Optimal Route Determination Automation System for Covid-19 Medical Waste Disposal Based on 3D Building Modeling

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Abstract

Urbanization is a contributing factor to global warming, as asphalt, concrete, and other light-absorbing materials replace vegetated areas, causing an increase in Land Surface Temperature (LST) and creating Surface Urban Heat Islands (SUHI). Although thermal satellite imagery has been a powerful tool in mapping LST and SUHI spatio-temporal changes, the number of studies in Africa, including Egypt, remains limited. Thus, in this research, an automated model was developed in ArcGIS and used to map LST and SUHI and detect Urban Hot Spots (UHS) in Alexandria city, Egypt, using Landsat 8 time series (2013 to 2021). The results revealed an increase of 41.31% in urban areas and a decrease of 49.51% in agricultural areas, a change that was demonstrated by a decline in the Normalized Difference Vegetation Index (NDVI) from 0.84 in 2013 to 0.53 in 2021. Correspondingly, LST and SUHI displayed an increasing pattern, with the highest recorded values observed in 2021. Thus, this study showed the negative impact of urbanization on Alexandria city's temperature – a city that is already facing a climate catastrophe because of the sea level rise resulting from climate change. Furthermore, the developed estimation model can be similarly useful for climate change researchers and decision makers.

Keywords: Climate Change, Global Warming, Landsat 8, Land Surface Temperature Surface Urban Heat Island

1. Introduction

Epidemic disease outbreaks are one of the disasters with tremendous impact on humans [1]. They have the ability to become a pandemic and cause global losses and crises when not handled effectively. Endemic outbreaks were defined by the World Health Organization (WHO) as "the occurrence of cases of disease that are beyond normal expectations" [2] and are usually caused by infectious diseases through person-to-person contact, animal-to-person contact, or from the environment or other media. There have been outbreaks of several infectious and deadly diseases in the last two decades such as Severe Acute Respiratory Syndrome (SARS) in 2003, Marburg fever in 2007, influenza H1N1 in 2009, Ebola virus in 2014, and Middle East Respiratory Syndrome Coronavirus (MERS-Cov) in 2014. These were observed to have affected both humans and the economy within the country of origin and the globe due to panic and fear of their spread.

According to WHO, the 2019 Covid-19 has been spreading globally since March 2020 with more than 118,319 positive cases and 4292 deaths recorded [3]. Moreover, Surabaya (Figure 1), the capital city of East Java and the second largest in Indonesia after Jakarta, has the second highest population in the country with 2,874,314 people. The city is also the largest metropolitan area in eastern Indonesia known as GerBangKertoSuSiLa (Gresik–Bangkalan–Mojokerto–Surabaya–Sidoarjo-Lamongan).

Furthermore, Surabaya is the economic, commercial, industrial, and educational center of East Java and eastern Indonesia. The report published on June 20 by the National Covid-19 Task Force *(Satgas)* showed that East Java had the largest number of confirmed Covid-19 deaths with a total of 12,074. The East Java Task Force further noted that Surabaya City had the highest number of deaths in the province with 1382.

Epidemic outbreaks usually cause a sharp increase in infections over a short period, thereby, leading to a dramatic increase in the quantity of medical waste, so there needs to be an appropriate response [4] and [5]. It is important to note that this waste requires effective handling in order to control the spread and transmission of disease as well as to minimize its economic impact. This is the reason it is necessary to provide a medical waste monitoring system as well as an effective and responsive logistics network to deal with the drastic increase in waste disposal [6] and [7]. Over the years, optimization models and methods have been formulated to investigate logistical problems to ensure a quick and precise decision-making process in responding to infectious disease outbreaks [8] and [9].

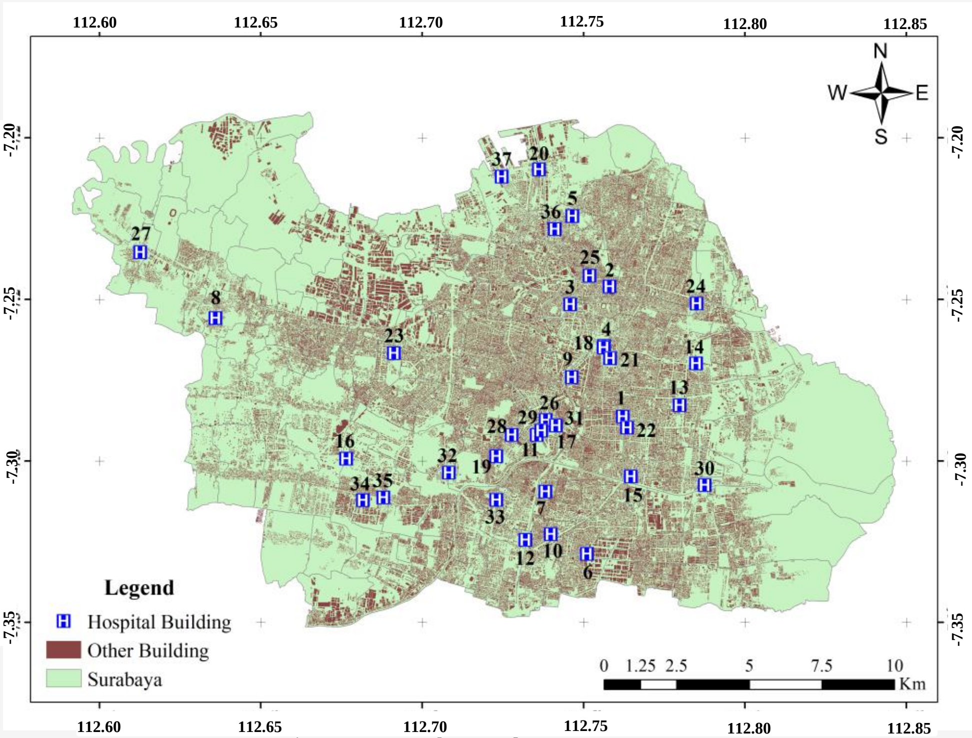

Figure 1: Surabaya administration area

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Proper management of medical waste disposal is necessary to avoid the spread of epidemics due to medical waste that can potentially spread into the environment. However, the main challenge is that the best logistics system to manage medical waste effectively has not been implemented in some places [10] and [11]. This is despite the fact that medical waste stockpiles are increasing exponentially as the number of patients with outbreaks increases and the absence of appropriate treatment can accelerate the spread of disease and pose significant risks to both medical staff as well as patients. Therefore, according to Singh et al., [12] decision making and optimization tools or systems are required to monitor medical waste conditions and logistical models for collection.

Study on 3D building has been used to estimate solid waste in cases of building deconstruction to reuse or recycle materials [9] and [13]. In previous study, the use of 3d modeling to display cadastral data ownership rights on buildings [14] and [15]. Onoda [16] using 3d modeling for education on smart cities waste management. A study conducted by Joneghani et al., [17] and [18] proposed a multi-objective mixed linear programming model to address the problem of sustainable location allocation in medical waste management so as not to endanger human health and the environment. This model designs a sustainable network for the storage, decontamination, recycling, incineration, and disposal of medical waste [17] and [19]. This 3D research needs to be combined for the purpose of waste management in Covid-19 to get an appropriate and effective management process.

The above existing research needs to investigate medical waste's real-time monitoring and logistics management, which poses significant challenges in real-life scenarios. In particular, the current approach fails to consider important factors such as the shortest route and priority of destination points, resulting in sporadic waste disposal practices. To overcome these deficiencies, we conducted this study to develop a system to monitor and manage medical waste generated in various designated health facilities for Covid-19 patients in Surabaya and other cities in general. By implementing a real-time waste collection schedule and designing optimized logistics routes, this research aims to increase waste management efficiency. To achieve this, we used Dijkstra's VRP algorithm to model logistical routes, enabling the identification of the shortest distance between locations [20]. This approach not only minimizes public exposure to waste but also ensures time and energy efficiency.

It is hoped that the results of this research effort will provide valuable insights and practical solutions for the Surabaya government in managing medical waste effectively, especially in the context of the ongoing Covid-19 pandemic and the possibility of future pandemics. The developed system incorporates Geographic Information System (GIS) technology, which can improve real-time monitoring and decision-making capabilities in waste management systems. By visualizing medical waste in buildings in 3D using GIS, authorities and waste management teams can comprehensively understand waste disposal patterns. Real-time monitoring of medical waste in health facilities and transport routes allows timely intervention and adjustment of waste collection schedules, ensuring waste is collected before it reaches critical levels or poses a health risk. 3D visualization of medical waste inside buildings can help identify potential hot spots or areas with higher waste disposal rates, enabling better resource allocation and planning of waste collection. GIS-based tools can also help assess the impact of waste management interventions and track trends over time, enabling continuous improvement and informed decision-making [21].

Overall, the integration of GIS technology with Dijkstra's VRP algorithm provides a powerful solution to overcome the challenges of medical waste management in real time. By creating an efficient waste collection and disposal system, this research not only contributes to public health and safety, but also serves as an example for other cities facing similar waste management issues during the health crisis.

2. Materials and Methods

Covid-19 medical waste was generated through the activities implemented by health facilities to handle Covid-19 cases. It is classified as hazardous and toxic *(Bahan Berbahaya Beracun/B3)* due to the existence of substances that can transmit diseases, sharp objects, toxic materials, and others. This means it requires a special handling process to ensure it does not endanger medical staff, patients, or the general public. One of the stages associated with the management of this waste is the transportation from the hospital to the hazardous and toxic (B3) Waste Temporary Disposal Site. This is usually conducted using trucks with closed container boxes to prevent the exposure of waste to the environment during the journey. It is necessary to determine an efficient route for the transportation of the waste in order to minimize the potential of exposing the public to the waste as well as to reduce costs.

2.1 Data Simulation

Dataset shown on Table 1 is the location, capacity, and total number of Covid-19 patients in Surabaya were obtained from the official website of the city of Surabaya lawancovid-19.surabaya.go.id. Meanwhile, the number of patients in each hospital was determined through simulation by calculating the portion of hospital capacity to the hospital's total capacity throughout the city as indicated in the following the Equation 1:

$$HP = \sum P \left(\frac{HC}{\sum H} \right)$$

Equation 1

where:

HP	:	Number of hospital patients
$\sum P$	:	Total of all patients
HC	:	Hospital capacity
$\sum H$	:	Total hospital capacity

Table 1: List of hospitals with the number of patients and percentage of bed capacity
*Added number to be connected with the map

No	Hospital	Bed Capacity (patients)	Percentage Capacity
1	Mental Hospital Menur Jawa Timur	123	5.624
2	Dr.M.Soewandhie Regional Public Hospital	251	11.477
3	Adi Husada Undaan Wetan Hospital	130	5.944
4	Husada Utama Hospital	158	7.225
5	Lung Hospital Surabaya	25	1.143
6	Royal Hospital Surabaya	37	1.692
7	Dr. Ramelan Surabaya Public Marine Hospital	29	1.326
8	Bhakti Dharma Husada Regional Public	144	6.584
9	Siloam Hospitals	16	0.732
10	Islamic Hospital Jemursari Surabaya	12	0.549
11	St. Vincentius A Paulo Catholic Hospital	41	1.875
12	Bhayangkara H.S. Samsoeri Mertojoso Hospital	73	3.338
13	Haji Public Hospital Surabaya	31	1.417
14	Universitas Airlangga Hospital	92	4.207
15	Premier Hospital Surabaya	40	1.829
16	National Hospital	62	2.835
17	Surabaya Medical Center	36	1.646
18	Husada Utama Specialist Hospital	1	0.046
19	Kodam V Brawijaya Level III Hospital	66	3.018
20	PHC Medical Centre	8	0.366
21	Dr. Soetomo Regioanal Public Hospital	392	17.924
22	Manyar Medical Centre	31	1.417
23	Mitra Keluarga Hospital	11	0.503
24	Mitra Keluarga Hospital Kenjeran	20	0.914
25	Adi Husada Hospital Kapasan	54	2.469
26	Darmo Hospital	26	1.189
27	Darus Syifa' Islamic Hospital	11	0.503
28	Mayapada Hospital Surabaya (MHSB)	41	1.875
29	William Booth Hospital Surabaya	40	1.829
30	Gotong Royong Hospital	32	1.463
31	Surabaya Medical Center	22	1.006
32	Ewa Panggalila Marine Hospital	25	1.143
33	Bhakti Rahayu Public Hospital	21	0.960
34	GRAHA MEDIKA Mother and child hospital	10	0.457
35	Wiyung Sejahtera Hospital	37	1.692
36	Al Irsyad Hospital	12	0.549
37	Dr. Oepomo Marine Hospital	27	1.235

The weight of waste in each hospital was calculated by multiplying the number of patients with an estimated average waste per patient per day of 2.5 Kg [10]. It is pertinent to note that there are 37 hospitals used as Covid-19 referral health facilities across Surabaya as shown in Figure 2. The maximum storage period required for Covid-19 medical waste by health facilities is 2 days at room temperature. This is because it was generated at the B3 waste storage facility following the circular regulation of the Minister of Environment and Forestry of the Republic of Indonesia number SE.2/MENLHK/PSL B3/PLB.3/3 /2020.

2.2 3D Building Data

The 3D Building data was obtained from OpenStreetMap with each building represented by a polygon. Moreover, the height of the building was calculated through the median DSM data with a resolution of 8.1M on each building polygon [22]. The addition of the mass point data from stereo-plotting was used to obtain the DSM data from several sources including IFSAR, TERRASAR-X, and ALOS PALSAR based on the vertical datum EGM2008 [23]. Furthermore, the median was selected to avoid inaccuracy or the too-extreme difference in height with a non-dominant area. ArcGIS data was used to display the polygons' heights in 3D according to their respective attributes. It is also important to note that the hospital building data are displayed using different colors based on the quantity of waste while the other buildings are displayed in white as observed in Figure 3.

2.3 Road Network Data and Determination of the Shortest Route

This research utilizes Dijkstra's algorithm to determine the shortest route from network data for the VRP problem. Dijkstra's algorithm is a popular and widely used method for finding the shortest path in a graph. It is known for its optimality, meaning it can guarantee finding the shortest route from a single source point (e.g., TPA) to all destination points (hospitals) in a non-negative weighted graph, such as a road network. The process involved maintaining a set of intersections S, from the initial location S, to the destination location D, to compute the last shortest path.

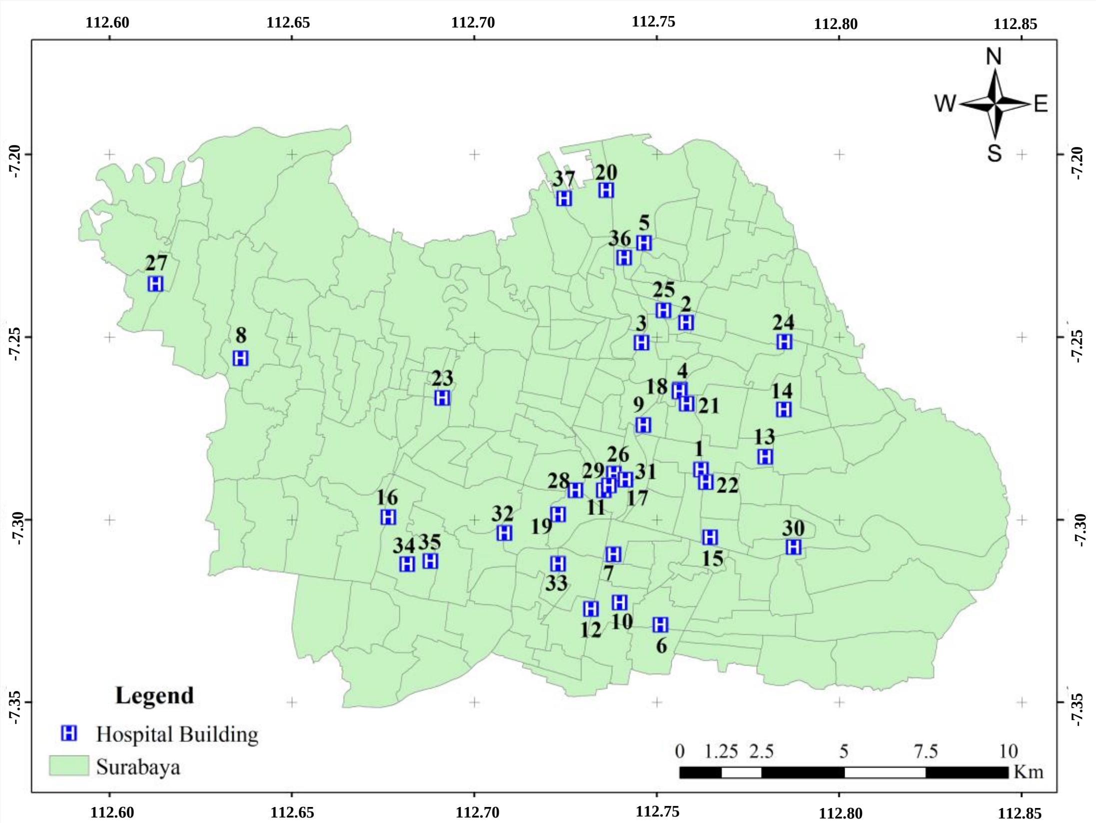

Figure 2: The location of the Covid-19 referral hospital in Surabaya

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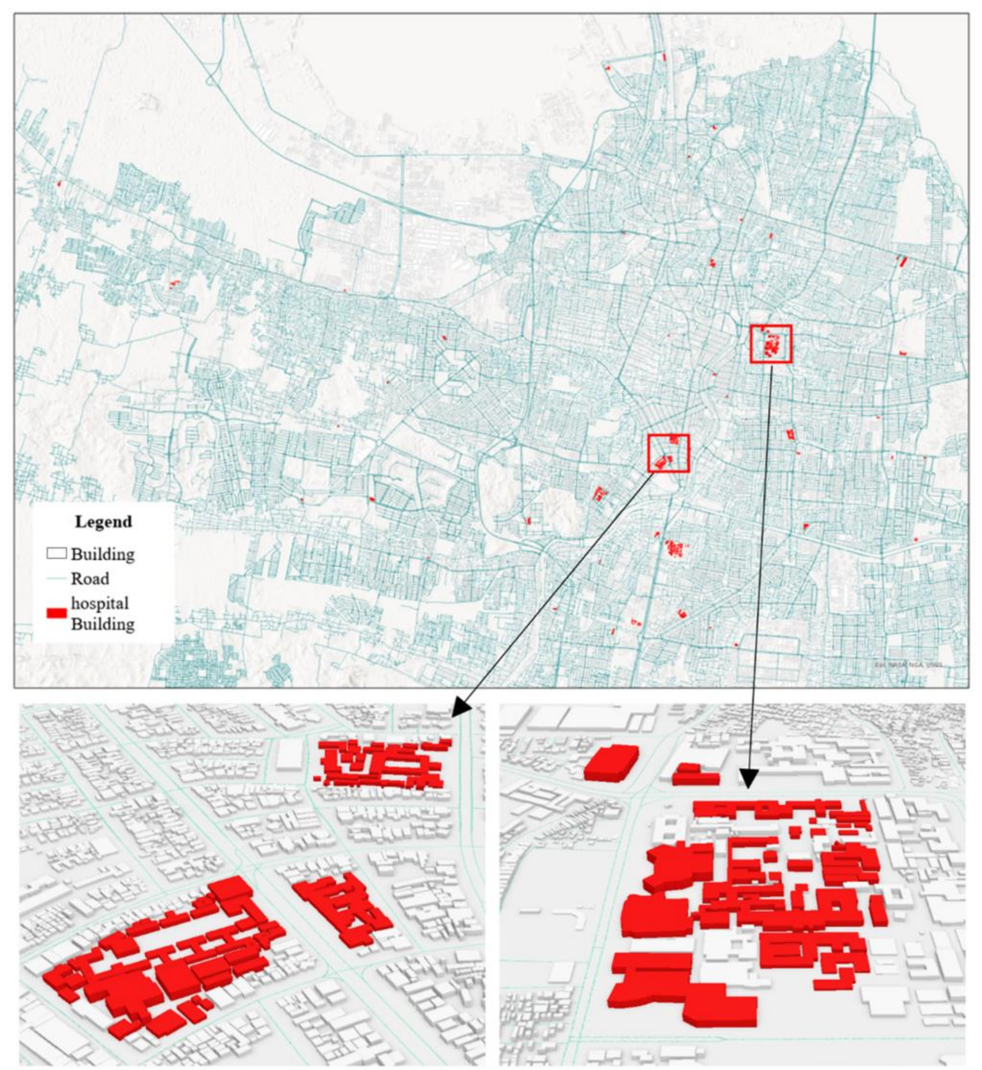

Figure 3: An example of a 3D building visualization in ArcGIS. The hospital buildings are indicated by the red color

The algorithm repeatedly determined the intersection with the minimum shortest path estimate, added it to the intersection set S, and updated the shortest path estimate of all the neighbors of these intersections not in S. The process continued until the destination intersection was added to S [24]. Dijkstra's algorithm efficiently handles complex and extensive road networks, making it well-suited for finding optimal routes for waste collection vehicles navigating through various locations [25]. Furthermore, Dijkstra's algorithm can be adapted with variations like the priority queue or the Fibonacci heap data structure to enhance its efficiency in dealing with large-scale road networks. This adaptability is particularly valuable in this research, as the vehicle routing problem often involves optimizing routes in dense urban areas with numerous health facilities and waste collection points.

Additionally, the ease of implementation of Dijkstra's algorithm is another advantage for this study. Its straightforward implementation allows to quickly apply the algorithm to process road network data and find optimal routes for waste collection vehicles. This efficiency is crucial in real-time monitoring scenarios, where waste collection schedules may need frequent adjustments to ensure timely and effective waste management.

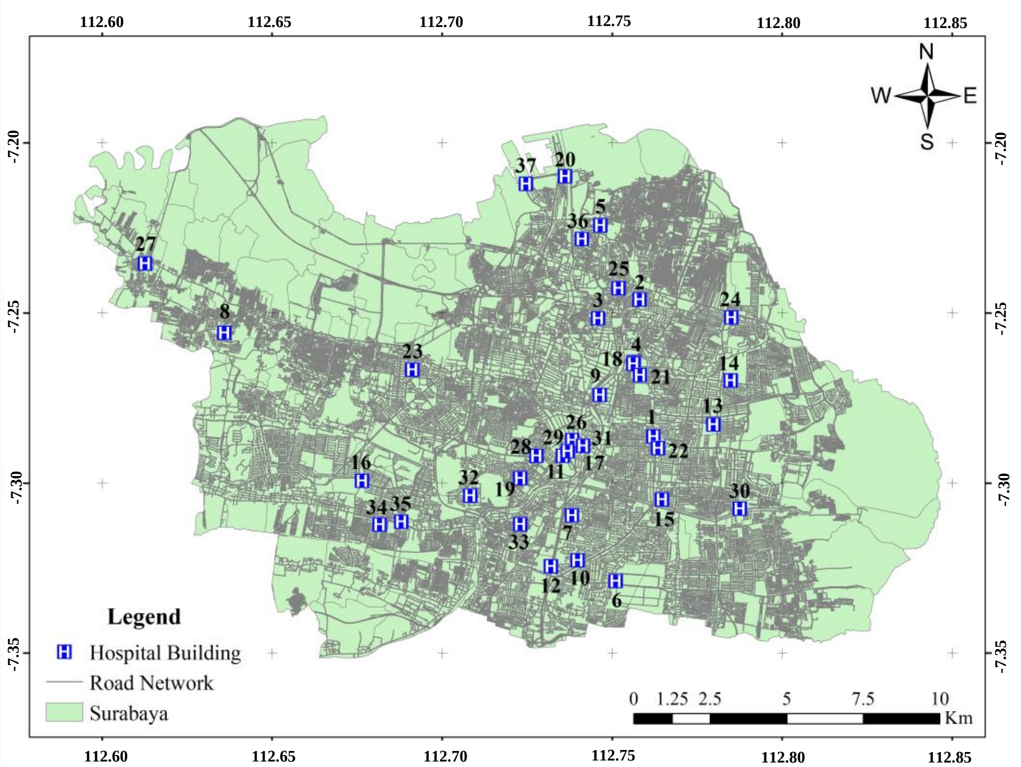

Figure 4: Road network display in Surabaya

Figure 4 shows the road network data needed to map the survey area obtained from OpenStreetMap. This open source geographic data platform includes information about the streets, vertices, and edges that make up an area's road network. OpenStreetMap as the data source was chosen due to the wide availability of data which is continuously updated by the user community, thus providing a sufficiently accurate and relevant representation for routing analysis. This method used Dijkstra algorithm to calculate the best route from TPA to the hospitals with shortest path and the amount of waste.

2.4. Visualization on 3D maps

The 3D Map Visualization processing flow can be shown in Figure 5. The system requires five datasets that can be obtained from the open source website, namely DEM data, OSM Building Dataset, Road Building Dataset, Hospital Location, and Covid-19 Patient. First, DEM (Digital Elevation Model) data can be accessed at (https://tanahair.indonesia.go.id/demnas/) to provide an elevation value for a location which is then extracted to produce a height attribute value. Second, the OSM Building Dataset can be accessed at (https://osmbuildings.org/) to obtain building data in polygon form. Building polygon attributes are processed to form a 3D building model. The results of the 3D building model were overlaid with DEM height data so that the shape and model of the building at the observation location and its height information were obtained. Third, the Road Dataset is obtained open source on the website (https://www.openstreetmap.org/) with polyline data format. The road data in the form of a polyline is then processed to form a network dataset that can show the fastest route from the initial location (hospital) to the destination location (medical waste disposal). Fourth, Hospital Location data is obtained from (https://www.google.co.id/maps) which shows the position of the list of hospitals in Surabaya. This data is processed as a reference in determining waste collection stops. Fifth, Covid-19 patient data can be accessed at (https://lawancovid-19.surabaya.go.id/) and used to estimate the amount of medical waste based on the number of patients exposed to COVID-19. The processing results of network datasets, waste collection stops, and medical waste estimation are overlayed, and then route analysis is performed to determine the fastest route for medical waste disposal.

The simulation phase is built using the results of 3D Building Overlay and Route Analysis to predict medical waste disposal routes that are able to avoid the risk of public exposure and reduce transportation costs. Finally, a 3D visualization of medical waste routes is displayed online on the website so that people can access and obtain information more easily.

3. Results and Discussion

The patient and waste data were simulated by comparing the percentage of hospital capacity to all the Covid-19 patients recorded every day. An attempt was made to simulate the hospital capacity in 5 days from April 28, 2022 to May 2, 2022 and the results obtained concerning the patient data are presented in the following Table 2. It is important to note that all Covid-19 recorded patients were assumed to be hospitalized without considering those in self-isolation and this made it possible to have the number of patients every day exceeding the available hospital capacity. However, this study only focuses on the visualization of waste and route analysis and this means the quality of the dataset relating to the patients can be ignored. Table 2 shows the number of patients in five consecutive days at 37 hospitals in the city of Surabaya.

Table 2: The number of patients in each hospital on 5 consecutive days

No	Hospital	Patient of Day				
		1	2	3	4	5
1	Mental Hospital Menur Jawa Timur	166	166	166	166	166
2	Dr. M. Soewandhie Regional Public Hospital	340	339	339	339	339
3	Adi Husada Undaan Wetan Hospital	176	176	176	176	176
4	Husada Utama Hospital	214	214	214	214	214
5	Lung Hospital Surabaya	34	34	34	34	34
6	Royal Hospital Surabaya	50	50	50	50	50
7	Dr. Ramelan Surabaya Public Marine Hospital	39	39	39	39	39
8	Bhakti Dharma Husada Regional Public	195	195	195	195	195
9	Siloam Hospitals	22	22	22	22	22
10	Islamic Hospital Jemursari Surabaya	16	16	16	16	16
11	St. Vincentius A Paulo Catholic Hospital	55	55	55	55	55
12	Bhayangkara H.S. Samsoeri Mertojoso Hospital	99	99	99	99	99
13	Haji Public Hospital Surabaya	42	42	42	42	42
14	Universitas Airlangga Hospital	125	124	124	124	124
15	Premier Hospital Surabaya	54	54	54	54	54
16	National Hospital	84	84	84	84	84
17	Surabaya Medical Center	49	49	49	49	49
18	Husada Utama Specialist Hospital	1	1	1	1	1
19	Kodam V Brawijaya Level III Hospital	89	89	89	89	89
20	PHC Medical Centre	11	11	11	11	11
21	Dr. Soetomo Regioanal Public Hospital	531	530	530	530	530
22	Manyar Medical Centre	42	42	42	42	42
23	Mitra Keluarga Hospital	15	15	15	15	15
24	Mitra Keluarga Hospital Kenjeran	27	27	27	27	27
25	Adi Husada Hospital Kapasan	73	73	73	73	73
26	Darmo Hospital	35	35	35	35	35
27	Darus Syifa' Islamic Hospital	15	15	15	15	15
28	Mayapada Hospital Surabaya (MHSB)	55	55	55	55	55
29	William Booth Hospital Surabaya	54	54	54	54	54
30	Gotong Royong Hospital	43	43	43	43	43
31	Surabaya Medical Center	30	30	30	30	30
32	Ewa Panggalila Marine Hospital	34	34	34	34	34
33	Bhakti Rahayu Public Hospital	28	28	28	28	28
34	GRAHA MEDIKA Mother and child hospital	14	14	14	14	14
35	Wiyung Sejahtera Hospital	50	50	50	50	50
36	Al Irsyad Hospital	16	16	16	16	16
37	Dr. Oepomo Marine Hospital	37	37	37	36	36

The highest number of patients was at Dr. Soetomo Regioanal Public Hospital, with a number of patients on the first to fifth day a total of 531 patients, while the least number of patients was at Husada Utama Specialist Hospital, with a total of 1 patient. Table 3 shows that on five consecutive days, on average, there is no addition or reduction in the number of patients in all hospitals. The simulation of the quantity of medical waste in each hospital every day is indicated in Table 3 with due consideration for a two-day pick-up schedule. This means there was no waste remaining on each day of collection. The Figure 6 shows the hospital building colored by the current amount of the medical waste. Table 3 shows the amount of waste in kg units generated on five consecutive days with the number of patients listed in Figure 5.

Table 3: Total waste in each hospital on 5 consecutive days

No	Hospital	Waste of day (kg)				
		1	2	3	4	5
1	Mental Hospital Menur Jawa Timur	4747.6	2373.8	4747.6	2373.8	4747.6
2	Dr.M.Soewandhie Regional Public Hospital	9724	4847.7	9695.4	4847.7	9695.4
3	Adi Husada Undaan Wetan Hospital	5033.6	2516.8	5033.6	2516.8	5033.6
4	Husada Utama Hospital	6120.4	3060.2	6120.4	3060.2	6120.4
5	Lung Hospital Surabaya	972.4	486.2	972.4	486.2	972.4
6	Royal Hospital Surabaya	715	1430	715	1430	715
7	Dr. Ramelan Surabaya Public Marine Hospital	557.7	1115.4	557.7	1115.4	557.7
8	Bhakti Dharma Husada Regional Public	5577	2788.5	5577	2788.5	5577
9	Siloam Hospitals	629.2	314.6	629.2	314.6	629.2
10	Islamic Hospital Jemursari Surabaya	228.8	457.6	228.8	457.6	228.8
11	St. Vincentius A Paulo Catholic Hospital	786.5	1573	786.5	1573	786.5
12	Bhayangkara H.S. Samsoeri Mertojoso Hospital	1415.7	2831.4	1415.7	2831.4	1415.7
13	Haji Public Hospital Surabaya	1201.2	600.6	1201.2	600.6	1201.2
14	Universitas Airlangga Hospital	1787.5	3560.7	1773.2	3546.4	1773.2
15	Premier Hospital Surabaya	1544.4	772.2	1544.4	772.2	1544.4
16	National Hospital	1201.2	2402.4	1201.2	2402.4	1201.2
17	Surabaya Medical Center	700.7	1401.4	700.7	1401.4	700.7
18	Husada Utama Specialist Hospital	14.3	28.6	14.3	28.6	14.3
19	Kodam V Brawijaya Level III Hospital	2545.4	1272.7	2545.4	1272.7	2545.4
20	PHC Medical Centre	157.3	314.6	157.3	314.6	157.3
21	Dr. Soetomo Regioanal Public Hospital	7593.3	15172.3	7579	15158	7579
22	Manyar Medical Centre	1201.2	600.6	1201.2	600.6	1201.2
23	Mitra Keluarga Hospital	214.5	429	214.5	429	214.5
24	Mitra Keluarga Hospital Kenjeran	772.2	386.1	772.2	386.1	772.2
25	Adi Husada Hospital Kapasan	1043.9	2087.8	1043.9	2087.8	1043.9
26	Darmo Hospital	1001	500.5	1001	500.5	1001
27	Darus Syifa' Islamic Hospital	214.5	429	214.5	429	214.5
28	Mayapada Hospital Surabaya (MHSB)	1573	786.5	1573	786.5	1573
29	William Booth Hospital Surabaya	772.2	1544.4	772.2	1544.4	772.2
30	Gotong Royong Hospital	1229.8	614.9	1229.8	614.9	1229.8
31	Surabaya Medical Center	429	858	429	858	429
32	Ewa Panggalila Marine Hospital	972.4	486.2	972.4	486.2	972.4
33	Bhakti Rahayu Public Hospital	400.4	800.8	400.4	800.8	400.4
34	GRAHA MEDIKA Mother and child hospital	400.4	200.2	400.4	200.2	400.4
35	Wiyung Sejahtera Hospital	715	1430	715	1430	715
36	Al Irsyad Hospital	457.6	228.8	457.6	228.8	457.6
37	Dr. Oepomo Marine Hospital	529.1	1058.2	529.1	1043.9	514.8

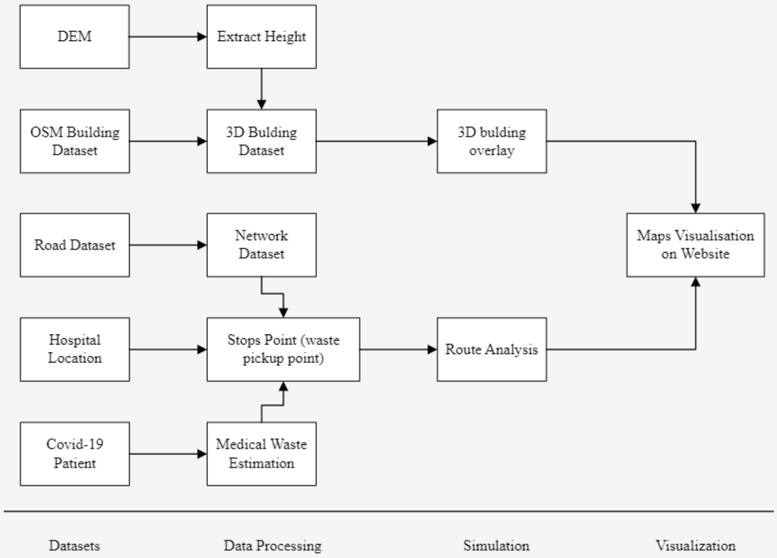

Figure 5: 3D map visualization flow

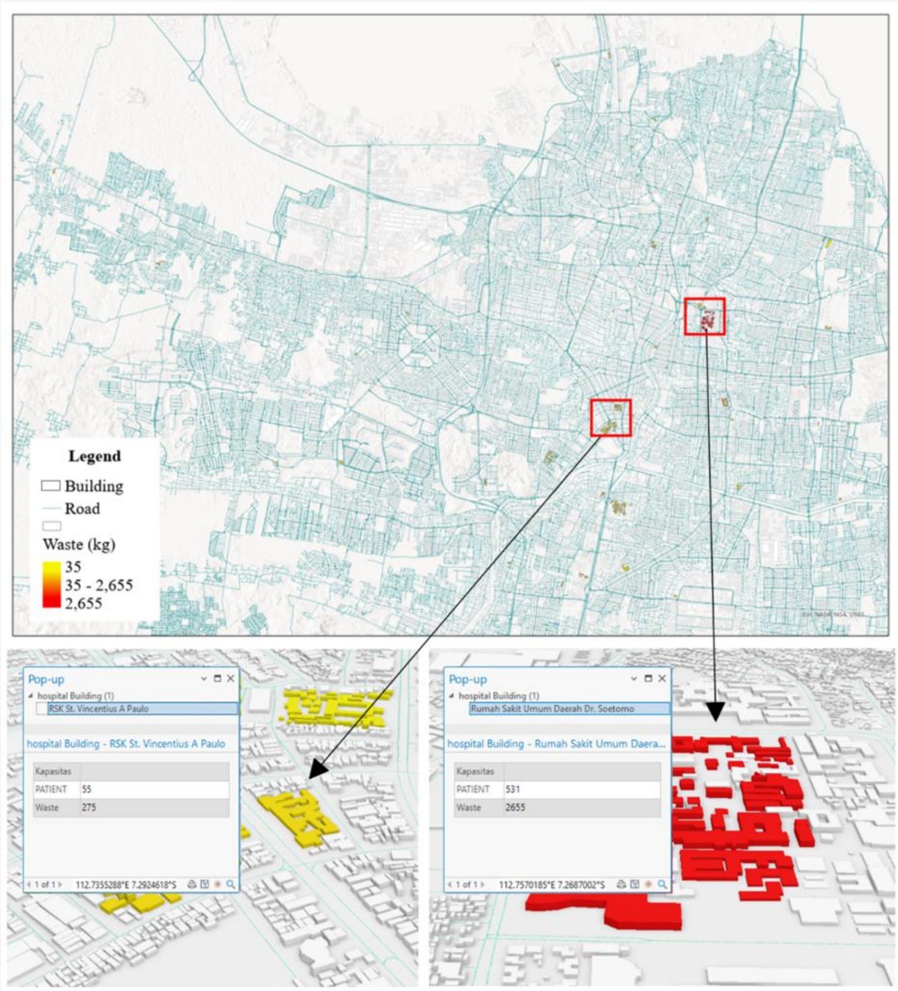

Figure 6: 3D building displays the quantity of waste in each hospital is represented by the color of the building

Table 4: Comparison of the conventional and VRP methods

		Conventional	VRP methods	Efficiency (%)
Day 1	Total distance	417.17 km	156.42 km	62.5
	deployed truck	10	6	40
Day 2	Total distance	417.17 km	121.49 km	70.87
	deployed Truck	10	4	60

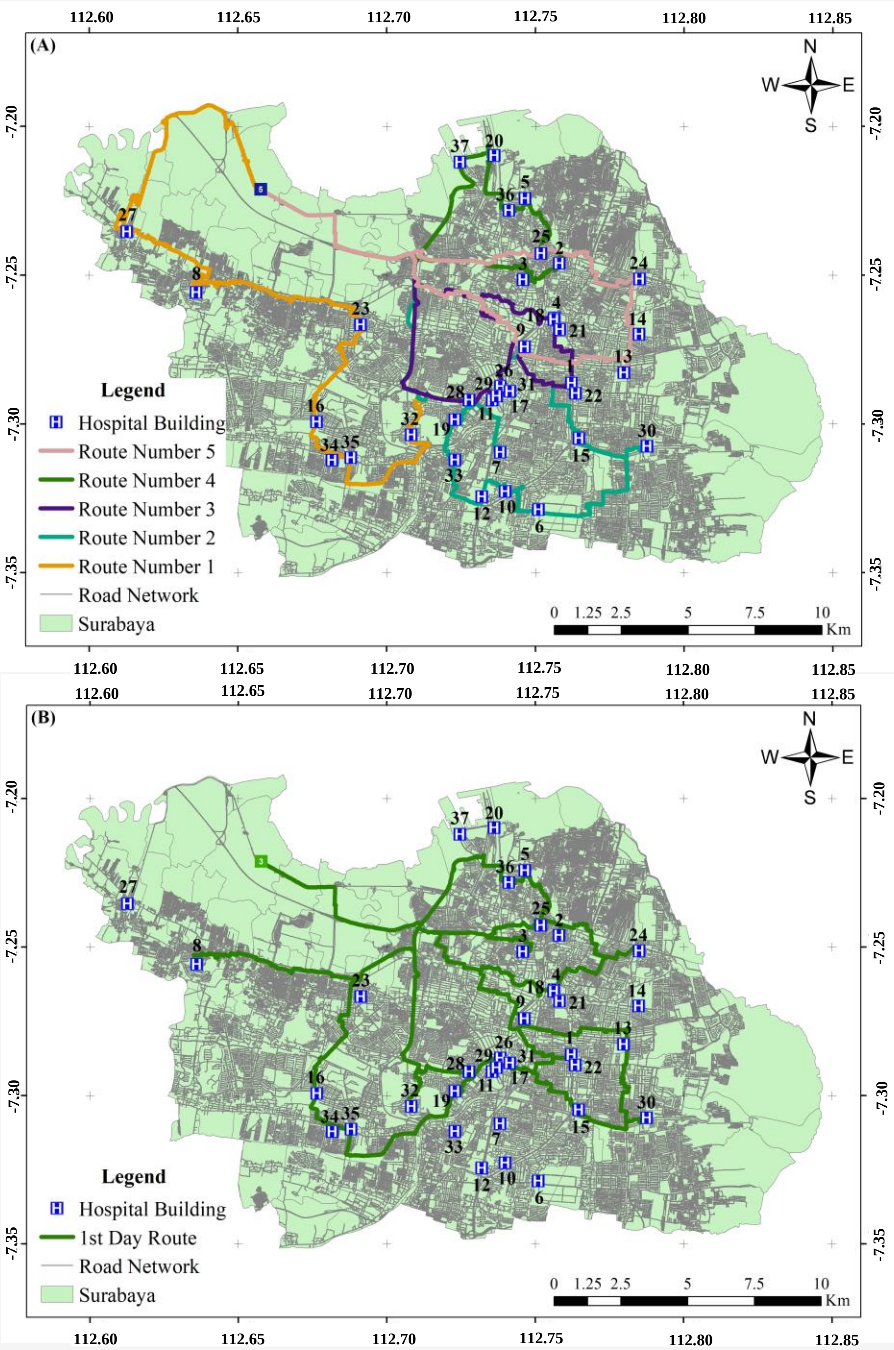

Figure 7: (a) Route from conventional method (b) Optimation Route formed for 1st day

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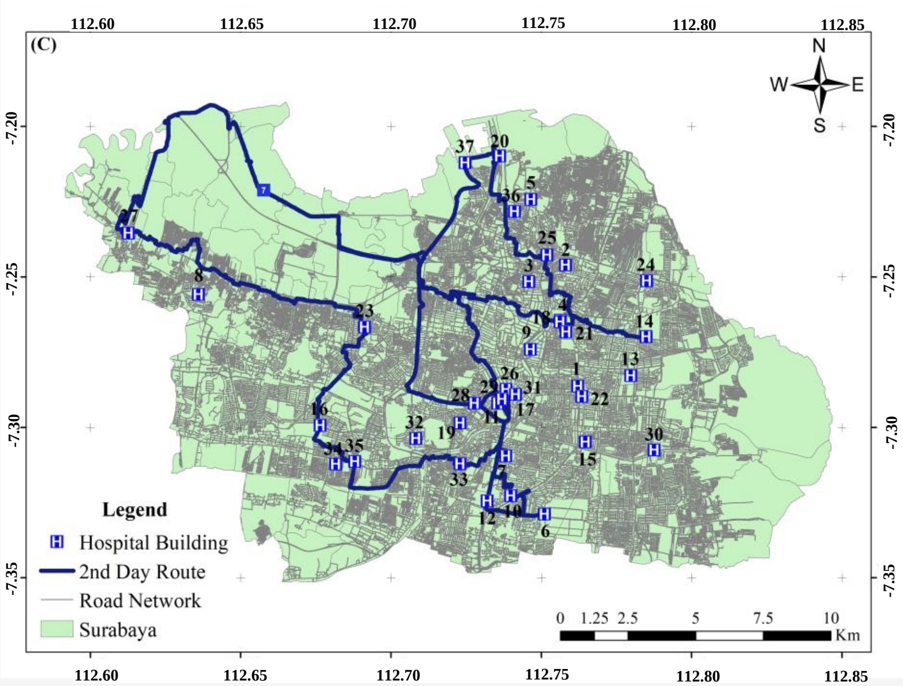

Figure 7: (c) Optimation route formed for 2nd day (Continue from previous page)

Table 3 shows that Dr. Soetomo Regional Public Hospital followed by Husada Utama Hospital followed by Adi Husada Undaan Wetan Hospital. Meanwhile, Husada Utama Specialist Hospital generates the least amount of waste. Table 3 shows that the waste generated is in line with the number of patients in the hospital. From the information in Tables 2 and 3 above, it is then visualized in Figure 6, which is a 3D building that displays the quantity of waste in each hospital which is visualized with different colors according to the amount of waste produced. In Figure 6 shows the distribution of the amount of hospital waste is visualized in yellow with the least amount of waste and increasingly red with the highest amount of waste. The color visualization of this building is divided into three classes with the amount of waste less than 35 kg, 35 – 2655 kg, and more than 2655 kg. In Figure 6, it can be seen that the appearance of the building is dominated by yellow, which indicates that hospitals in Surabaya City produce an average of around 35-2655 kg of waste each day.

The calculation of the waste data was followed by the routing simulation. This involved marking the hospitals where waste needs to be picked up as a stop or pick-up point. The waste was designed to be collected every two days and this led to the generation of two route patterns as presented in Figure 7. The conventional method of collecting hospital medical waste was also simulated and divided based on the 5 sub-regions in Surabaya with the medical waste designed to be collected routinely every day from every hospital. In this case, the trucks assigned to pick up in one area cannot move to another area, even when the distance is close. This means the collection path cannot be minimized. Moreover, the distance traveled by the proposed and conventional methods is compared in Table 4. It was discovered that the variation in the number of trucks deployed per day was influenced by the quantity of waste in each hospital. This is due to the possibility of the trucks to gather garbage from different hospitals in order to return to the TPS with a full load. It was discovered that the conventional method traveled a total distance of 412km per day by using 10 trucks. This is a high number which is due to the need for the trucks to visit every hospital as well as the existence of regional limitations reducing the opportunity for optimization. Meanwhile, the VRP method changes based on the current condition of the waste in each hospital and takes advantage of the 2-day collection limit to ensure more waste is stockpiled before collection. The VRP can save distance about 260.65km or 62.5% on the first day and 295.68km or 70.87% on the second day. Likewise, the method can save the number of trucks by 40% (4 trucks) on the first day and 60% (6 trucks) on the second day.

4. Conclusion

This study has successfully developed an information system for monitoring Covid-19 medical waste and determining the shortest routes for its transportation from health facilities to landfills in Surabaya. The integration of a 3D map display with different color representations for medical waste quantity has proven to be an effective means of visualizing the waste status in real-time. This approach, combined with the utilization of the Dijkstra algorithm for route optimization, enhances waste management efficiency and reduces the risk of waste exposure during transportation. The website dedicated to Covid-19 monitoring in Surabaya city utilizes real-time datasets, including the GIS-based 3D waste monitoring system with color-coded representation, making it easier for policymakers to monitor and manage medical waste effectively. The optimized route determination for waste transportation minimizes transportation costs and ensures timely waste collection, which is crucial in preventing the spread of Covid-19.

The process involved simulating the patient and waste data by comparing the percentage of hospital capacity to a daily record of all Covid-19 patients for 5 days from April 28, 2022 to May 2, 2022. The findings showed that the proposed method has a 66% mileage and 50% truck deployment efficiency per day compared to the conventional method of transportation. This is associated with the possibility of always updating the route based on the condition of the existing waste [26]. This is in accordance with the research by K. Webster et al. 2016 concerning the route determination method on the river route network to calculate the shortest distance in an adaptive and efficient manner. which can also be applied to other areas that use river transportation. This method can be applied to normal conditions (not during a pandemic) in city governments. Especially big cities that produce medical and non-medical waste in large quantities so that time efficiency and distance for waste transportation can be saved.

The implementation of this model in the Covid-19 pandemic situation in Surabaya produced very good results. Therefore, it provides practical significance and insights into the monitoring and selection of medical waste pathways for the 37 referral Covid-19 hospitals in Surabaya listed on lawancovid-19.surabaya.go.id.

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