SSURJET

Sir Syed University Research Journal of Engineering & Technology
2023, Vol. 13, No. 1,
https://doi.org/10.33317/ssurj.515

Municipal Solid Waste Management using GIS Analysis: A Case Study of Sehwan City

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Received July 07, 2022; Revised December 12, 2022; Accepted December 14, 2022

Abstract

One of the fundamental issues of the 21st century and one of the key tasks of a municipal administration is to manage solid waste effectively and efficiently. Cities are developing extremely, and the issue of Municipal Solid Waste (MSW) is becoming critical due to the growth in quantity and complexity of generated waste and the shortage of land for its disposal. By 2050, the world's waste creation is expected to have increased more than doubled the rate of population increase. The area is mostly residential, and most of the solid waste is created in the home, such as food and vegetable waste. There are few bins placed in Sehwan city and those are not placed at the proper locations, due to this reason inhabitants of the city are throwing their municipal waste on the street's sides and vacant plots. The research aim of the study was to develop a Geographic Information System (GIS) technology. This research contained three objectives; identifying the existing MSW management condition and their effect on different factors such as health and the environment; reallocation of waste collection bins in the study area using GIS buffer analysis; and proposing a route plan for the collection of MSW using GIS network analysis. Furthermore, based on GIS technology, this work provides a framework for optimizing the waste collection and transportation system. The GIS method includes the digitization of a map showing the current placement of bins and the actual condition of solid waste. Through the digitized map, the location of bins can be analyzed, by using some proximity distance. A 50m buffer is used to see the proximity distance of bins, and a 20m buffer is also used around sensitive buildings. The new dataset of the road helped to see the road edges and junctions in the city. Road junctions and proximity distance route plans were made for the research study area. The result showed that the misplacement of waste bins in Sehwan city affects the environment, waste laying around the bins causes land pollution, and also municipal waste on road affects the health of people. More than 82% of the inhabitants are unsatisfied with the management of the solid waste disposal system in the study area also 90% of residents are suffering from different diseases. This study will help the planner and authorities cope with municipal solid waste issues. Municipal authorities must follow technologies and research studies to solve the solid waste issues of people in their local areas.

Index Terms: *Geographic Information System, Municipal Authorities, Route Optimization, Municipal Solid Waste, Waste Collection.*

I. INTRODUCTION

Municipal Solid Waste Management (MSWM) is a major issue since the 90s, encompassing a wide variety of activities such as waste generation, storage, collection, transportation, recycling, and disposal while conforming to public health, sustainable development, and economic requirements [1]. One of the core problems of the 21st century, and the crucial duties of a municipal administration, is to manage solid waste economically and efficiently [2]. MSWM is among the most significant environmental issues [3]. Cities are rapidly expanding, and the issue of Municipal Solid Waste (MSW) is becoming increasingly critical as the quantity and complexity of waste generated increase and the shortage of land for its disposal [4]. Unplanned expansion and slum development result from migration, and these places create large amounts of unmanageable solid waste [5]. In recent years, rapid urbanization has considerably increased MSW output [6]. Growing populations, economies, increasing urbanization, industrialization, and increased living standards all contribute to continual increases in MSW production globally. Cities in emerging nations that are rapidly increasing are significant contributors, i.e., like other developing countries, Pakistan is confronted with significant MSW management issues [7]. Because of poverty, population growth, urbanization, and a lack of funds, MSW disposal has been a major challenge in underdeveloped countries. Disease transmission, fire dangers, odor nuisance, air and water pollution, visual annoyance, and economic losses are some of the most prevalent issues associated with inappropriate dumping [8]. In general, low-income municipalities spend around 20% of their budgets on waste management, while over 90% of waste is still dumped or burnt in the open. Solid Waste Management (SWM) is a universal issue affecting every single person in the world [9]. According to the World Bank, annual MSW output for metropolitan areas should be over 1.3 million tons in 2012, and this quantity should double by the end of 2025 [10]. The challenges of SWM are not new and it has been adopted by scholars across the world. Waste is a problem not just because of rising volumes, but also because of an ineffective management system [11]. The production of waste is a necessary stage in all industrial operations and human endeavors. The majority of these wastes will almost definitely be improperly disposed of in nature due to a lack of recycling methods, a reality that contributes to

significant environmental issues globally [12]. Pakistan is also dealing with the high quantum generation of solid waste. This can be visualized because of the irresponsible behavior of residents and lack of education, as large lots of waste lying in a disorderly manner in every nook and corner in several areas of cities which can be experienced [13]. Between 2015 and 2025, Pakistani cities are expected to grow by 21.1 million inhabitants [14]. Solid waste production in Pakistan ranges from 0.283 to 0.612 kg per capita, with a 2.4 percent annual increase rate [12], and [15]. In general, the quantity of solid waste generated in large cities has been growing, and the more urbanized a region is, the larger the amount of waste generated per capita [16]. The management of MSW is one of today's most critical matters. Because all previous low-cost (low-control) disposal practices are no longer acceptable, the national, regional, and local governments are constantly confronted with this challenge. For instance, in India, a GIS optimum routing model was built to calculate the cheapest and most efficient routes for collecting solid waste for transporting to a landfill [17]. Because present MSW management systems in low and middle-income countries have high collection and transportation costs of 80–90 percent and 50–80 percent, respectively. Therefore, optimization of MSW collection and transportation become a major concern in MSW management system design. In general, different waste sources are dispersed throughout urban areas in an unorganized manner, which raises the cost of waste collection and transportation [18].

II. LITERATURE REVIEW

Cities in Pakistan are becoming less livable as a consequence of problems such as a lack of adequate infrastructure and services, and individuals are significantly affected by the availability of solid waste collection [19]. During the period of last five decades, cities with low-income countries around the globe, have witnessed huge migration. With the increase in population, migration, industrialization, and economic development in the world, the problems of management of MSW also increased. Management of municipal solid waste is mostly complex nowadays due to the ever-increasing magnitude of waste.

The management and disposal of municipal solid waste are the biggest challenges to secondary cities in Pakistan. One can witness huge dumplings on the curbsides of these secondary cities, which pose a serious threat of disease to the inhabitants [20]. According to studies, Integrated Waste Management (IWM) adopts a holistic, ecologically friendly, cost-effective, and socially acceptable approach to waste management. It entails the utilization of a variety of treatment solutions at the local level, as well as consideration of the total solid waste stream [21]. The rise in solid waste production is one of the effects of global urbanization. In the early 1990s, Asia as a whole spent about USD 25 billion annually on SWM; by 2025, that amount is anticipated to rise to nearly USD 50 billion. The lack of attention paid to control mechanisms hurts safety, health, and the environment. SWM does not appear to be a priority, and regulations are not sufficiently enforced. No integrated SWM system exists in any of the cities [22]. In Karachi, due to poor waste collection, a lack of space, and restricted use of alternate disposal techniques, waste is frequently burnt illegally in crude form as a last option, leading to piled-up mountains of waste [23]. It has been determined that the current MSWM system is inadequate and ineffective in Karachi [24]. Waste is merely carried to collection points and is then buried in disposal sites. As a result of this system, bad smells and pollution of the air, soil, and water are already affecting the health of residents and ecosystems [25]. The MSWM model's aim in the 1970s was modest and restricted, such as selecting appropriate transfer stations or optimizing waste collection routes for vehicles. In the 1980s, the focus was extended to include MSWM on a system level, to minimize MSWM costs. In the 1990s, MSWM models primarily incorporated economic (e.g., system cost and benefit), environmental (air pollution, water pollution), and technological considerations (the maturity of technology) [26]. Vehicle emissions from collection vary based on factors such as truck type, fuel type, efficiency, and route characteristics, but collection is always the most fuel-intensive activity in SWM systems [27].

Today many materials such as plastics are considered degradable and toxic materials that contain solid waste, primarily various types of chemical waste produced by industry. Similarly, the amount of harmful waste generated has been undergoing intense change [28].

In Africa, waste is unattractive and lowers social morale. The spread of diseases has been related to poor waste management [29]. Complicated waste management systems, in particular, situating MSW management and disposal facilities and optimizing waste collection and transportation, have been a favorite field of GIS applications since the birth of the technology [30].

Local waste created by homes, businesses, and governmental sectors is referred to as MSW [31]. One of the effective solutions to such a problem is to adopt an efficient MSWM system. The MSWM system's implementation is influenced by several critical elements, including country regulations, environmental management strategies, economic and technological capabilities, and public education and environmental awareness [32].

There has been the development of new technologies to improve waste management systems, such as GIS, which has contributed significantly to the waste management system in a very short period. The research aims to study the current SWM and its effects on factors such as health and the environment in Sehwan city and provide solutions for those mishaps in systems. Furthermore, based on GIS technology, this work provides a framework for optimizing the waste collection and transportation system.

The method included allocating and reallocating waste collection bins and rescheduling waste collection using GIS routing optimization. The advantages of the suggested technique were evaluated in terms of reducing solid waste collection, as well as the financial and environmental costs of the collection system.

III. METHODOLOGY

A. Study Area

Geographically the area is located with latitude 26.428828 and longitude 67.863436. There are 15 wards in Sehwan

city. The population of Sehwan city according to the 2017 census report is 66,923. The overall area of Sehwan taluka is 533747 acres and the Sehwan city's area is approx. 395 acres. The city is also recognized as a taluka in the Jamshoro District. Sehwan was once part of the Dadu District, but following the establishment of the Jamshoro District, it became part of the Jamshoro District. The location map of Sehwan city is shown in figure I below:

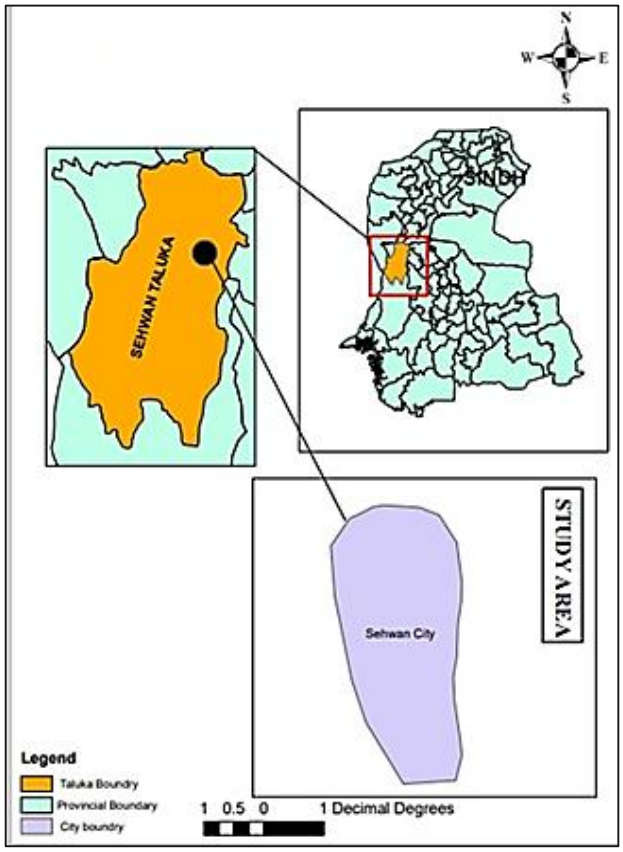

Figure I: Location Map of Sehwan City

Food and vegetable waste, waste paper, plastic, poly bags, metals, glass, and wood materials account for most of the solid waste in the study area. There are very few bins for garbage in the city, due to this resident throws their garbage here and there. Those wastes couldn't be collected by the standard waste collection vehicle, which deteriorates the environment, due to irregular placement of waste sites and other prohibitive obstacles. A few bins or containers placed in the city of their existing site are insufficient in the area. The collection of waste is not proper. As a result, the largest portion of domestic waste is dumped on vacant plots. Waste not disposed of properly usually finds its way into sewers is eaten by animals or is burnt next to roads. Such actions are detrimental.

B. Data Collection and Analysis

Primary and secondary data are used in the study. Key community interviews and a structured questionnaire survey were used to gather primary data on the MSWM of the study area. Sample size 384 from the 'de Morgan' table is obtained. 'Cronbach alpha' and one-sample t-test were used to analyze the raw data. One-sample t-test was used to check which factors affect the MSWM. Google Earth Images were used to generate spatial data from GPS data. The information of different types and forms has been converted into the GIS database. The network analyzer extension of GIS software (ArcGIS 10.8) was used to suggest the location of waste bins, optimize the route, and prepare final maps. Figure II given below shows the detailed methodology. The instrument Cronbach's alpha test is used to determine the survey's internal consistency. The test checks the reliability and consistency of the sample collection. For the current study, the test gave a value of $\alpha = 0.919$ therefore the data were found to be reliable for the study. The raw data were analyzed through SPSS software using t-test analysis.

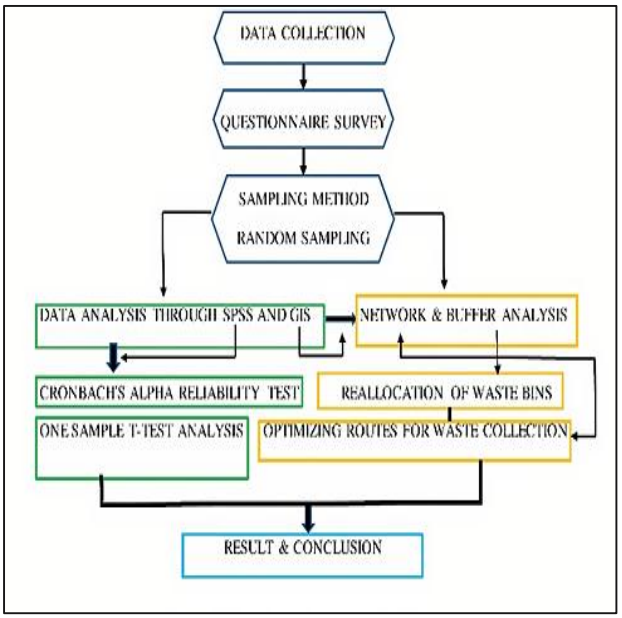

Figure II: Research Methodology Flow Chart

C. Statistical Analysis

To analyze the raw data descriptive frequency/percentage analysis and t-test analysis are used. Analysis reveals that more than 39% of residents have primary-secondary education levels and 26% are uneducated. More than 82% of the sample size population is unsatisfied with the management of the solid waste disposal system in the study area. It was observed 86.98% of respondents said they have no proper dumping site in the city and also there are no large bins in the study area. That is why 52.08% of residents throw their municipal waste nearby houses, 26.04% in open spaces or vacant lands and only 13.02% of residents throw their municipal waste in containers. 86.98% of residents do not separate their household waste. More than 70% of residents use plastic bags to store their household waste. Also, more than 50% of residents store their household waste for 1-3 days, and 25.26% of residents store their household waste for 3-5 days. The analysis also reveals that there is no regular collection of municipal waste in the study area. Due to the mismanagement of MSWM, residents face different issues as 34.90% of respondents said waste is laying around the road, 13.02% face odor issues, and 53.09% of respondents face rates and fly issues. Unmanageable MW causes environmental and health issues, more than 90% of residents are suffered from different diseases such as

diarrhea, dengue, typhoid, cholera, malaria, cough, asthma, skin disease, and other symptoms, etc.

To find out the different impacts of different factors t-test analysis was used.

Table I describes the residents of the city who store their municipal waste for more than 3-4 days which creates serious negative health impacts. Storage of household waste ($t = -0.018$, $p<0.05$) was a strongly significant factor that creates serious negative health impacts.

Table II shows when there is not any waste bin in the city people throw MSW in nearby houses, roadsides, or empty plots that creating land pollution. No waste bin in the study area factor effect environmental pollution. No waste Bin ($t = -0.051$, $p<0.05$) was a strongly significant factor that affects the environmental pollution as when there is not any waste bin in the city people throw MSW in nearby house, roadside or an empty plot that create pollution.

Table III shows the current poor practice of municipal solid waste can affect or harm biodiversity both directly and indirectly. Unmanageable SW issues create pollution, affect health, and cause diseases such as diarrhea, dengue, typhoid, cholera, malaria, cough, asthma, skin disease, and others.

Current issues of SWM in the study area factor effect on the biodiversity, current issues of SWM ($t = -0.062$, $p<0.05$) was strongly significant factor that effect on the biodiversity. Poor waste management can harm biodiversity both directly and indirectly.

Table IV shows unmanageable SW issues in the study area factor effect on health, unmanageable SW issues ($t = -0.039$, $p<0.05$) was a strongly significant factor that affects health and causes different disease such as diarrhea, dengue, typhoid, cholera, malaria, cough, asthma, skin disease, and others.

Table I: Storage of Household Waste Effect on Health (One-Sample Test)

	Test Value = 2.09		
	t	**df**	**Sig. (2-tailed)**
Storage of Household Waste	-.018	383	.986

Table II: No Any Waste Bins Factor Effect on Environment Pollution (One-Sample Test)

	Test Value = 1.97		
	t	**df**	**Sig. (2-tailed)**
Answer Regarding Placement of Large Bins in Sehwan City	-.051	383	.960

Table III: Current Issues of SWM Factor Effect on Biodiversity (One-Sample Test)

	Test Value = 4.41		
	t	**df**	**Sig. (2-tailed)**
Current Issues of Solid Waste Management in City	-.062	383	.950

Table IV: Unmanageable SW issues Factor Effect on Health (One-Sample Test)

	Test Value = 4.37		
	t	**df**	**Sig. (2-tailed)**
People Suffering from Different Diseases Due to Unmanageable Solid Waste Issues	-.039	383	.969

D. Buffer Analysis

To alleviate the difficulty caused by bins being so close together, a buffer of 20 meters is built around schools, hospitals, and religious structures [33]. We also create 50m buffer zones around current waste bins, and it has been discovered that by relocating certain bins in the area, the entire area may be covered. According to a literature review and field survey findings, a 100m distance is adequate for individuals [34].

Figure III shows the inappropriate open dumping site in the study area, it shows that most of them use vacant plots for their solid waste dumping.

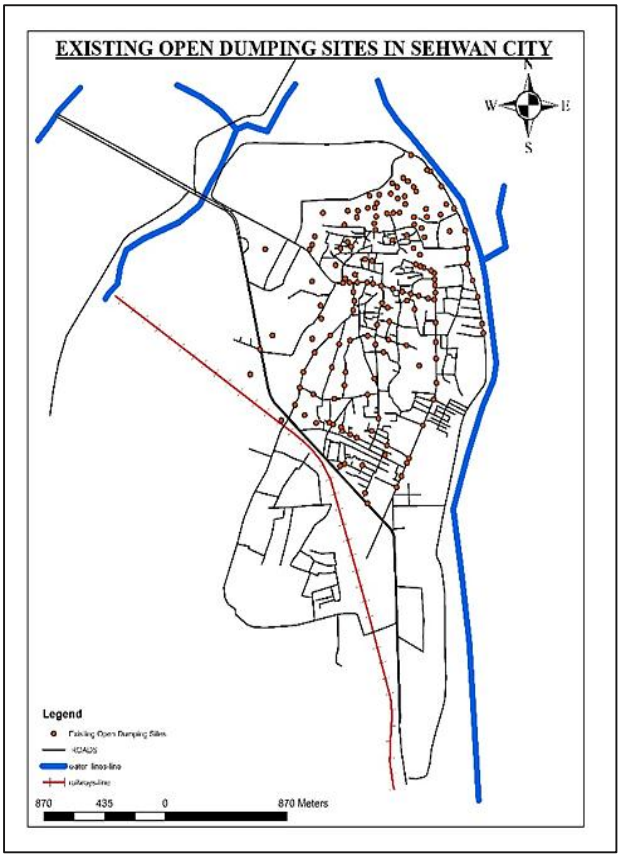

Figure III: Existing Open Dumping Sites in the Sehwan City

Figure IV shows the buffer analysis used for reallocating or allocating the waste bins in the study area. It shows that no waste bin or dumping site is within proximity distance, in most of the areas dumping sites are on the roadside and 3,4 dumping sites are in one place.

Figure V shows the study area's proposed waste bins and dumping sites. Route 1-6 shows the different routes and lengths for vehicle collection points.

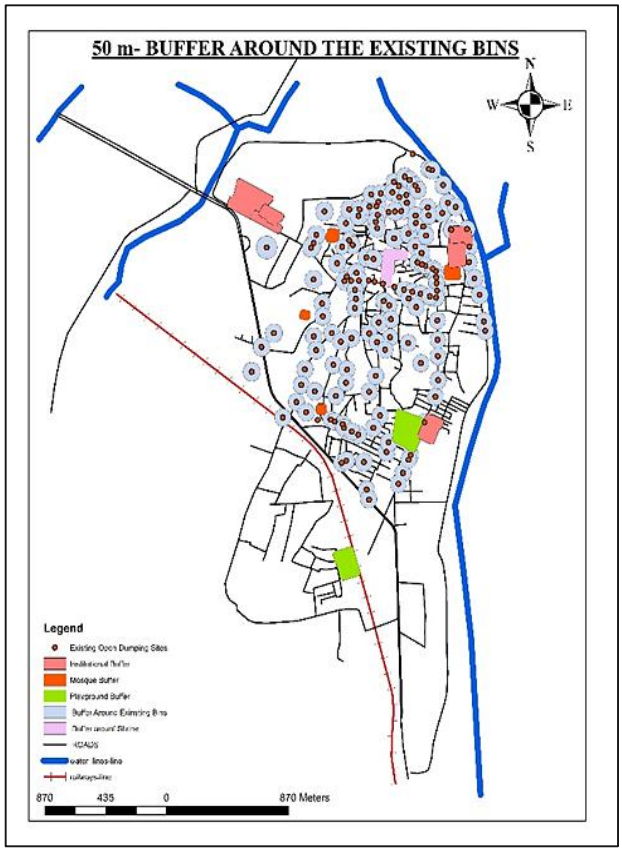

Figure IV: Buffer Analysis Around Existing Bins

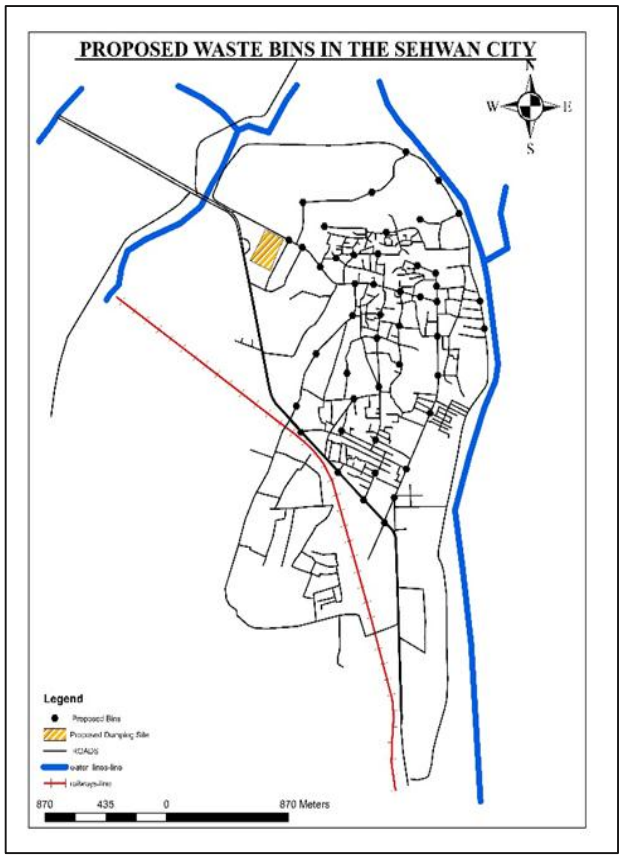

Figure V: Shows the Proposed Waste Bins in the Sehwan City

From the survey results, it was observed that the junction is a good idea for allocating the solid waste bins because the streets inside the city are not wide enough to accommodate the heavy waste-collecting vehicles. Usually, vehicles of residents and small transport like 'Chingchi Rikshaw' is used on inner city roads so that traffic jams do not occur in the junction areas and waste collection vehicle easily collect the solid waste from bins and move it from one junction to another. So most of the bins are allocated at the road junction so that it will not cause difficulty in collecting solid waste through vehicles.

E. Network Analysis

Following the reallocation of waste collection containers, we move on to the optimization of the garbage collection vehicles route. Researcher Tavares and associates, state that, "Successful decision-making in the field of management systems necessitates the introduction of vehicle routing methods capable of exploiting new technologies such as geographic information systems" [35]. The majority of previous work on optimal routing for solid waste collection has been oriented toward minimizing the traveled distance and/or minimizing the time [36]. The routing system of the vehicles followed the proposed waste collection bins and find out the shortest path for routing network analysis in Geographic Information System (GIS) [37-40]. Figure VI shows the proposed route plan for collecting solid waste in the study area. Different route plans for waste collection vehicles were considered. A maximum of 5 to 6 vehicles will be used to collect solid waste from bins [41-46].

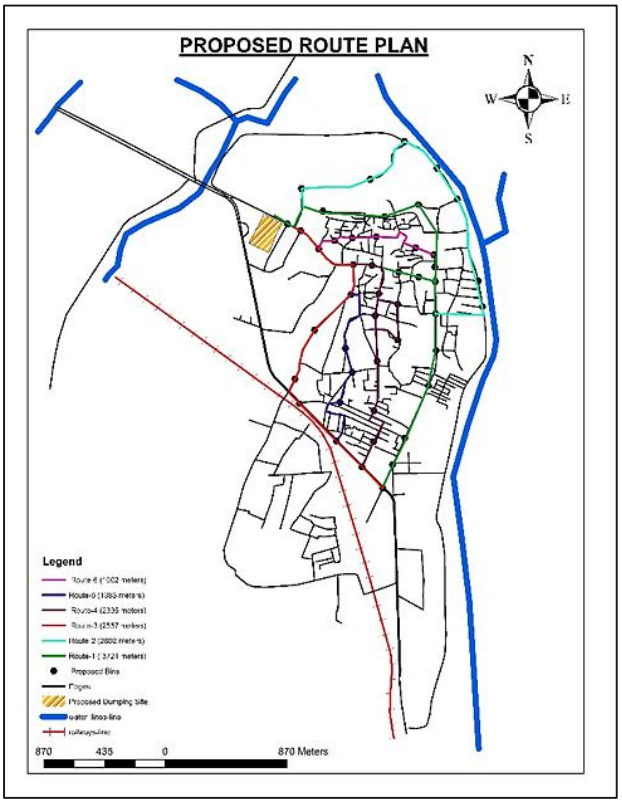

Figure VI: Proposed Route Plan for SW Collection

IV. CONCLUSION

The study aimed to identify the current condition of MSWM in the study area and find out the factors that affect management through different surveys and t-test analyses. Hence, the goal of this research was successfully achieved,

through the proposed methodology. A methodology was based on primary and secondary data collection. The structured questionnaire was designed for primary data collection. Descriptive frequency/percentage and One sample t-test are used to analyze the sample size of the questionnaire. The result of the analysis reveals how the factors affect human health and the environment and management. Furthermore, GIS analysis was used. A 50m buffer is created around the existing bin's location/inappropriate dumping site and it is found that the entire area can be covered by relocating some bins in the study area. Also, we can see that no bin is in the proximity distance of 20m from sensitive areas building. GIS network analysis is used to find the optimal routes for vehicles. It will assist authorities and planners in reducing the effects of MSW on public health, which inevitably demands its collection, safer treatment, and disposal. The suggested model also supports municipal authorities in their decision-making process regarding MSW management.

Acknowledgment

The authors would like to thank the management of Mehran University of Engineering and Technology Jamshoro, Pakistan, for their support and their assistance throughout this study.

Authors Contributions

The topic and the paper's technique were chosen by Gopal Das. The study paper's data were also gathered by Komal, who also created the questionnaire and gathered the literature review. Data are analyzed and interpreted by Mir Aftab Hussain Talpur. Imtiaz Ahmed Chandio evaluated the research paper as a whole and provided useful recommendations to improve its value.

Conflict of Interest

The authors declare no conflict of interest and confirm that this work is original and not plagiarized from any other source, i.e., electronic or print media. The information obtained from all of the sources is properly recognized and cited below.

Data Availability Statement

The testing data is available in this paper.

Funding

This research received no external funding.

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