A Method for Evaluating Spatial Characteristics of Illegal Garbage Dumping Issues in Mountain Villages of Taiwan Using Exploratory Special Analysis

Chin Hsien Liao

Department of Land Resources, College of Agriculture, Chinese Culture University, Taiwan
Email: ljx15@ulive.pccu.edu.tw (C.H.L.)
Manuscript received January 2, 2024; revised January 29, 2024; accepted February 6, 2024; published August 13, 2024

***Abstract*—The issue of spatial characterization in the context of illegal garbage dumping issues in mountainous regions has emerged as a pressing concern in recent years. The methodology involves analyzing the environmental factors that lead to illegal dumping of garbage problems by studying case examples of trash waterfalls in mountain areas and conducting a literature review. Geographic information systems supplement this analysis to determine the spatial distribution of illegal dumping of garbage problems and the potential spatial factors that lead to their occurrence. The expected results include the establishment of a multiple-ring buffer of the spatial factor maps and then converting vector data into raster data of 20 m in length and width using a Geographic Information System. The Geographic Information System "raster calculation" function is then used, to sum up the scores of the illegal dumping of garbage potential classification layers to create the raw scores of the possible map of illegal garbage dumping. Finally, the box-and-whisker plot percentile method is used to identify statistically significant outliers, considered the threshold score for recognizing high-potential areas. This study provides a more systematic concept and methodology to help people solve the problem of dumping in the study site in the mountainous areas of Taiwan.**

***Keywords*—illegal dumping, trash waterfall, investigation method, exploratory spatial analysis, geographic information system**

I. Introduction

In recent years, the problem of insufficient waste removal resources has become increasingly serious in mountainous settlements due to changes in lifestyle and industry. In response to the release of the Global Waste Management Outlook by the United Nations Environment Program in 2015, policy recommendations were formulated to provide practical solutions to address the issue of waste management in specific regions and mountainous areas [1]. Most studies on waste management focus on urban areas and neglect rural areas [2]. The unique environmental conditions in mountainous areas make it challenging to remove waste, and it can also lead to water resource pollution upstream [3]. From a social perspective, most rural communities in mountainous areas face a lack of resources for waste transportation and prevention. This can result in illegal dumping or open burning of waste [4–6]. Several studies have examined the impact of garbage on the ecological environment, but fewer have discussed controlling the source of waste generation.

However, Illegal dumping has become a rampant issue in Taiwan's mountain areas, and it's only getting worse with the increasing amount of waste. For instance, Taiwan's Environmental Protection Administration (EPA) has compiled 4,748 cases of non-compliance with waste disposal regulations since 2020. Most Illegal dumping often occurs due to inadequate waste management infrastructure, including insufficient transportation systems and collection facilities [7, 8].

Illegal dumping is a significant issue in rural mountainous areas due to uneven transportation performance, household garbage disposal habits, and waste disposal methods. It is difficult to judge the reasonableness of the allocation of garbage resources in rural mountainous areas using the methodology and cognition of urban garbage disposal [9]. Additionally, unbalanced population distribution means that some areas may have a higher concentration of waste while others have very little. The long transportation distances to urban areas can further complicate waste management, as it can be costly to transport waste to these areas. All of these factors can contribute to increased storage costs, as waste may need to be stored for longer periods of time [10].

Moreover, most waste treatment policies and studies have historically focused on removing waste in urban areas, including public participation in designing recycling programs [11–13]; Participation in composting [14]; Participation in a door-to-door recyclable waste collection system [15]. The studies mentioned above have focused on municipal waste management and have a rich research base and experience.

The uneven development of local socioeconomics impacts waste removal, and waste's spatial and temporal distribution may be highly uneven [16]. This spatial analysis must consider the environmental conditions and garbage disposal behavior of households in these areas. Identifying the spatial factors contributing to waste management and emphasizing the importance of spatial characteristics and factors in planning and managing waste effectively is crucial. Therefore, strengthening the research and discussion of related primary data is urgently needed for better waste management and monitoring. The findings will give the local authority some valuable information.

II. The Spatial Issue of Illegal Garbage Dumping in Mountain

The literature review section of the study is divided into two parts. The first part defines illegal garbage dumping, while the second part explores the spatial pattern methodology of illegal garbage dumping.

A. Defines Illegal Dumping of Garbage

Due to the remote location of mountainous areas, it becomes challenging to monitor the dumping of garbage on either public or private lands [17]. As a result, people, including ordinary households, migrant workers, and businesses, dumping garbage in the mountains is the most cost-effective way to dispose of waste in such areas. However, this act has led to environmental damage, including pollution of groundwater and soil, which is a typical tragedy of shared communal land. For instance, a village in Chiayi County is mountainous, making it feel like an isolated island. The village can only dispose of garbage twice a week, which often leads to overflowing garbage at the relay point or temporary storage point. Some villagers or tenants in the mountainous areas of their hometowns discard poor quality or unsellable agricultural products, food waste, or large furniture by the roadside, which creates garbage hotspots. The garbage often piles up and overflows like waterfalls, leading to environmental filthiness, illustrated in Fig. 1.

Fig. 1. Photos of the illegal dumping and trash waterfall.

B. Explores the Spatial Pattern Methodology of Illegal Garbage Dumping

Michael Goodchild defines spatial analysis as an attempt to emphasize the importance of spatial factors in human society and to analyze human society phenomena by examining the spatial patterns and processes of variables. Geo-referenced data, which quantifies phenomena with geographic information, produces spatial homogeneity and spatial heterogeneity characteristics. However, geospatial analysis techniques can be used to solve these problems in rural mountainous areas, regardless of transportation performance, household waste disposal behavior, or waste removal methods [18, 19]. Illegal dumping can be influenced by various factors such as socioeconomic status, demographics, availability of waste collection facilities and recycling sites, as well as spatial characteristics [20]. Spatial data analysis, such as spatial autocorrelation (SAR) and global weighted average (GWR), and non-spatial data analysis, such as ordinary least squares (OLS), are often used to address the problem of illegal dumping in Poland and Turkey [21]. GWR model OLS and GWR are used to predict several independent variables that may affect illegal dumping [22]. A spatial hotspot analysis approach is necessary as the regression model requires a complete Illegal dumping event point, which cannot be obtained from the source. In previous research literature and initiatives, various factors have been identified as affecting the accumulation of garbage in mountainous areas. Spatial analysis can be helpful for monitoring and managing natural resources and pollution levels. It involves monitoring the distribution and total amount of garbage to estimate the resources required for garbage removal. Additionally, it helps in understanding the spatial factors that contribute to the accumulation of garbage, which can provide essential insights for management and prevention efforts. For example, analyzing and modeling collected data to identify waste generation trends, dumping hotspots, and possible illegal dumping behaviors would help develop measures to prevent waste in mountainous areas. The Exploring Spatial Data Analysis (ESDA) technique has recently matured. The buffers can be fixed distance or concentric (multiple-ring) to conduct exploratory spatial data analysis (ESDA) and discuss to visualize waste collection site distribution in the Jakarta area [23]. This study used a fixed-distance buffer valuation method with scores indicating illegal dumping risk to solve the spatial decision-making problem.

III. Materials and Methods

The process of constructing the potential classification index for illegal garbage dumping involves several steps detailed in this study, illustrated in Fig. 2.

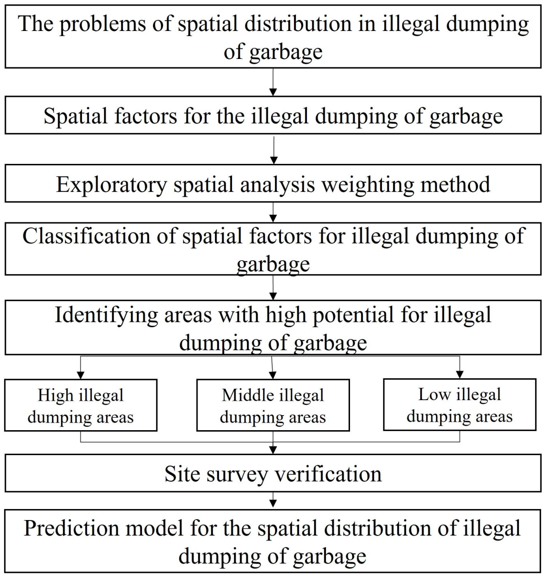

Fig. 2. Research route.

A. Exploratory Spatial Factors of Illegal Dumping Garbage

The study utilized a literature review and future field surveys to determine the common conditions that lead to the formation of illegal garbage dumping and large-scale dirty spots. The initial predictive factors considered were population density, distance from roads, electricity coverage, slope, and current land use conditions, which are illustrated in Table 1.

Table 1. Spatial factors for the illegal dumping of garbage

Spatial factor	Classification of spatial factors for illegal dumping of garbage	Sources of the graphs
Population density	The score is higher for areas with lower population density and lower for areas with higher population density. The opposite is also true.	Population Maps by NLSC
Distance from roads	An average person's maximum acceptable walking range is 10 minutes (about 1 km).	Road Maps by NLSC

Spatial factor	Classification of spatial factors for illegal dumping of garbage	Sources of the graphs
Electricity coverage	The grading of the 100-meter electric coverage area 1. no coverage (5 points) 2. with coverage (0 points)	Electronic Maps by NLSC
Slope	The risk of unauthorized dumping increases as the slope gets steeper. To assess the risk of dumping, this study assigns a score of 1 to Grade 1 slopes, 2 to Grade 2 slopes, and so on, with a score of 5 given to Grade 5 slopes and above.	Slope Maps by NLSC
Current land use conditions	Land use can be categorized 1. low intensity (5 points) - forest, water conservancy, and transportation uses 2. medium-low intensity (4 points) - mining and salt, agricultural use 3. medium intensity (3 points) - public use 4. medium-high intensity (2 points) - other uses 5. high intensity (1 point)-building, recreational use	Land Use Investigation Maps by NLSC

B. *Exploratory Spatial Analysis Weighting Method*

This paper utilizes GIS to conduct a land suitability analysis, as illustrated in Fig. 3. First, a multiple-ring buffer of spatial factor maps is established. Then, the vector data is converted into raster data 20 m in length and width using GIS.

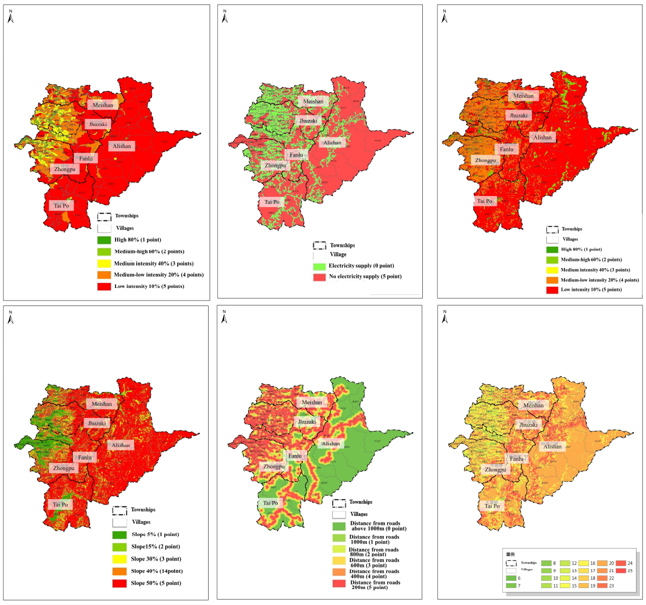

Fig. 3. Classification of spatial factors for illegal dumping of garbage.

Similarly, the vector data is converted into raster data, and the scores of the five types of classification and grading maps are summed up to obtain the raw scores of the illegal garbage of dumping potential maps. The box-and-whisker plot percentile method is used to identify statistically significant outliers, which serves as the threshold to determine high-potential areas and their locations.

According to the raw potential score chart, the potential score of the hotspots in the grid units of the areas within the study area would range from 6 to 30. In order to grasp the statistically significant extreme values, which can be used as the basis for categorizing the areas with high potential, medium-low potential, and no potential for the time being, the "box-and-whisker plot percentile method" will be used to define the threshold of high potential in this study.

The Box-and-Whisker Plot Percentile Method (BWPM) is a statistical method used to analyze data. It involves identifying the minimum, maximum, median, first quartile (Q1), third quartile (Q3), and interquartile range (IQR = Q3-Q1) of the data. Based on this information, the method calculates a reasonable range of maximum and minimum values for the data. Any values that fall outside this range are considered extreme values.

To calculate the reasonable distribution range, we use the following formula, as in Eqs. (1, 2):

$$\text{Minimum value range: } \alpha = Q1 - 1.5IQR \tag{1}$$

$$\text{Maximum value range: } \beta = Q3 + 1.5IQR \tag{2}$$

If the minimum value of a set of data is greater than α, it is considered within the reasonable range. Otherwise, it is an extreme value. Similarly, if the maximum value of a set of data is less than β, it is considered within the reasonable range. Otherwise, it is an extreme value. Table 2 illustrates the scores of the five classification levels summed up to obtain the raw scores of the potential map for illegal garbage dumping.

Table 2. Spatial factors for the illegal dumping of garbage

Spatial factor	The score indicates a risk of illegal garbage dumping A higher score = higher risk. (ha/%)					
	0 score	1 score	2 score	3 score	4 score	5 score
Population density	39,431.11	5,934.11	8,460.09	12,845.07	19,946.06	29,533.56
	33.9%	5.1%	7.3%	11.1%	17.2%	25.4%
Distance from roads	0.00	1,864.59	6,090.50	135.69	29,446.95	78,612.28
	0.0%	1.6%	5.2%	0.1%	25.4%	67.7%
Electricity coverage	0.00	245.14	2,200.88	7,944.50	18,478.80	87,280.69
	0.0%	0.2%	1.9%	6.8%	15.9%	75.1%
Slope	0.00	9,319.05	6,768.16	12,026.91	11,268.34	76,765.17
	0.0%	8.0%	5.8%	10.4%	9.7%	66.1%
Current land use conditions	35,266.46	0.00	0.00	0.00	0.00	80,883.55
	30.36%	0.0%	0.0%	0.0%	0.0%	69.64%

The results of each spatial factor classification and the raw potential scores of each grid area are presented in the following format. Quartiles represent a data set's 25th, 50th, and 75th percentiles, containing 25%, 50%, and 75% of the data, respectively. Consider a set of n measurements, $x1$, $x2$, ..., xn, arranged in increasing or decreasing order. The Pth percentile is a value, denoted by x, such that P% of the measurements are less than or equal to x, and (100-P)% of the measurements are greater than or equal to x.

After analyzing the data, it was found that the potential scores for illegal garbage dumping were mainly concentrated in the 13 to 24 range, making up more than 95% of the total. Box-whisker diagrams were used to determine the statistically significant thresholds of high-potential areas. The potential scores of hotspots in each grid unit of the six townships within the study area ranged from 6 to 25 points, as shown in the "Raw Potential Score Chart" above. To categorize areas with high potential, medium-low potential, and no potential, the project used the box-and-whisker plot percentile method to define the high-potential thresholds.

The Box-and-Whisker Plot Percentile Method (BWPM) lists the maximum, minimum, median, first quartile (*Q*1), third quartile (*Q*3), and interquartile range ($IQR=Q3-Q1$) of a set of data. The BWPM calculates the range of reasonable maximum and minimum values for a given data set, and those that do not fall within this range are considered extreme values. The formula for the reasonable distribution range is in Table 3.

Table 3. Illegal garbage dumping potential scores - box-and-whisker plot percentiles and extreme values

Statistical Items	Statistics	Note
Min	6	Lowest raw score of all blocks
Max	25	Highest raw score among all blocks
Q1	17	All blocks are ranked from lowest to highest based on their raw scores and the accumulated raw scores of the blocks in the 25th percentile.
Q2	19	All blocks are ranked in ascending order based on their raw scores, with the 50th percentile raw scores totaled.
Q3	20	All blocks are ranked from lowest to highest in raw scores, and the raw scores of the 75th percentile blocks are accumulated.
IQR	3	IQR=Q3-Q1
α	12	α=Q1-1.5*IQR
β	24	β=Q3+1.5*IQR

Based on the provided table, grid blocks with a cumulative score of less than 6 points can be considered areas with no potential for illegal garbage of dumping. On the other hand, areas with a score of more than 24 points can be identified as high-potential areas. GIS aggregate polygons analysis can be used to identify high-potential hotspot grids. If these grids are within 100 m of each other, they are considered the same aggregation unit. These priority areas can be designated for future monitoring or publicity.

IV. Result and Discussion

According to the statistics, several hotspot areas with high potential cover approximately 11,544.25 hectares. This accounts for around 9.9% of the overall area of the six villages. It finds further details in Table 4.

Table 4. Statistics of illegal garbage dumping in each village

Scale	<1 ha		1-5 hectares		>5 hectares		Total	
Townships	**count**	**ha**	**count**	**ha**	**count**	**ha**	**count**	**ha**
Tai Po	39	11.79	22	53.89	43	1,980.53	104	2,046.21
Zhongpu	140	30.28	40	89.85	37	546.15	217	666.27
Jhuzaki	128	37.71	43	100.88	42	1,468.52	213	1,607.11
Alishan	59	19.42	32	84.02	83	3,754.09	174	3,857.52
Meishan	134	36.71	68	176.97	52	1,483.05	254	1,696.73
Fanlu	91	27.09	40	89.96	43	1,553.35	174	1,670.40
Total	591	162.99	245	595.57	300	10,785.69	1,136	11,544.25

These hotspot areas are primarily located on steep slopes with low population density and are currently used with low intensity, such as for forests. They are situated near roads and are not covered by any electricity within a radius of 100 m.

After an analysis of high-potential areas, it was discovered that 10 out of 13 locations with trash waterfalls and dirty spots are within 100 m of the high-potential areas. Additionally, all these sites are within a 500-meter radius of the high-potential areas. Notably, the following locations, Fanlu 1, Fanlu 2, Meishan 2, Jukasaki 1, Jukasaki 2, and Alishan 1, are directly located within the predicted area. These findings are precious in identifying unknown illegal garbage of dumpings and can help to improve prevention and control measures. It finds further details in Table 5, Fig. 4.

Table 5. Statistics on the validation results of the hierarchical indicators of illegal garbage dumping

Type	**Number**	**Prediction accuracy**			
		Within prediction range	Within 100 m	Within 200 m	Within500 m
illegal garbage dumping	Fanlu1	O			
	Fanlu2	O			
	Meishan1				O
	Meishan2	O			
	Zhongpu1			O	

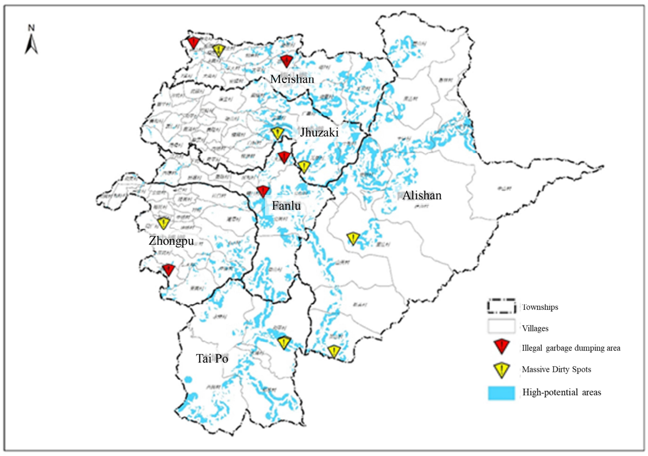

Fig. 4. Illegal garbage dumping high potential areas and survey area map.

V. Conclusion

The term "Trash Waterfall" describes the accumulation of waste in mountainous areas caused by inadequate transportation or illegal dumping. This phenomenon can significantly impact the environment and lead to the growth of garbage piles, commonly known as the "broken window effect". To prevent such situations, it is essential to take preventive and corrective measures. A study suggests using a GIS-based exploratory spatial analysis technique for land suitability analysis.

To identify areas that are at a high risk of garbage accumulation, the study uses a detailed process that involves creating multiple ring buffers of spatial factor maps using GIS. These spatial factor maps are created by analyzing variables such as population density, proximity to water bodies, and waste generation rate. After creating these spatial factor maps, this paper obtains the raw scores for the illegal garbage of dumping potential map by adding up the scores from the five categories of classification layers. These five categories include population density, accessibility, land use, topography, and distance to water bodies. To identify statistically significant outliers, the study used the box-and-whisker plot percentile method. This helps to find the threshold of scores for high-potential areas and their location. The study can then use this information to identify areas with a high risk of garbage accumulation. This method is highly effective in identifying high-potential areas and is used by waste management organizations to plan and implement waste management strategies. By identifying areas at a high risk of garbage accumulation, this paper can take proactive measures to prevent the accumulation of garbage and maintain a clean and healthy environment.

This study indicates that illegal garbage of dumping sites are most commonly found in sparsely populated areas with steep slopes, low-intensity use, and no electricity coverage within 100 m. Forested areas adjacent to roads are also common locations for such sites. The study suggests that the generation of trash waterfalls may be linked to the lack of transportation energy in mountainous regions, making transporting and monitoring waste challenging.

The findings of this study can help local governments manage their resources more effectively when it comes to garbage removal in mountainous regions. By identifying potential sites for illegal garbage dumping and increasing monitoring resources, such as manpower for inspections or placement of monitors, they can reduce the amount of illegal waste generated in mountainous areas.

Conflict of Interest

The author declares no conflict of interest.

Funding

The present paper results from research project No.112-2410-H-034-046. The National Science and Technology Council financed the research by kindly providing me with information and assistance.

Acknowledge

The author is grateful to the editor and anonymous reviewers whose valuable comments and insightful remarks have led to widespread improvement to the earlier versions of the manuscript.

References

[1] B. Alfthan *et al.*, "Waste management outlook for mountain regions: Sources and solutions," UNEP: Nairobi, Kenya; GRID-Arendal: Arendal, Norway; ISWA: Vienna, Austria, 2016.

[2] J. Aleluia and P. Ferrão, "Characterization of urban waste management practices in developing Asian countries: A new analytical framework based on waste characteristics and urban dimension," *Waste Management*, vol. 58, pp. 415–429, 2016.

[3] L. Semernya, A. Ramola, B. Alfthan, and C. Giacovelli, "Waste management outlook for mountain regions: Sources and solutions," *Waste Management & Research*, vol. 35, no. 9, pp. 935–939, 2017.

[4] A. Dabholkar, B. Muthiyan, S. Srinivasan, S. Ravi, H. Jeon, and J. Gao, "Smart illegal dumping detection," presented at the 2017 IEEE Third International Conference on Big Data Computing Service and Applications (BigDataService), 2017, pp. 255–260.

[5] F.-C. Mihai and A. Grozavu, "Role of waste collection efficiency in providing a cleaner rural environment," *Sustainability*, vol. 11, no. 23, p. 6855, 2019.

[6] L. Du, J. Zuo, J. Vanzo, R. Chang, and G. Zillante, "Assessing and predicting the illegal dumping risks in relation to road characteristics," *Waste Management*, vol. 169, pp. 332–341, 2023.

[7] B. Šedová, "On causes of illegal waste dumping in Slovakia," *Journal of Environmental Planning and Management*, vol. 59, no. 7, pp. 1277–1303, 2016.

[8] G. K. Ijemaru, L.-M. Ang, and K. P. Seng, "Swarm intelligence internet of vehicles approaches for opportunistic data collection and traffic engineering in smart city waste management," *Sensors*, vol. 23, no. 5, p. 2860, 2023.

[9] A. Thakur, S. Kumari, S. Sinai Borker, S. P. Prashant, A. Kumar, and R. Kumar, "Solid waste management in Indian Himalayan region: Current scenario, resource recovery, and way forward for sustainable development," *Frontiers in Energy Research*, vol. 9, p. 609229, 2021.

[10] G. K. Óskarsson, S. Agnarsson, and B. Davíðsdóttir, "Waste management in Iceland: Challenges and costs related to achieving the EU municipal solid waste targets," *Waste Management*, vol. 151, pp. 131–141, 2022.

[11] K. M. Keramitsoglou and K. P. Tsagarakis, "Public participation in designing a recycling scheme towards maximum public acceptance," *Resources, Conservation and Recycling*, vol. 70, pp. 55–67, 2013.

[12] B. Seng, T. Fujiwara, and V. Spoann, "Households' knowledge, attitudes, and practices toward solid waste management in suburbs of Phnom Penh, Cambodia," *Waste Management & Research*, vol. 36, no. 10, pp. 993–1000, 2018.

[13] E. Drimili, R. Herrero-Martin, J. Suardiaz-Muro, and E. Zervas, "Public views and attitudes about municipal waste management: Empirical evidence from Athens, Greece," *Waste Management & Research*, vol. 38, no. 6, pp. 614–625, 2020.

[14] M. Kevrekidou, "Exploring the public views concerning the introduction of 'Pay-As-You-Throw' waste management systems in Greece," Master's Thesis, International Hellenic University, Thessaloniki, Greece, 2016.

[15] T. Tsalis, S. Amarantidou, P. Calabró, I. Nikolaou, and D. Komilis, "Door-to-door recyclables collection programmes: Willingness to participate and influential factors with a case study in the city of Xanthi (Greece)," *Waste Management & Research*, vol. 36, no. 9, pp. 760–766, 2018.

[16] C. Wu *et al.*, "Assessment of the health risks and odor concentration of volatile compounds from a municipal solid waste landfill in China," *Chemosphere*, vol. 202, pp. 1–8, 2018.

[17] J. Mushtaq, A. Q. Dar, and N. Ahsan, "Spatial–temporal variations and forecasting analysis of municipal solid waste in the mountainous city of north-western Himalayas," *SN Applied Sciences*, vol. 2, pp. 1–18, 2020.

[18] L. A. Guerrero, G. Maas, and W. Hogland, "Solid waste management challenges for cities in developing countries," *Waste management*, vol. 33, no. 1, pp. 220–232, 2013.

[19] A. Singh. (2019). Remote sensing and GIS applications for municipal waste management. (pp. 22–29). [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0301479719306152

[20] S. Syafrudin *et al.*, "Analysis of factors influencing illegal waste dumping generation using GIS spatial regression methods," *Sustainability*, vol. 15, no. 3, p. 1926, 2023.

[21] S. Keser, S. Duzgun, and A. Aksoy, "Application of spatial and non-spatial data analysis in determination of the factors that impact municipal solid waste generation rates in Turkey," *Sustainability*, vol. 32, no. 3, pp. 359–371, 2012.

[22] M. Agovino and G. Musella, "Separate waste collection in mountain municipalities. A case study in Campania," *Land use policy*, vol. 91, p. 104408, 2020.

[23] N. D. Febrianto, E. Suryadinata, Z. Amalia, M. F. Hidayat, R. Yulistiani, and S. Arifin, "Mapping Garbage Dump and Landfill in DKI Jakarta Using GIS (Geographic Information System) Technology," presented at the 2022 International Conference on Science and Technology (ICOSTECH), 2022, pp. 1–5.