Besides, various studies have evidenced a feeble structure in the mountainous region of India [10, 11]. A study conducted by Kuniyal [9] reported the Indian Himalayan region evidenced no adequate sites or infrastructure available for dumping the MSW generated by tourists or local visitors. Another study was carried out in 12 high-altitude cities of India, which reported open dumping and were lacking landfill sites for disposal [10]. Further, a study reported contamination of soil due to open dumping in the mountainous region of Himachal Pradesh [12]. In mountainous regions, people from rural areas are migrating to cities for various reasons to receive maximum facilities or basic amenities, for example, uninterrupted electricity, water and a better standard of living, which lacks behind in rural or remote areas. But this has put the mountainous cities a great challenge in the form of MSW generations, a nuisance in the environment and juxtapose menace to public health [6].

In the context of the aforementioned challenges, it is important to know MSW pattern and its generation rates in advance by using the latest technologies, like Geographical Information System (GIS) and statistical modelling approaches. The lifestyle has changed throughout the world, and technology has become part and parcel of the human race. Geographical Information System (GIS)-based MSW management plan has made a revolution with its efficient technological advantages [13]. GIS is utilized to execute municipal solid waste (MSW) management, as it renders a strong framework for managing, importing and analysing spatial data [14]. Furthermore, literature revealed that GIS has been widely used in the selection of MSW location facilities and other related applications, such as optimization of a route and waste collection system, location allocation of bins, respectively [15–18]. The information or data of MSW generation, composition and their spatial–temporal variations [17, 18] are significant for designing the MSW management plan for a particular region. Various studies used forecasting models for MSW generation or other human-related waste predictions [19, 20]. However, several approaches have been applied to forecast MSW generation, like time series analysis, descriptive statistical models, regression analysis and artificial intelligence techniques, respectively [21, 22].

Various studies have been conducted on the MSW management of low-altitude regions of India, and ample data are available. However, literature depicts less attention or research on the MSW management in mountainous areas of India. The municipal solid waste produced across Indian mountainous cities lacks behind the proper MSW management system. Also, the availability of data on municipal solid waste in remote mountains is negligible [6]. In brief, it was noticed that limited data and vague information were available of Indian mountainous areas, for instance, the MSW generation rates, collection and transportation methods, disposal and treatment system, respectively. For the amelioration of MSW management strategy, reliable data on the existing management of MSW have a declamatory influence. Nevertheless, various variables play an important role in the generation rates of MSW, such as the standard of living, population, economy, rate of consumption and geography [2]. Amid these factors, urban population and economy are two significant factors, which have more influence on the quantity of waste [23].

The motive behind this research work was to examine and understand the current scenario and hurdles in MSW management activities, MSW generation and composition, collection and transportation, disposal and treatment processes within the high-altitude city of Srinagar. In the present study, GIS-driven mapping of the MSW management system was carried out by creating different spatial maps. Further, the current study area is experiencing exponential urban growth, as by the year 2035, the city will have more than 3 million inhabitants [24]; thus, ample municipal solid waste will be produced. It was identified from the literature that no predictive model was available in the Srinagar city for predicting the MSW generations. So, to understand the future challenges of MSW generation pattern, the forecasting model was developed for the Srinagar city. The study has great significance because no other research has been done till date at this depth and this is first of its kind in the Western Himalayan region of Srinagar city. Besides, the database of this study will aid policy and decision-makers, researchers and other stakeholders, respectively.

1.1 Background information of Srinagar city

Srinagar city is the most beautiful tourist destinations in the world, once known as "Venice of East", due to its mesmerizing and picturesque beauty, covered with lofty mountains of Pirpanjal range and Kailash Parphat. The city is known for its beautiful Dal lake with colourful Mughal gardens of Nishat, Harwan and Shalimar gardens. The city is the summer capital of J&K, which lies in the north-western part of the Himalayas, India, and it has a unique topography, climate and living standard. The study area covers 294.53 km^2 [25] and lies within the coordinates of 33° 59′14″N and 34° 12′37″N latitude and 74° 41′06″E and 74° 57´27″E longitude at an elevation of 1580 m above mean sea level. Srinagar city has four seasons with a contrasting climate, as winters are harsh with snow and summers are moderate. The mean temperature in the city during winter remains 7.5 °C and 19.8 °C in summer, respectively. The Srinagar city has been enlisted in the hundred fastest growing cities of the world [26]. The population of the city was 1.23 million during 2011 and is also the main urban hub in the Kashmir Valley [25]. The city has seen an influx in development owing to relocation of citizens from rural areas to get maximum available facilities. The population of the city recorded a growth trend of 1.83% annually [24], and the population was estimated at 1.81 million during 2019 by using the arithmetic mean method [27]. The city has witnessed an increment of MSW generations due to population growth [28]. Unplanned urban management of Srinagar city has shown a major effect on the environment and standard of life, respectively [29].

Municipal solid waste produced from the city comes from 35 municipal administrative wards of the Srinagar city. Also, the city has one sanitary landfill site with an area of 45.52 hectares, which is 7 km from the city (Fig. 1). In addition, the MSW (i.e. from collection to disposal) is solely managed by the Srinagar Municipal Corporation (SMC) employees. To elucidate the relationship between MSW generation and population growth, the annual data of the aforementioned parameters were gathered from Srinagar Municipal Corporation office (Table 1). Due to the ample amount of MSW generated in the Srinagar city and is lacking a proper sorting system, it has become an unmanageable problem, and most of the waste was landfilled.

2 Methodology

2.1 Data collection

The study started with the primary and secondary data collection, which was gathered from different sources and utilized. From primary data, qualitative indicators have been very practicable for understanding the dynamics of a waste management system to prevail the selective information about the quality of service, while the quantitative approach was utilized to establish MSW flow. Both qualitative and quantitative approaches were comported by field investigation, photography, group discussions and personal interviews. The interviews were conducted to the local authorities, stakeholders, engineers and all other working employees of Srinagar Municipal Corporation (SMC). Also, to determine the consistency of the MSW management system, observational data were collected by field visits to the study area official waste collection points, unofficial dumping points and to the landfill site, respectively. Further, the interview was conducted with ragpickers, waste buyers and scrap dealers to understand the dynamics of informal waste recycling system of Srinagar city. While the secondary data were collected from the various government legal documents, a scientific literature survey, local NGO reports and previous studies relate to MSW trends of Srinagar city. The data collected provide baseline information about the MSW management practices of Srinagar city. Also, quantitative MSW generation data of 10 years during (2010–2019) were obtained from the weighing bridge office of Srinagar Municipal Corporation (SMC).

2.2 Physical composition of waste samples

Municipal solid waste composition is heterogeneous, and they can differ from place to place and is relevant for certain variables such as time or season [30, 31]. In this study, MSW composition analysis was done for two seasons (i.e. winter and summer) during 2018–2019. The sampling was carried out as per the ASTM-American Society for Testing and Materials [32] and UNEP/IETC [33]. The nature of the MSW was mixed form, and samples were taken directly from the truck and unloaded on the concrete floor with

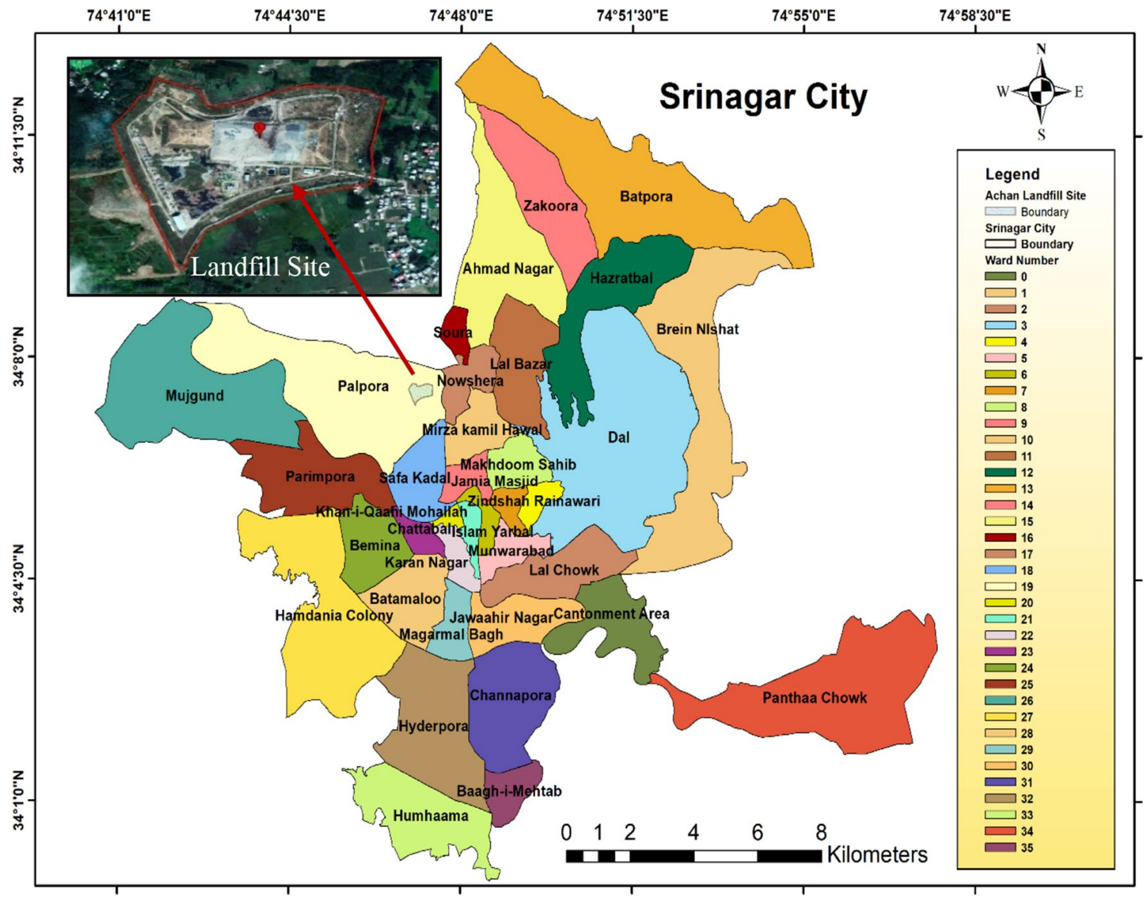


Fig. 1 Srinagar municipal boundary showing ward-wise location map with google aerial view of Achan landfill site

Table 1 Historical data on MSW generation of Srinagar city

Year	Population	MSW (Mt year^{-1})	Households
2010	984,537	76,856	171,550
2011	1,236,829	82,585	178,213
2012	1,259,463	87,738	181,777
2013	1,282,511	95,510	185,413
2014	1,305,981	160,168	189,121
2015	1,329,880	135,922	192,903
2016	1,354,217	131,967	196,762
2017	1,378,999	141,506	200,697
2018	1,778,999	148,520	204,711
2019	1,811,554	159,950	208,805

Source Srinagar Municipal Corporation

the help of concerned labourers. The quarter and conning method has been used for sampling process [27]. The electronic weighing scale was used to weigh the MSW samples, a total of 1000 kg of waste analysed for two seasons (i.e. winter and summer), respectively. Further, municipal solid waste was abridged to 100 kg in the second iteration process, and a total of 20 samples were taken ($n=10$ samples per season). During sampling process, the MSW was found in smidgens and was difficult to weigh and was broadly classified into 12 components, viz. food/organic waste, yard/garden waste, polythene, plastic, diapers, paper and cardboard, textiles, rubber & leather, metals, glass, wood and inerts, respectively (Table 2).

The statistical analysis was accomplished by employing a one-way analysis of variance (ANOVA) test in the SPSS software (version 25) to examine the seasonal variances and to know whether the deviations were significant. ANOVA statistical method has been applied in various fields by researchers, it is utilized to examine the differences between two or more sample means [34].

2.3 Geospatial database

To understand and design the municipal solid waste management (MSWM) system, visualizing and understanding the distribution pattern of MSW generation, collection & transportation and disposal of a certain area is essential. So, the fore methodology was proposed for the better

Table 2 Results of the MSW composition of two seasons during (2018–2019)

Components	Winter	Summer	Average
Food/organic waste[a]	45.10 ± 3.74	54.30 ± 5.20	49.70
Yard/garden waste[a]	2.1 ± 0.72	5.3 ± .97	3.70
Polyethene[a]	6.20 ± 1.05	4.8 ± 0.88	5.50
Plastic[a]	5.7 ± 0.78	4.47 ± 0.86	5.09
Diapers[a]	6.11 ± 1.10	2.57 ± 0.98	4.34
Paper & cardboard[a]	3.50 ± 0.44	4.58 ± 1.06	4.04
Textiles[a]	0.79 ± 0.12	0.86 ± 0.35	0.83
Rubber & leather[a]	0.8 ± 0.11	1 ± 0.50	0.90
Metals[a]	0.5 ± 0.07	0.92 ± 0.15	0.71
Glass[a]	0.40 ± 0.05	0.7 ± 0.18	0.55
Wood[a]	1.60 ± 0.09	0.9 ± 0.22	1.25
Inerts[b]	27.20 ± 3.22	19.60 ± 2.44	23.40
Total	100.00	100.00	100.00

Values represent averages of samples, and numbers in parentheses are standard deviations of samples

[a]All the values are in percentages (%)

[b]Inert material includes gravel, dust and nonreactive waste

MSW management plan for the mountainous region of Srinagar city. The data of municipal boundaries were collected from the Srinagar Municipal Corporation (SMC) office. The mapping software ArcGIS 10.3.1 (Geographical Information System) and Google Earth Pro were utilized to create different geospatial maps. The ArcGIS software facilitates to maintain the database and analysis of different parameters. The data collected were geo-referenced, and the similar projection (i.e. WGS 1984 UTM Zone 43 North) was assigned for all layers. The base map of Srinagar city was prepared by digitization with pertinent information. Besides, the Global Positioning System (GPS) was utilized to collect geographical coordinates of open waste points. Further, geospatial maps like administrative ward-wise locations, density map of population and wastebin, MSW generation map and the spatial distribution map of open waste points with illegal dumping sites of the high-altitude Srinagar city were prepared in the GIS environment with different tools. The spatial and thematic data representation of the aforementioned parameters will provide an effective entropy and the status of a particular parameter within the specific area of the Srinagar city.

2.4 Statistical analysis

Municipal solid waste (MSW) involves various important steps, which needs to be analysed, e.g. MSW generation, precollection, treatment and its disposal [35]. The waste prediction is a primary step for the planning of municipal solid waste management (MSWM) system in different cities, under certain social and economic conditions, which have a strong influence on the quantity of MSW generation in different time frames [36, 37]. Predictive modelling and prognostic indices support the decision-making process precisely and accurately [22, 38]. The waste prognostic tool can be utilized for predictions of MSW generation on a few input parameters. Based on previous literature, two variables were identified, i.e. population and households, which may have an impact on the MSW generation rates of Srinagar city. Moreover, the statistical forecasting analysis was performed in Minitab (version 19) software for MSW generation on previous historical data and prognostic indicators, i.e. population (x_1) and households (x_2), respectively, while the dependent variables to be predicted were MSW(y), and (x_1, x_2) were two independent variables, referring to population and households. The historical data for the model were obtained from the office of Srinagar Municipal Corporation (SMC).

In this study, the second-order multiple regression model was adopted for municipal solid waste generation forecasting for one decade (i.e. 2020–2030) of the Srinagar city. Besides, the linear trend model has been adopted for time trend evaluation, which was defined on outcomes derived from the prefatory model fits. Hence, it was apparent that a linear trend model provided the best fit and was more accurate in approximation to accept a relationship in our data. Additionally, it was possible to project municipal solid waste distribution patterns of the above-cited 12 MSW categories, viz. food/organic waste, yard/garden waste, polythene, plastic, diapers, paper and cardboard, textiles, rubber and leather, metals, glass, wood and inert waste, respectively. The obtained percentage values of 12 MSW components were utilized for the municipal solid waste distribution pattern in forecasted data, while, for regression analysis, municipal solid waste was taken as a response variable, and the predictor variables were population and households of the Srinagar city. Further, the significance of the model has been ascertained at a probability of 95% ($a = 0.05$) and model was fitted.

3 Results and discussion

3.1 Waste composition

MSW generated from different sources deviates because of different reasons, like food habits, socio-economic conditions and living standards in high-altitude regions [6]. The aforementioned factors may affect the quantity and composition of MSW. Municipal solid waste composition renders vital information about the treatment of waste efficiently by applying appropriate technology. The findings of the municipal solid waste composition of two seasons (i.e. winter and summer) are ocular with standard deviations in Table 2. The average values of food/organic waste (54.30%) were higher in the summer, due to more consumption of fresh vegetables and fruits by people. While decrement of values in winter showed food/organic waste of (45%), due to nonavailability and less consumption of fresh fruits, farming is limited because cultivation areas are under snow in winter. Furthermore, observed findings of this study were well correlated with high-altitude regions of Himachal Pradesh, India and Nepal, having more than 50% of organic waste [39, 40]. Besides, findings of the Srinagar city are well agreed to the results of other South Asian countries, where organic waste was 57% in nature [4]. The garden/yard waste was (2.1%) and (5.3%) in winter and summer, respectively, whereas less waste in winter is due to the seasonal variation impact like snow and rainfall, while in summer, climate change and more waste of garden clipping/trimming come out from local tourist gardens and households, respectively.

The inert content was higher in winter (27.20%), which was due to the collected street sweeping waste from unpaved roads and drainage cleaned waste during the rainfall or snow season, while the summer season showed lower values of inert material (19.60%), due to the dry season. Similarly, a study was carried out in north Indian states, where the inert content was approximately 30.85% [41, 42] and was intimately in agreement with our findings of the inert content. Further, the results of recyclable waste (i.e. polythene, plastics, diapers, paper/cardboard, textiles, rubber & leather, metals, glass) revealed a slight variation for both the seasons, as average values showed (17.62%) were recyclable components (Table 2). while components like plastic, polythene and paper were segregated at the household level and ragpickers collect them from different houses and community bins, respectively. Most of the ragpickers were poor and their livelihood was dependent on collected recyclable items, as both household inhabitants and ragpickers sell recyclable waste to local scrap dealers to earn money from it.

Further, the diaper waste depicted higher values in winter (6.11%), because of low temperatures and to avoid the frequent washing of babies, while in summer (2.57%), values show drop-off trend comparatively. It was reported from a study conducted in Lahore, Pakistan, where diaper values changed for both the seasons (i.e. winter and summer), respectively [43]. Further, the present study showed that wood waste (1.60%) was higher in summer relative to lower in winter (0.90%), respectively. This decreasing value in the winter season was due to the high usage of wood in homes for heating purposes, because the climate of the region changes and goes down to below freezing temperature. Furthermore, ANOVA was calculated in the SPSS software to check the deviations were significant or not. The statistical analysis performed for two seasons (winter and summer) of MSW composition revealed (p value = 0.413). Hence, it was clear from the findings that the seasonal difference between winter and summer was statistically nonsignificant. So, it was concluded that there is no statistic deviation between the overall MSW generated in both seasons. The seasonal variances of two seasons were evaluated for the MSW components. Moreover, the data were obtained from the compositional analysis of MSW, and their values have shown a significant interaction between the type of MSW generated and the season in which MSW was generated, $F (2,18) = 10.42$, p value = 0.001. The reason is presumed that seasonal changes in consumption habits and the lifestyle of people. However, MSW is highly organic, so compositing method will be beneficial to minimize the municipal solid waste of Srinagar city, and it will prevent environmental stress, which are resultants from landfill sites [44, 45].

3.2 MSW storage, collection and transportation

Municipal solid waste management (MSWM) system can only be designed efficiently if the substructure framework satisfies equally to handle the waste generated [11]. As per Solid Waste Management (SWM) Rules 2016, it is necessary to ensure waste collection and transportation system should be in a proper manner, which gratifies both public and environmental protection. Developing countries, like India, the existing scenario of MSW management infrastructure is under-equipped to grip up the massive waste generated, which can eventually create open dumping sites. Further, global literature exemplifies various approaches to handle the MSW due to unconventional methods of management and unimplemented government or environment waste policies.

In this study, the municipal solid waste collection was done in two phases, i.e. primary and secondary collection. The primary collection of MSW was done by SMC workers through a door-to-door collection with an efficiency of 75% [46]. Further, street sweeping waste was dumped in community waste bins, or at open waste locations, while no segregation was done of collected MSW. Although there are some initiatives by SMC with some private NGOs by introducing the two-bin system, less response was given by the inhabitants of the city, due to lack of awareness, while awareness camps influence on the behaviour of people to segregate different types of waste, due to their concern about the environment and need to participate in solutions [47]. The MSW from households, educational institutes, offices and restaurants was dumped into secondary storage community waste bins and was emptied daily by the local authorities. Besides, in some parts of the city, there was no particular schedule for the secondary collection of MSW. Also, MSW within the cantonment area (i.e. military area) was excluded, as they are responsible for their MSW collection and transportation. Srinagar city has 576 community bins, 556 collection points and 98 official open waste points without waste bins. Furthermore, MSW from community bins was collected in 192 different equipment's, like mechanical compactor vehicles, dumper placers, JCB/Skid steer, trucks, load carriers and other vehicles provided by the municipal authorities of the Srinagar city. Also, it was observed that much of MSW was collected in exposed trucks and other vehicles, which creates scattering or littering of waste on roads and may attract flies and mosquitos [48]. As per SMC, approximately 70% of MSW generated was collected and transported from various generation points to the Achan landfill site daily.

It was noticed during the observational study that the MSW generated was indiscriminately dumped on the roadside, riverbanks, streams, lakes and in wetlands, which is largely adopted by residents of the area. Further observations showed low-income areas having a lack of understandings were indiscriminately dumping MSW in open areas and drainage channels, which may ultimately obstruct the drainage network, affect human health and mountain ecosystem, respectively [6, 49]. Furthermore, observations in the present study area showed waste collectors were prone to diseases, for instance, the collected waste contains rotting organic content which can contaminate with pathogens [50]. Also, MSW in open waste bins can create air pollution, dog menace and transmission of vector diseases in the atmosphere. In addition, community waste bins were without cover and during rainfall or snow season receives extra moisture, which in turn becomes a hectic job for SMC workers during collection and transportation process.

MSW generated from adjacent districts, like Budgam, Ganderbal and Pampore, which was accumulated to outlying areas of Srinagar city, and this puts extra pressure on the existing collection system. While, during the observation study, locations of most waste bins or collection points were on the roadside, it was difficult to collect waste due to traffic flow. This inappropriate location on roadsides of community waste bins was prone to accidents and diminishes the beautification of the city. Besides, it was identified the unskilled labourer's, unplanned transportation system, inefficient route management and traffic congestion lead to the delay and reduce the frequency of MSW collection. Hence, there were no proper planning and tracking of MSW collection routes and no effort for optimization of routes in the Srinagar city [17]. Recently, MoEFCC (Ministry of Environment, Forests and Climate Change) changed the Municipal Solid Waste (Management and Handling) Rules, 2000, and upgraded it with Solid Waste Management (SWM), Rules 2016 for improvization of MSW management across India. In 2014, the Government of India started the Swachh Bharat Mission (SBM), which targets to strengthen and provide sanitation by adopting scientific methods for MSW management [51]. Hence, it was recommended to replace open waste bins with closed storage bins to reduce the impact on the environment and humans, respectively.

3.3 MSW disposal and treatment system

Municipal solid waste (MSW) in developed countries, like the USA and European nations, is treated scientifically with sustainable methods, but developing countries have a different scenario. In this study municipal solid waste generated from different sectors was transported in SMC vehicles to the Achan landfill site. The landfill has currently three cells in which two cells are filled and the other two has reached its capacity, and limited space is left for dumping. Due to the unavailability of land, the current landfill has been constructed on the wetland without environmental consideration [52], and this can create a threat to the mountain ecosystem. The residents have faced social and health problems due to odorous gases produced from the landfill site; however, several times local administration was informed by inhabitants to transfer the landfill site, but no response from the concerned authorities. Waste dumping sites have been linked to slew calumnious health diseases [49], including respiratory disorders and certain vector-borne illnesses, like dysentery, yellow fever and typhoid, respectively.

In the present study, landfill gas's (LFG's) produced was burned through a gas flare outlet system, while emissions produced were entering into the atmosphere and may cause air pollution. A study has shown that the methane generation from the MSW disposal site was 1.17 tons during 2012 in the Srinagar city [53]. The greenhouse gas (GHG) emissions like methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O) [54] are produced during the anaerobic decomposition of municipal solid waste. Methane is extremely potent, with a propensity for global warming of 25 times greater than carbon dioxide [55]. Also, the greenhouse gas emissions can aggravate high impact on the fragile ecosystem of a mountainous city of Srinagar [56, 57]. It was reported from a study conducted in China, where air pollutants and GHG's released from MSW disposal and treatment process showed a high impact on the air quality and human health [56]. In the context of above-mentioned factors like uncovered landfills, odorous and greenhouse gas emissions can restrict the sustainable and proportionate growth of the Srinagar city's society, economy and environment, respectively [56]. Moreover, the bad odour and air pollution can be minimized by a prompt covering of dumped waste and applying diluting chemicals on it, which can abbreviate bad odour to some extent. Further, the gases produced from the landfill can be collected and utilized for various purposes.

The municipal solid waste (MSW) collected from secondary storage of Srinagar city was in the heterogeneous from different collections points. For segregation of waste, one mechanical segregator having a capacity of 30 tons day^{-1} is installed and has confined capability to segregate the huge quantity of MSW. Nearly (30–35%) of heterogeneous MSW was fed into the mechanical segregator which segregates MSW for compostable, refused derived fuel (RDF) and inert material, respectively, while the rest (65–75%) of MSW was dumped into the landfill. The compostable waste was used to prepare compost for agricultural purpose in a mini compost plant with a capacity of 2 Mt day^{-1}. Mostly, the compost remained unsold due to its low-quality and poor management, while refused derived fuel (RDF) was occasionally purchased by cement factories. Also, it was observed that some recycling occurs at households, and local rag pickers purchase recyclable waste at some cost, while informal recycling occurs in the city. An integrated approach can be the best option to minimize the waste, as it is economical and reasonable [58] for MSW management. Moreover, MSW management of the Srinagar city can be amended by implementing the Integrated Solid Waste Management (ISWM) framework as shown in Fig. 2 [27].

During an observation study, it was identified that the landfill cells were not fully lined and a huge quantity of leachate was flowing out through cells. Further, small pools of leachate were observed around the landfill site and are prone to many vector diseases. The leachate has affected groundwater quality [59], due to the heavy influx of leachate with less capacity for treatment. Mostly leachate was diverted through pipes to adjacent Achan natural stream and may have an impact on it. Although the landfill has a leachate collection network with a limited capacity of 120 KLD (Kilolitres day^{-1}). Also, the leachate plant of the landfill site was inoperative due to the complex MSW composition and high influx of leachate production.

3.4 Spatial analysis of MSW management

Management of waste is an environmental problem, having major relevancy in respective societies throughout the nations. It was identified in the global literature, MSW generation and composition were affected by different factors, for instance, population, lifestyle, geography, environment and economy, respectively. Besides, to analyse the above-cited factors and influence over MSW generations and its composition in a particular region, the utilization of efficient tools, like geographical information system, acts as a significant tool for it [35]. However, GIS and the latest technology are necessary and effectual in the collection, analysing, resolving and depicting spatial data of municipal solid waste on maps [60]. The obtained results from ArcGIS thematic and spatial mapping of the Srinagar city will provide the dynamics of various parameters of MSW management, such as population density, MSW generation, the density of wastebin, open wastebin locations with illegal disposal sites, respectively.

3.5 Spatial–temporal pattern of population and MSW generation

The population size of mountainous urban centres or cities is steadily growing, and about 36% area is covered by mountains in Asia and about 25% of the mountain population of developing world lives in cities [61]. In the present study, the population showed an eminent growth of 1.23 million inhabitants during 2011 [25], but due to urban sprawl, spatiotemporal variations of the population have increased at a growth rate of 1.83% annually, and the estimated population is 1.81 million inhabitants during 2019.

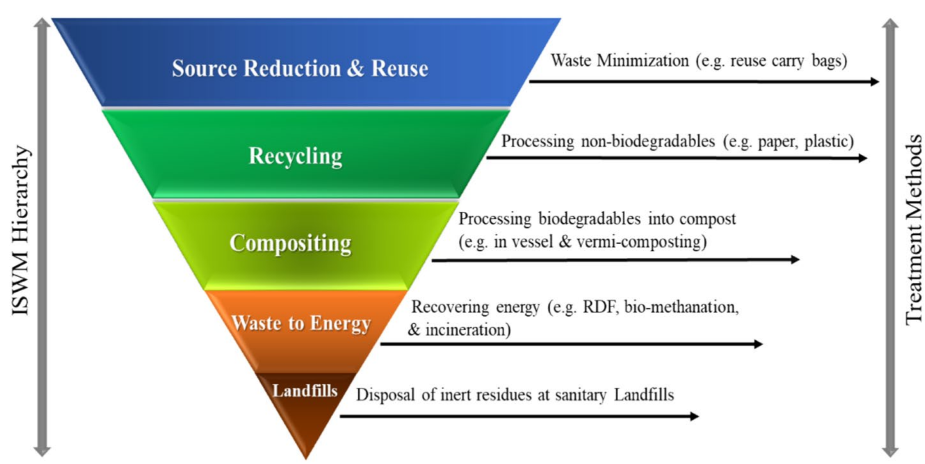


Fig. 2 Integrated solid waste management system hierarchy [27]

Further, Srinagar Metropolitan Region (SMR) will show a growth of 2% annually in the next decade; hence, the population will surpass 3 million inhabitants by the year 2035 [24]. The urban population density of the study area was 4141 persons km^{-2} [25], while density has been estimated during 2019, which reveals the gross density with an enhanced trend of 6145 persons km^{-2}. The increment in the city's population will directly elevate the MSW generation, and these two factors can significantly affect the human health and environment, respectively [62]. It was observed that population growth has increased MSW generation rates in different areas of the Srinagar city. Various studies have utilized the population density to calculate the MSW generation [63, 64].

The existing spatial distribution pattern of a population and waste density across 35 administrative wards of Srinagar city is shown in Fig. 3a, b), respectively. The results of the population and the MSW generation were categorized into three types, i.e. high-density, medium-density and low-density wards, respectively. Municipal solid waste generation has a considerable co-relation with household income and size, respectively [65]. The average household of mountainous Srinagar city was 6.46 persons [24], MSW generation of each ward was calculated by assuming a normative approach of 0.48 kg capita^{-1} day^{-1}. The findings of high-density wards on thematic maps were quantile classified and revealed that the central part of the city, like ward number (4, 6, 7, 16, 20, 21, 22 and 23), was having higher population density ranging between (29,560 and 120,100) persons km^{-2}. The thematic map (Fig. 4b) showed a pattern of MSW generation with higher values ranging (30.04–35.65) Mt day^{-1} in the aforementioned administrative wards. The reason is that foresaid wards have the oldest residential areas of the city with large settlements, and also people live here from decades and have main business centres in these wards. The quality of MSW is dynamic, because it changes spatiotemporally [66], while above-mentioned wards have also various tourist and religious spots, and these can be the rationality of high MSW generations. So, these factors might be responsible for higher MSW generations due to higher densities of population, and socio-economic conditions of people were of a high standard in the respective wards.

The outcomes of medium-density wards, i.e. ward number (5, 8, 9, 10, 11, 17, 18, 22, 24, 28, 29, 30, 33 and 35), were having a medium range of population density between (7914 and 29,950) persons km^{-2}. Further, foresaid administrative wards depicted the MSW generation in a range of (22.98–30.04) Mt day^{-1}. Mostly, these wards were having a leading business, commercial and administrative offices, respectively, while the MSW generation was less in medium-density wards compared to high-density wards, due to low population and different levels of income groups [28]. In addition, the results of low-density wards, i.e. ward number (1, 3, 12, 13, 14, 15, 19, 25, 26, 27, 31, 32 and 34), showed the lowest values in terms of population density ranging (0–7913) persons km^{-2}, and the same case was in the values of MSW generations ranging between (0 and 22.98) Mt day^{-1}, respectively. These wards are settled in the outskirts and have newly established residential areas, where a substantial portion of land is consecrated to agriculture activities. Also, people have migrated from rural or central parts of the city to these wards, and most of the inhabitants belong to high business class and civil ranking government officials in the said area. The MSW generation in low-density wards was comparatively less than high- and medium-density wards of the city, because of less population density.

Spatio-temporal data of the MSW generation revealed variations along with the increment in the population (Table 3). So, population growth can aggravate enormous pressure on the tenuous MSW management system of the Srinagar city. It was reported in Botswana, where population growth and increment in spatial assiduity of the large settlement have arduously pressured facilities to handle the MSW generated [67], and the aforementioned study was considerably correlated with the present research study. In addition, population increases in summers due to tourist flow and migration of government offices from Jammu city to the current study area, as being a summer capital of Jammu and Kashmir territory. The overhead population due to tourism contributes additional 80 Mt day^{-1} of MSW [46] during the tourism season, and it brings pressure on the existing MSW management system, and also monthly variations can be visualized in Fig. 4. However, utilization of population or demographic characteristics to the MSW generation are practicable in understanding municipal solid waste generation patterns for the particular area [68]. Besides, it will aid the policy and decision-makers to upgrade the existing municipal solid waste (MSW) management system of Srinagar city. Also, the present study showed well correlation with the report of a mountainous region of Georgia, where MSW generation increased, because of population increment [6], changes in living standard and by growth in tourist flow [69].

3.6 Spatial density outline of wastebin

Municipal solid waste produced from households, commercial or institutional areas should be dumped properly in community waste bins, though inadequacy of bins can create dumping sites. So, community wastebin or secondary storage bins must serve residents at a maximum. The spatial map findings represent the density of waste bins across the Srinagar city in Fig. 5 (1 dot represents one wastebin) in each ward. Presently, two types of waste

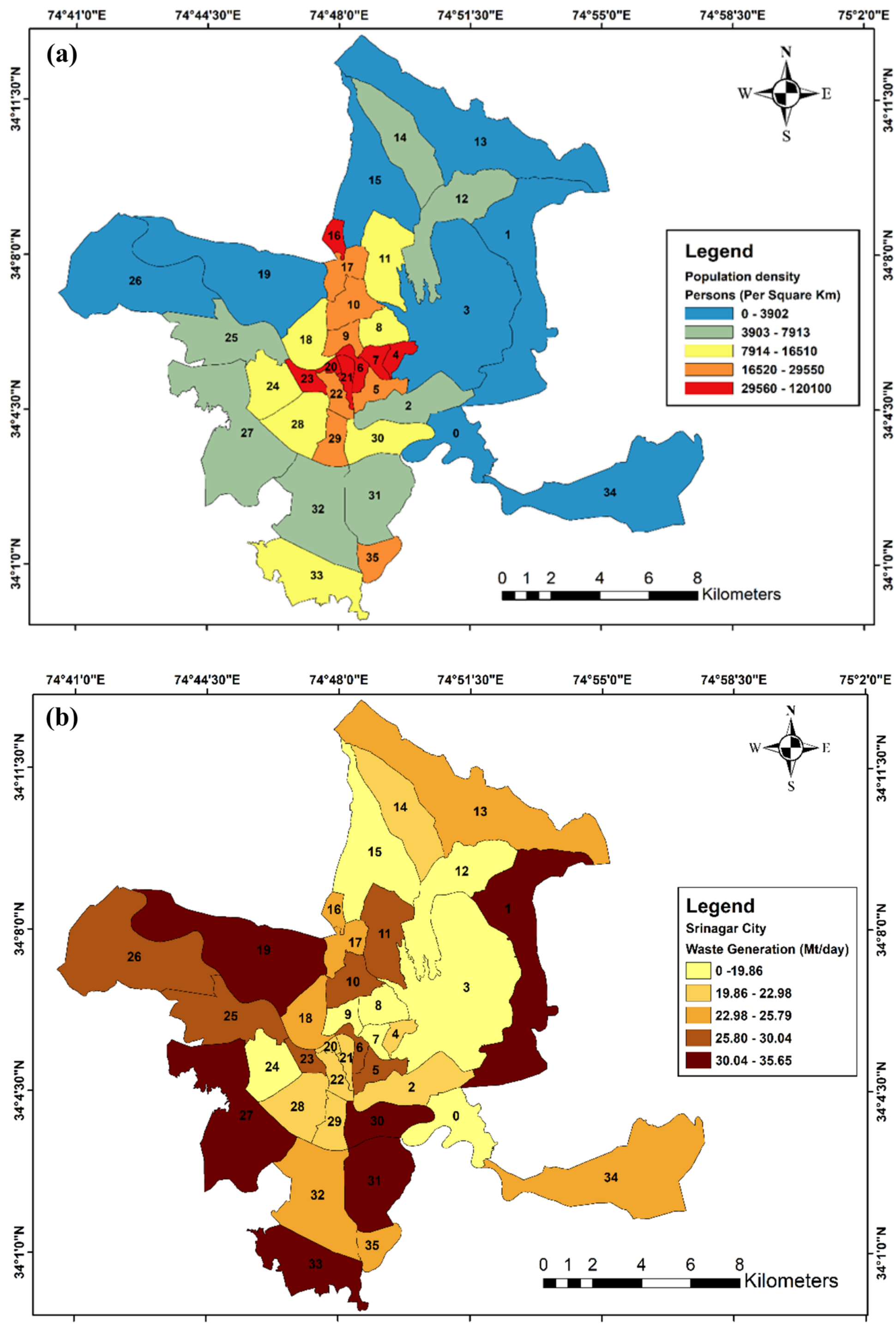


Fig. 3 **a** Spatial distribution pattern of population density **b** MSW generation density of Srinagar city

bins, i.e. dumper bins (3 m^3) and compactor bins (1 m^3, 2.5 m^3 and 5.5 m^3) are utilized for the MSW storage in the city. However, the locations of existing waste bins demonstrated nonuniformity, while each wastebin should be maintained at a distance of 250 m [27], but the current study area showed an interval of 500-m interval and some areas exceeded 1 km. The distribution pattern of community waste bins showed a high density in the central part of the city because these wards were densely populated. Besides, these areas were having an ample number of restaurants, guest houses and hotels, and they produce a considerable amount of waste. Also, the eastern part of the Srinagar city showed a significant number of waste bins, because this part of the city has several tourist spots and is home to many influential citizens. However, the suburbs of the city, such as northern, southern and western areas,

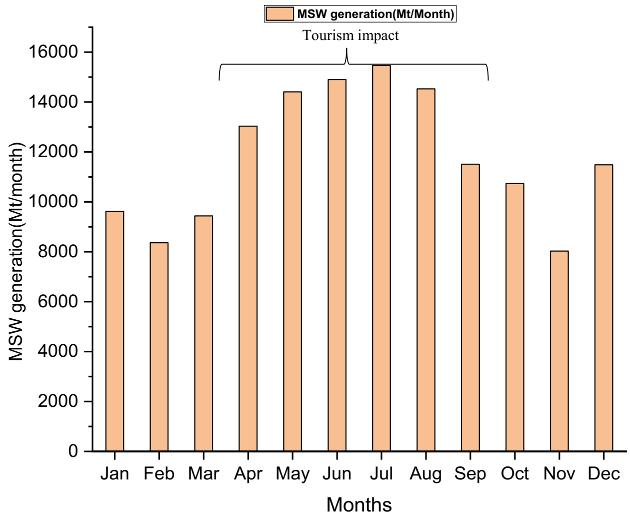


Fig. 4 Monthly variation of MSW generation (tourism impact) of Srinagar city

Table 3 Previous studies of MSW generation of Srinagar city

Year	Population (millions)	MSW generation (Mt day^{-1})	Studies
2005	0.94	428	CPCB
2011	1.23	550	SMC
2013	1.31	575	SMC
2018	1.77	668	SMC
2019	1.81	868	Present Study

CPCB, Central Pollution Control Board [77]; SMC, Srinagar Municipal Corporation [46, 78]

were having an inadequate number of waste bins and a low ratio relative to the central and eastern parts of the Srinagar city, which indicated a nonuniformity in the distribution pattern of waste bins. The inadequacy of waste bins in these wards might be due to lack of resources, official open waste points and less attention by the local authorities. Besides, the overall correlation between waste bins and municipal solid waste generation showed a poor relationship in the Srinagar city, Fig. 6. However, the uneven distribution structure of waste bins can be resolved by optimizing and allocating the appropriate location of waste bins as per the density of population [18].

3.7 Spatial pattern of open waste points

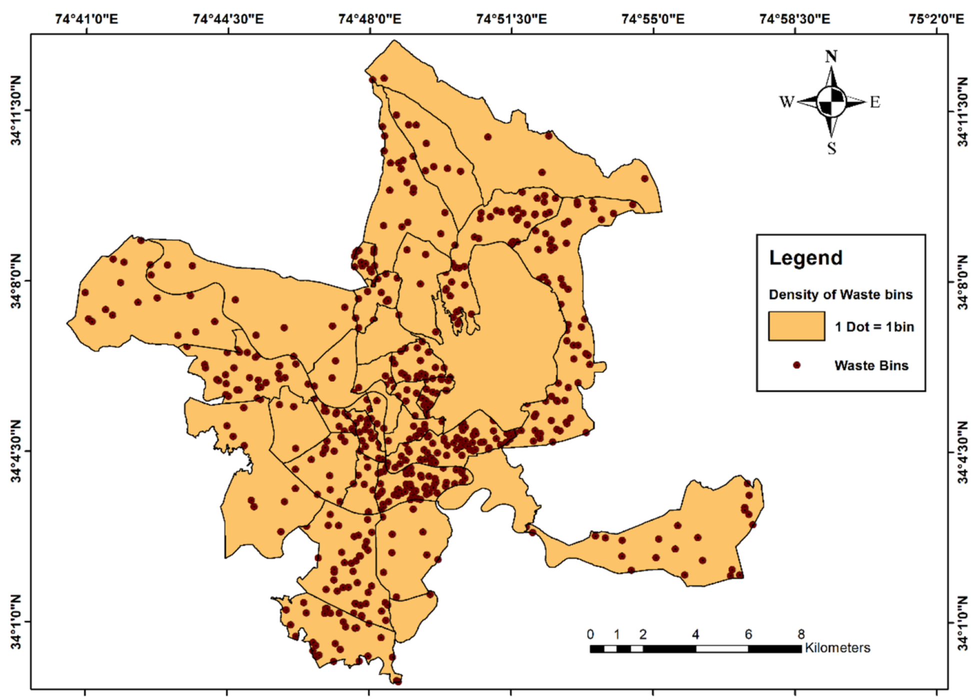
In our study, during field investigation, 91 locations of open waste points and two illegal dumping points were identified in the Srinagar city, depicted in (Fig. 7). The spatial distribution of these open waste points was either along roadsides or on walkways, and illegal dumping sites were located in or close to wetland areas. Indiscriminate dumping occurs on foresaid sites, and the accumulation of waste has been found at numerous locations on the roads and in water bodies around the city. It is evident that open disposal sites, if not closed, can contribute to acrid odours, greenhouse gases [70], and leachate contamination, which can degrade the quality of air, soil and surface or underground water resources, respectively [6, 12, 71]. It was documented in a study in the northeast of Tokyo, Japan, during 2014, where harmful and industrial waste was dumped in the Ibaraki mountains [6].

The spatial distribution pattern reveals that open waste points have a high concentration in the central part of the city, e.g. wards of (Mirza Kamil Hawal, Jamia Masjid and Munawarabad). The reason might be that internal roads have narrow access and were inaccessible to SMC collection vehicles and due to nonavailability of waste bins in the respective wards. Such waste points have become a food court for street animals and can trigger epidemics if they are not controlled, whereas illegal dumping sites in the city (i.e. Anchar lake and Khushal Sar lake) water bodies are heavily compromised by the informal dumping and their water quality has deteriorated. It was reported immense pollution has occurred in Anchar lake due to wastewater ingress and other anthropogenic activities in its periphery [72]. Various small-scale dumping sites were identified around the periphery of the famous Dal lake, where the inhabitants of houseboats or small islands discharge the waste directly in this fragile water body [73]. A study conducted in Kathmandu, Nepal, reported that open dumping was practised in a mountainous region [40], where waste was often disposed on the flood plains and may have a major impact on the mountain ecosystem. Further, in some mountainous regions, illicit dumping of waste was adopted, which is identified as a waste crime [6]. However, it was suggested that open waste sites should be replaced with a closed type of waste bins across the city. Further local authorities should come up with legal action against violators and stringent policies should be drafted to close these illegal dumping sites.

3.8 Forecasting of MSW generation

To design an effectual plan of MSW management, it is important to forecast MSW quantities generated in a city or region [19]. So, it is utmost important to project the MSW in advance for the Srinagar city, so it can be properly managed and also preclude its impact on the environment. An increasing trend of MSW generation can have various factors and adequate planning of MSW management can be attained by predicting it. The prediction was based on the historical data of municipal solid waste, provided by the Srinagar Municipal Corporation (SMC),

Fig. 5 Existing ward-wise distribution of wastebin density across Srinagar city



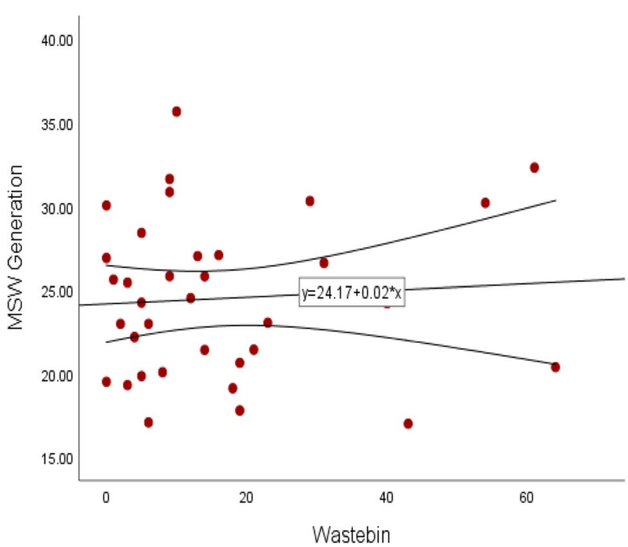


Fig. 6 Scatterplot between wastebin and MSW generation

Table 1. It has been reported by Kumar et al. [74] that cities with a population of 1–2 million have an MSW generation rate ranging between (0.19 and 0.53 kg capita^{-1} day^{-1}) across various Indian metropolitan cities, while another study reported that South Asian countries generate MSW with a mean value of 0.52 kg capita^{-1} day^{-1} [4].

As per the CPCB report, the MSW generation of Srinagar city was 428 Mt day^{-1} during 2005, and it is evident from previous studies that MSW generation has shown a growing pattern (Table 1). The reason might be increased population conjugated with improved incomes has resulted in the economic growth of the city, and this has increased MSW generation rates, while lifestyle and food habits of the people in the city have shown dynamic changes from the last couple of years. The population of the Srinagar Metropolitan Region is expected to surpass 3 million by the year 2035 [24]. In this contrast, MSW generations will increase in the city and may impact on the existing MSWM system. The municipal solid waste generated has been calculated by taking a normative approach of (0.48 kg capita^{-1} day^{-1}), respectively [74]. So, the estimated population was about 1.81 million, and the total MSW generated during 2019 was 868 Mt day^{-1}. Furthermore, Table 4 depicts the forecasted findings of MSW generation (Mt year^{-1}) for the years (2020–2030) with factors, i.e. population (x_1) and household (x_2) of the Srinagar city. The time series trend analysis with a gap of one year was plotted to interpret the trend and seasonality in datum (Fig. 8). Also, the above time series generated linear and nonstationary trend, so mean and variance of values are not fixed over time. So, in this study, it is apparent that the average value increases, which shows the increment in values. Hence, it is anticipated that the MSW generation of Srinagar city may increase in the next 10 years.

The MSW distribution pattern of each component as shown in Table 4 (Columns 3–13) was estimated on composition percentage over a prognosis period of Srinagar city. The historical data showed uptrend between (2010 and 2019); however, trend analysis did not show any seasonality as data are provided annually (Fig. 8). The y-axis

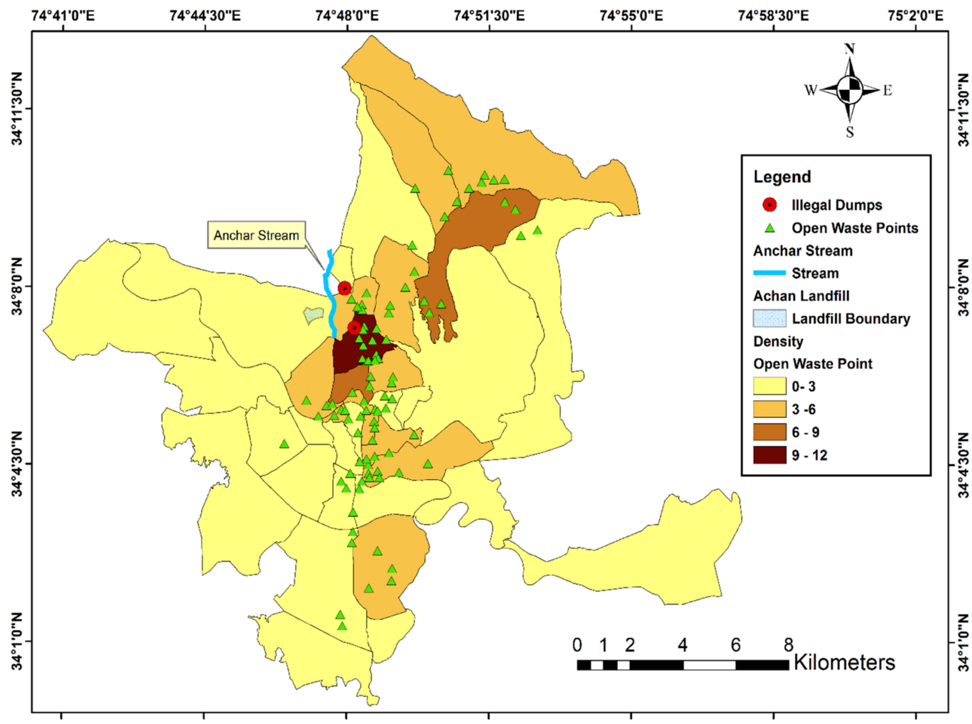


Fig. 7 Spatial distribution density of open waste points and location of illegal dumpsites

shows municipal solid waste evaluated, and the *x*-axis depicts the time or index calculated. Further, variables, i.e. population (x_1) and household (x_2), had significantly ($p < 0.001$) impacted MSW generation, whereas household (x_2) has the firmest impact. So, the increment of households in Srinagar can relatively elevate MSW generations. The final quadratic term (Eq. 1) of the variable household (x_2) was observed with a substantial impact on the response variable of municipal solid waste (y).

$$y = -332312 + 2.79x_2 \quad (1)$$

The forecasting precision in the current study model was satisfactory, as the mean absolute percentage error (MAPE) exhibited a value of 8 and was in agreement with a norm of less than 10%, which means it lies in a highly accurate forecasting category [75]. The p value = 0.001, which showed the relation between dependent variables (y) and independent variables (x) in this model was statistically significant ($p < 0.1$). In addition, the model showed a coefficient of correlation ($R^2 = 75.39\%$), which means that up to 73.39% of the variance of dependent variables of MSW (y) is explicated by the independent variable of household (x). This study was well correlated with the analysis performed in Johannesburg, South Africa, where an independent variable of a household showed a significant effect on waste generation [62]. Hence, this statistical indicator showed the generated model of (Eq. 1) can explain the dynamics of MSW generation and thus validated the generated model. This generated information could be vital for proper planning and designing of the MSW management system in Srinagar city.

3.9 Alternatives to improve MSW management

Srinagar city has a fragile ecosystem and urgently needs to implement eco-friendly treatment alternatives and solutions for MSW. Although the waste cannot be managed or controlled by single technologies, implementation of integrated MSW management system is highly recommended. The integrated waste management facility should be implemented as per the compliance of Solid Waste Management (SWM) Rules, 2016 [51]. The following alternative methods were proposed, which were based on the above findings of MSW composition, management and spatial analysis of the Srinagar city.

(1) High organic waste content can be converted into high-quality rich compost for agriculture, so small compost plants can be installed in different communities, hotels, and city restaurants, respectively, while biogas plant can be introduced, which is a feasible technology as per the nature of more organic waste in Srinagar city. Further, 4R's (reduce, reuse, recycling and recovery) [76] should be encouraged and this will minimize MSW.

(2) Introducing waste segregation at the source with a dual wastebin system (i.e. biodegradable and non-biodegradable), and waste collection fees from MSW

Table 4 Forecasted MSW generation of Srinagar city from 2020 to 2030

Year	Forecast (Mt year^{-1})	MSW distribution of each component based on predicted values (Mt year^{-1})										
		Organics[a]	Polyethene	Plastic	Diapers	P&C[b]	Textiles	R&L[c]	Metals	Glass	Wood	Inerts
2021	174,184	93014.26	9580.12	8865.97	7559.59	7037.03	1445.73	1567.66	1236.71	958.01	2177.30	40759.06
2022	183,659	98073.91	10101.25	9348.24	7970.80	7419.82	1524.37	1652.93	1303.98	1010.12	2295.74	42976.21
2023	193,134	103133.56	10622.37	9830.52	8382.02	7802.61	1603.01	1738.21	1371.25	1062.24	2414.18	45193.36
2024	202,609	108193.21	11143.50	10312.80	8793.23	8185.40	1681.65	1823.48	1438.52	1114.35	2532.61	47410.51
2025	212,084	113252.86	11664.62	10795.08	9204.45	8568.19	1760.30	1908.76	1505.80	1166.46	2651.05	49627.66
2026	221,558	118311.97	12185.69	11277.30	9615.62	8950.94	1838.93	1994.02	1573.06	1218.57	2769.48	51844.57
2027	231,033	123371.62	12706.82	11759.58	10026.83	9333.73	1917.57	2079.30	1640.33	1270.68	2887.91	54061.72
2028	240,508	128431.27	13227.94	12241.86	10438.05	9716.52	1996.22	2164.57	1707.61	1322.79	3006.35	56278.87
2029	249,983	133490.92	13749.07	12724.13	10849.26	10099.31	2074.86	2249.85	1774.88	1374.91	3124.79	58496.02
2030	259,458	138550.57	14270.19	13206.41	11260.48	10482.10	2153.50	2335.12	1842.15	1427.02	3243.23	60713.17

[a]Organics (food and garden/yard waste), [b]P&C (paper and cardboard), [c]R&L (rubber and leather)

generators should be implemented. Also, the concerned department should come up with strict laws against illegal dumping, which can reduce waste crime and save the environment.

(3) Collection of waste at regular intervals by informing residents with proper timings and utilization of the central bin system in each predetermined colony or society. Each roadside collection point should be designated at equal distance, and this will cater to more households.

(4) The advanced technologies can be applied to existing landfills, where the problem of bad landfill gases and bad odour can be diagnosed by installing biochemical reactors and the landfill gas collection system [56]. Further, leachate plants should be upgraded with high capacity treatment plants to get maximum efficiency in the treatment of the leachates.

(5) Also, the implementation of smart policies, current laws and regulations, involving private sectors with public–private partnership (PPP) model, educating people by organizing awareness camps in local communities, schools, colleges and at institutional levels.

(6) The installation of a smart monitoring system like waste transmitters and sensors can be applied on waste bins and GPS tracking system on collection vehicles, which will help to optimize the MSWM system. Further, a web-based monitoring and a computerized management information system (MIS) can be used to capture, store and retrieve the related data and information. MIS can grapple magnanimous amount data, for instance, waste collection points, location of dustbins, secondary storage points and other related information.

(7) The collection routes and location of wastebin can be optimized by using geospatial technology [17], which will provide the best collection routes and suitable wastebin location for the Srinagar city.

4 Conclusion

The MSW management study conducted mainly emphasized to ameliorate the existing waste management system of a high-altitude Srinagar city. The outcomes showed a population explosion from adjacent rural areas has tremendously pressurized the current MSW management system. Composition analysis of MSW demonstrates variations in both the seasons (i.e. winter and summer) during 2018–2019. Organic waste depicted higher values (53.40%), followed by inert content (23.40%) and recyclable waste 16.79%, respectively. Due to high organic waste, the compositing/vermicomposting technique was suggested for the treatment of MSW. The impact on seasonal

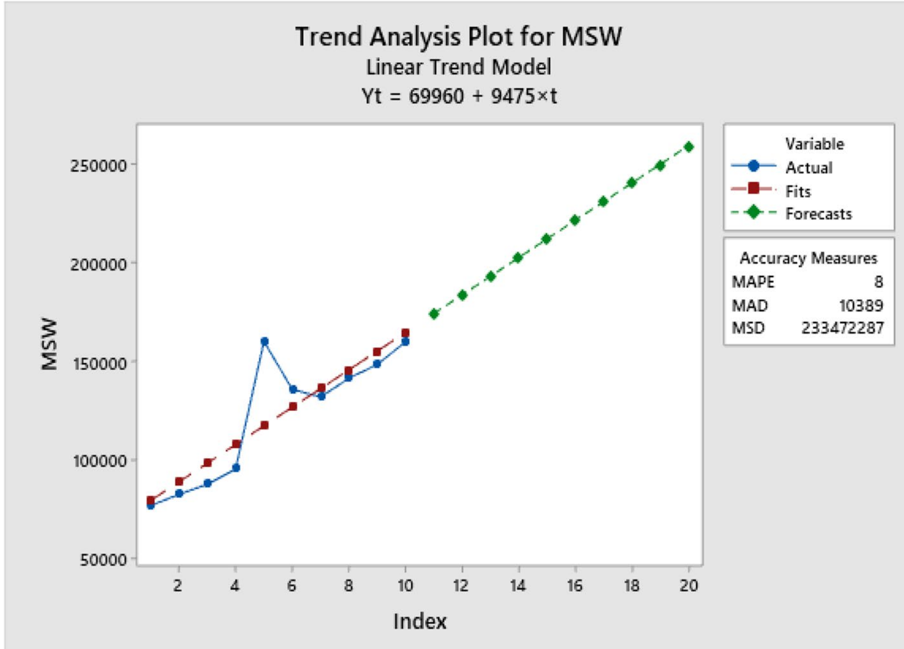


Fig. 8 Trend analysis plot of municipal solid waste generation of Srinagar city

variances was checked, and the results showed deviations between the MSW generated in two seasons were statistically nonsignificant ($P > 0.05$).

The thematic and spatial mapping was performed in ArcGIS software, and the results showed the dynamics of various parameters of MSW management, viz. density of population, MSW generation, density map of waste bins, open wastebin locations with illegal disposal sites, respectively. The findings of high-density wards revealed that central part of the city, like ward number (4, 6, 7, 16, 20, 21, 22 and 23), was having a higher population density of (29,560–120,100) persons km^{-2} among all and generated highest MSW of (30.04–35.65) Mt day^{-1}, while outskirts of the city, such as low-density wards (1, 3, 12, 13, 14, 15, 19, 25, 26, 27, 31, 32 and 34), represented the lowest population density among all wards, ranging (0–7913) persons km^{-2}, with lower values of MSW generation between (0 and 22.98) Mt day^{-1}. The spatial analysis of 35 wards demonstrated that the population density impacts on MSW generation across the Srinagar city. It was observed from spatial analysis that community waste bins were having an unequal distribution pattern across the city. It was identified that a total of 91 open waste points without waste bins were creating a threat to public health and the environment.

The forecasting was carried out, which exhibited the MSW generation trend between 2020 and 2030, and the model estimated a total of 216,82,10 Metric tons of MSW will be generated during the aforementioned years (a decade). The study results provided insights of MSW management in the mountainous city of Srinagar and will assist the policy makers, researchers and town planners for proper planning and designing of MSW management of the Srinagar city. Also, the study approach can be applied in other high-altitude regions around the globe having well-high conditions.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author declares that there is no conflict of interest.

Ethical standard The research completely adheres to all applicable ethical standards.

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