CHAPTER 7

To Solve Hospital Waste Management Conundrum in an Unplanned City -A Case of Varanasi

7.1 Demographic of City

Varanasi or Kashi (Longitude 83.0 Latitude: 25.20) is one of the oldest living cities in the world. It is one of the oldest continuously inhabited cities in the world. It is also a commercial and industrial center famous for its muslin and silk fabrics, perfumes, ivory works, and sculptures. The city is situated on the bank of the Ganges and is known for its ghats, congested streets, and road infrastructure. According to the last census done in the year 2011, the population of Varanasi district is 3,676,841, and the population density is 2395 per.sq.km. This figure must have revised upward in the last decade. Which makes Varanasi a dense population district. According to an estimate, the present population of the central city is more than 1.7 million and is estimated to cross 2.3 million by the year 2035(World Population Review,2022). As the city has organically habituated over centuries, the urban development in the city could be more unplanned. Eastern Uttar Pradesh (Varanasi is one of the districts in Eastern Uttar Pradesh) is one of the country's least developed regions and has very few relatively developed cities.

Moreover, healthcare facilities in rural areas need to be improved, as one primary healthcare center is designated for 30,000 people, while this number is effectively more because of systemic inefficiencies. The city attracts people from catchment areas for its services (healthcare, education, etc.) and economic opportunities.

7.2 Healthcare Infrastructure:

The medical infrastructure of Varanasi comprises multi-specialty hospitals, single-specialty hospitals, medical centers, private clinics, primary healthcare centers, and other facilities. According to data available by India Environmental Portal, the total number of healthcare facilities (HCF) in Varanasi is 718, out of which 59(55 authorized and four defaulters) are government HCF, while 659 (513 authorized and 146 defaulters) are private HCFs. It included one-ninety-three registered hospitals and diagnostic centers. Although HCFs are dispersed in every part of the city, there are two main clusters, namely the vicinity of the famous educational center Banaras Hindu University (BHU) and Orderly Bazar (older region of Varanasi lies on the other side of Varuna River). The city has five government hospitals and one medical college. In 2021, the Prime minister of India declared that nine medical colleges will be established in Eastern Uttar Pradesh, making it a medical hub in north India. These efforts may reduce some burdens from Varanasi's incredibly strained healthcare system. But doctors graduating from these colleges will prefer to open clinics and hospitals in a city with relatively better infrastructure, and Varanasi fits the bill here.

7.3 Hospital Waste Management:

The total number of hospital beds in Varanasi is 13572. which account for 3441.45 kg/day of biomedical waste. This estimate doesn't include waste generated from the unorganized sector or standalone clinics. In a report submitted by Uttar Pradesh Pollution Control, there is no individual biomedical waste treatment facility in the city. In and around there are three common biomedical waste treatment facilities (CBWTF) Table 2.1. The number of HCF who obtained membership from CBWTF is 568, while 146 HCFs have no membership from any treatment facilities or their treatment plants. Except for Sir Sunder Lal hospital (Hospital within the campus of Banaras Hindu University), no other hospital or medical center has an incinerator for medical waste disposal. Leaving hospital waste in residential areas in the city poses a severe public health concern.

Table 7.1: Common Biomedical Waste Treatment Facilities Near Varanasi

SN	Name of facility	Location	Capacity
1	Centre for Pollution Control	Mohansarai, Varanasi	1250 (Kg/day)
2	Silicon Welfare Society	Banka, Bahadurganj, Ghazipur	2400 (Kg/day)
3	Sangam Mediserve (P) Ltd.	Raidopur, Handia, Allahabad	5000 (Kg/day)

Currently, Four Hundred Twenty-Five HCFs in the city are registered with the Centre for Pollution Control (CPC) Pvt. Ltd. CPC is handling wastes from all these hospitals with the help of their four Vehicles, having a 1-ton capacity each. The company has its incineration plant in Mohansarai (Rajatalab), Varanasi. Considering the rising demand for hospital waste management and limited facilities, the city needs to start Integrated healthcare waste management (IHWM). The city requires more CBWTF shortly.

Let's take a look at a two-layer distribution network with three sets of disjoint vertices that represent the Processing Facilities (also known as the depots), Collection Points (often known as the intermediate facilities), and Hospitals (often known as the demand Points), respectively. This allows for the division of the distribution network into two levels.

The first echelon consists of the connections between the collection sites, the Processing facilities, and those that link collection sites. The collection sites are connected via the second echelon to the hospitals and the connections between hospitals. Some collections of weights accessible at one or more Processing facilities must be made to specific hospitals and are forced to transit through the Collection sites—two different sets of trucks, one at each echelon, transport waste. Trucks are typically taken for granted within a certain echelon to be homogeneous and capacitated.

Primary trucks are those that belong to the first echelon, while secondary vehicles are those that belong to the second echelon. Each Processing facilities and all collection sites have a fixed opening cost. Additionally, each truck typically comes with a fixed cost of utilization. Considering the maximum amount of waste that may be handled in the facility is a capacity restriction for each processing facility and collection site. It is believed that each open collection site must be reached by exactly one primary truck that routes from an open Processing site. Additionally, one secondary truck that routes from collection sites must normally serve each hospital.

The Problem seeks to determine the best locations for Processing facilities and collection sites and the best truck routes that meet hospital requests and do not go against capacity constraints, all while reducing system costs overall. The overall cost is determined by adding the fixed opening costs for open facilities, the usage fees for the routed vehicles, if any, and the routing costs.

7.4 Research Objective:

The objective of this study is three prongs:

1. Analyze the existing mechanism of hospital waste management in the case city.
2. Propose an integrated hospital waste management (IHWM) model for the city.
3. Use optimization modeling to plan logistics for the proposed IHWM model.
4. Case: Hospital Waste Management in Varanasi

7.5 Problem Introduction:

Our issue primarily involves a Processing facility, several collection sites, and several hospitals. They communicate with one another via a disabled truck that makes handling in the first echelon and a group of smaller trucks that make handling in the second echelon.

4. **Processing Facility**: Large Processing facility often placed away from the hospitals. The waste is treated at this facility, which collects it among collection sites before returning it to the Processing facility. Since the vehicle only makes one tour, it returns to the processing facility after having collection from every collection site.

5. **Collection Sites:** Smaller facilities are utilized to transship or consolidate the waste because they are closer to the hospitals than the Processing facility. A tiny truck with a little capacity is accessible at each collection site. Each truck collects the waste, tours a subset of the hospitals, and then drives back to the Collection site.

6. **Hospitals:** Endpoints of the distribution are typically situated in areas inaccessible to large vehicles. Only one-second echelon truck per hospital provides service.

Thus, in the problem, one can make the following decisions:

- **Location decisions:** Define the number and location of collection sites.
- **Allocation decision**: Assign each hospital to an open collection site.
- **Routing decisions**: Assign appropriate routes to each vehicle.

7.6 Healthcare Condition in Varanasi:

Multi-specialty hospitals, single-specialty hospitals, medical centers, private clinics, primary healthcare institutions, and other establishments make up Varanasi's medical infrastructure. According to data from the India Environmental Portal, the total number of healthcare facilities (HCF) in Varanasi is 718. Of these, 59 (55 authorized and four defaulters) are government HCFs, while 659 (513 permitted and 146 defaulters) are private HCFs. It contained 139 licensed hospitals and diagnostic facilities. Even though HCFs are spread throughout the entire city, there are two significant clusters: the area around Banaras Hindu University (BHU) and Orderly Bazar (on the other side of Varuna River). Figure 7.1 shows the geographical condition of Varanasi.

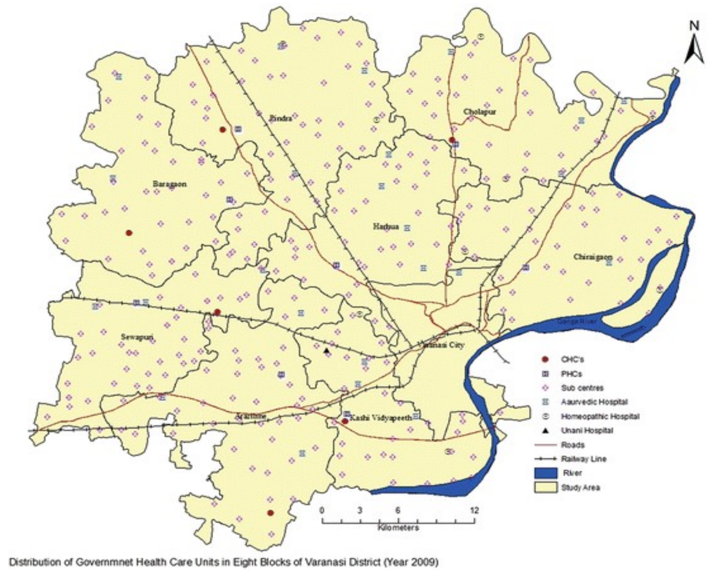

Figure 7.1: Government Healthcare Facilities in Varanasi (Source: Rai & Nathawat,2017)

7.7 Proposed IHWM System:

- Multi-sources
- Multi-echelon

This work focuses on the so-called two-echelon transportation system, a specific instance of a multi-echelon transportation system. The origins (or depots), where the freight is initially located, and the intermediate facilities (or satellites), where the freight is transshipped and/or consolidated before reaching the final destinations, are the only levels of facilities that are involved in such a system (customers). The so-called first echelon consists of the connections between origins and intermediate facilities, whereas the second echelon comprises the connections between intermediate facilities and final destinations. We will therefore consider a two-echelon logistics model for hospital waste disposal.

7.8 Mathematical Model Formulation: Different sets and indices, parameters and variables used in the mathematical model are written below.

Sets:

P	Set of Processing centers, indexed by *p*
C	Set of collection centers, indexed by c
H	Set of hospitals, indexed by h
I	Set of locations of start node, indexed by i
J	Set of locations of end node, indexed by j
V	Set of all nodes
A	Set of all arcs

Parameters:

q_h	demand(medical waste) of hospitals
DT1	Distance to cover in tier1
DT2	Distance to cover in tier2
W_p	The capacity of the truck at Processing facility P
W_c	The capacity of the truck at Collection center C
d_{ij}	Transportation cost per unit distance between i and j
F_p	Fixed cost of locating Processing facility P
F_c	Fixed cost of locating Collection center C
Cap_procesing	Capacity of Processing facilities
Cap_collection	Capacity of Collection centers

Variables:

$$Y_P = \begin{Bmatrix} 1 & if\ Processing\ center\ located \\ 0 & Otherwise \end{Bmatrix}$$

$$Y_c = \begin{Bmatrix} 1 & if\ Collection\ center\ located \\ 0 & Otherwise \end{Bmatrix}$$

$$Z_{ij}^{p} = \begin{Bmatrix} 1 & if\ Trip\ made\ between\ i \in I\ \ to\ j\ \in J\ \ in\ first\ echelon \\ 0 & Otherwise \end{Bmatrix}$$

$$X_{ij}^{c} = \begin{Bmatrix} 1 & if\ Trip\ made\ between\ i \in I\ to\ j\ \in J\ in\ second\ echelon \\ 0 & Otherwise \end{Bmatrix}$$

$V_{pc} \quad = \begin{cases} 1 & if\ Collection\ center\ appointed\ to\ particular\ processing\ facility \\ 0 & Otherwise \end{cases}$

$V_{ch} \quad = \begin{cases} 1 & if\ hospital\ appointed\ to\ particular\ Collection\ center \\ 0 & Otherwise \end{cases}$

Q_{ij}^{p} = Load on the Vehicle in the first echelon during travel from i to j

Q_{ij}^{c} = Load on the Vehicle in the second echelon during travel from i to j

U_c = Amount of waste Collected at the Collection center

Objective Function:

Minimize

$$\sum_{P} F_p * Y_p + \sum_{C} F_c * Y_c + \sum_{i \in P \cup C} \sum_{j \in P \cup C} \sum_{P} d_{ij} * DT1 * Z_{ij}^{p} + \sum_{i \in C \cup H} \sum_{j \in C \cup H} \sum_{C} d_{ij} * DT2 * X_{ij}^{c} \quad (1)$$

Constraints:

First Echelon:

Constraints for the first echelon of the model are shown from (2) to (14). Constraints (2) and (3) indicate that one arc enters and exists for the open Processing facility. Constraint (4) indicates that each collection center will be allocated to only one Processing facility. The vehicle will collect waste from the collection center and drop it to the Processing facility.

$$\sum_{j \in C} Z_{pj}^{p} = Y_p \quad , \forall\ p \in P, \quad (2)$$

$$\sum_{j \in C} Z_{jp}^{p} = Y_p \quad , \forall\ p \in P, \quad (3)$$

$$\sum_{p \in P} V_{pc} \leq 1 \quad , \forall\ c \in C \quad (4)$$

$$Z_{ic}^{p} \leq V_{pc} \quad , \forall\ i \in P \cup C,\ c \in C, p \in P \quad (5)$$

$$Z_{cj}^{p} \leq V_{pc} \quad , \forall\ j \in P \cup C,\ c \in C, p \in P \quad (6)$$

$$\sum_{i \in P \cup C} Z_{ic}^{p} = V_{pc} \quad , \forall\, p \in P, c \in C \tag{7}$$

$$\sum_{j \in P \cup C} Z_{cj}^{p} = V_{pc} \quad , \forall\, p \in P, c \in C \tag{8}$$

$$\sum_{i \in P \cup C} Z_{ic}^{p} = \sum_{j \in P \cup C} Z_{cj}^{p} \quad , \forall\, p \in P,\ c \in C \tag{9}$$

$$\sum_{i \in P \cup C} Z_{ip}^{p} = \sum_{j \in P \cup C} Z_{pj}^{p} \quad , \forall\, p \in P \tag{10}$$

Load on Vehicle:

Constraints (11) to (14) are defined for the waste-carrying capacity of the vehicle and Processing facility for the first echelon. The vehicle capacity is defined for the Collection center. Constraint (11) indicates that the vehicle has no load at the starting point of the collection center. Total waste at the processing center must be equal to or less that the Capacity of the processing facility.

$$Q_{pj}^{p} = 0, \quad \forall\, p \in P,\ j \in C \tag{11}$$

$$\sum_{i \in P \cup C} Q_{ij}^{p} - \sum_{i \in P \cup C} Q_{ji}^{p} = - V_{pj} * U_{j} \quad , j \in C, p \in P \tag{12}$$

$$\sum_{i \in C} Q_{ip}^{p} = \sum_{j \in C} V_{pj} U_{j} \quad , \forall\, p \in P \tag{13}$$

$$Q_{pj}^{p} \leq W_{p} * Z_{ij}^{p} \quad , \forall\, i \in P \cup C, j \in P \cup C, p \in P \tag{14}$$

Second Echelon:

Constraints for the second echelon of the model are shown from (15) to (27). Constraints (15) and (16) indicate that one arc enters and exists for the open Collection center. Constraint (22) indicates that each hospital will be allocated to only one Collection center. Vehicles will collect waste from the hospitals and drop it to the Collection center.

$$\sum_{h \in H} X_{ch}^{c} = Y_{c} \quad , \forall\, c \in C, \tag{15}$$

$$\sum_{h\in H} X_{hc}^{c} = Y_c \quad , \forall\, c \in C, \tag{16}$$

$$\sum_{h\in H} X_{ch}^{c} = \sum_{h\in H} X_{hc}^{c} \quad , \forall\, c \in C \tag{17}$$

$$X_{ij}^{c} \le V_{cj} \quad , \forall\, i \in C \cup H,\ j \in H, c \in C \tag{18}$$

$$X_{ji}^{c} \le V_{cj} \quad , \forall\, i \in C \cup H,\ j \in H, c \in C \tag{19}$$

$$\sum_{i\in C\cup H} X_{ij}^{c} = V_{cj} \quad , \forall\, j \in H, \forall c \in C \tag{20}$$

$$\sum_{i\in C\cup H} X_{ji}^{c} = V_{cj} \quad , \forall\, j \in H, \forall c \in C \tag{21}$$

$$\sum_{c\in C} V_{cj} = 1 \quad , \forall\, j \in H \tag{22}$$

$$X_{cj}^{c} \le Y_c \quad , \forall\, j \in H, c \in C \tag{23}$$

$$Q_{cJ}^{c} = 0, \quad \forall\, j \in H, c \in C \tag{24}$$

$$\sum_{\boldsymbol{i\in C\cup H}} Q_{ij}^{c} - \sum_{\boldsymbol{i\in C\cup H}} Q_{ji}^{c} = -\, V_{cj} * q_j \quad , \forall j \in H \tag{25}$$

$$Uc = \sum_{j\in H} V_{cj}\, q_j, \ , \quad \forall c \in C \tag{26}$$

$$\sum_{\boldsymbol{j\in H}} Q_{jc}^{c} = U_c \quad , \forall c \in C \tag{27}$$

Capacity Constraints:

Constraints (28) to (39) are related to the capacity of the collection center, Processing facility, and the vehicles associated with the Collection and Processing centers.

$$Uc \le Cap\_Collection * Yc, \ , \quad \forall c \in C \tag{28}$$

$X_{ij}^{c} = 0, \ \forall \text{I} \ \in \text{C}, \ \text{j} \in \text{C}, \text{c} \ \in \text{C}$ (29)

$X_{ij}^{c} = 0, \ \forall \text{i} \ \in \text{P2}, \ \text{j} \in \text{C}, \text{c} \ \in \text{C}, \text{if} \ \text{j} \neq \text{c}$ (30)

$X_{ij}^{c} = 0, \ \forall \text{i} \ \in \text{H}, \ \text{j} \in \text{H}, \text{c} \ \in \text{C}, \text{if} \ \text{i} = \text{j}$ (31)

$X_{ij}^{c} = 0, \ \forall \text{i} \ \in \text{C}, \ \text{j} \in \text{H}, \text{c} \ \in \text{C}, \text{if} \ \text{i} \neq \text{c}$ (32)

$\text{Q}_{\text{ij}}^{\text{c}} \leq \ W_c * X_{ij}^{c} \ \ , \ \forall \text{i} \in \text{C U H}, \text{j} \in \text{C U H}, \text{c} \in \text{C}$ (33)

$Z_{ij}^{P} = 0 \quad , \ \forall \ \text{i} \in \text{P}, \ \text{j} \in \text{P}, \text{p} \in \text{P}$ (34)

$Z_{ij}^{P} = 0 \quad , \ \forall \ \text{i} \in \text{P U C}, \ \text{j} \in \text{P}, \text{p} \in \text{P if} \ \text{j} \neq \text{p}$ (35)

$Z_{ij}^{P} = 0 \quad , \ \forall \ \text{i} \in \text{P} \ , \ \text{j} \in \text{C}, \text{p} \in \text{P if} \ \text{i} \neq \text{p}$ (36)

$Z_{ij}^{P} = 0 \quad , \ \forall \ \text{i} \in \ \text{C}, \ \text{j} \in \text{C}, \text{p} \in \text{P} \ \text{if} \ \text{i} = \text{j}$ (37)

$\text{Uc} \leq \text{Cap\_}Collection, \quad \forall \text{c} \ \in \text{C}$ (38)

$\sum_{j \in C} \text{Uc} * V_{pc} \leq \text{Cap\_}Processing, \text{p} \in \text{P}$ (39)

7.9 Results & Discussion:

The analysis of the current situation of healthcare waste management in Varanasi suggests that a lot of work must still be done to manage the waste efficiently. In this pursuit data were collected from t Varanasi's healthcare waste management organizations More than fifty hospitals having more than thirty beds were considered for this case study. This work has proposed an approach of managing waste in two phases. In the first phase there will be processing facilities and collections centers involved whereas in the second phase collection centers and hospitals will be there. The case uses five locations as processing facilities and fifteen locations for collection centers, which will be opened or closed as per the requirements the description about Processing facility and Collection center is shown in Table 7.2.

Table 7.2 Description about Processing and Collection center

	Processing Facility	Collection center
Storage Capacity (Kg)	5000	2000
Vehicle Capacity (Kg)	1500	850
Establishment Cost (Lakh Rupees)	50	1

To minimize waste handling, cost a mathematical model is developed with capacity and load constraints. Using GUROBI solver, we will solve the model and find that four Processing and eight collection centers are required to manage the waste properly. Every two collection centers are assigned to a processing center. All the hospitals are assigned to these eight collection centers. Vehicle start from the collection center and cover all the assigned hospitals to collect the waste then Big Vehicle from the Processing plant covers the assigned collection centers where final treatment of waste will be done. In this way it is optional to visit individual hospitals one by one.

7.10 Optimal waste Collection between Processing facility (PF) and Collection center (CC): Initially we have taken five proposed sites for Processing facility which is shown as P1, P2, P3, P4 and P5 at outer side of the city, which will handle the waste from fifteen collection centers (C1, C2…… C15) All the Processing facilities are shown in figure 7.2, From result we have observed that at a time four collection centers are open which are operating with eight collection centers.. Four of these five processing facilities been allotted to the current problem (P2, P3, P4 ,P5).

Table 7.3 Distance between Processing Facilities

	P1	**P2**	**P3**	**P4**	**P5**
P1	0	16.8	12.3	16.1	16.4
P2	16.8	0	13.3	11.8	12.9
P3	12.3	13.3	0	7.9	4.4
P4	16.1	11.8	7.9	0	5.6
P5	16.4	12.9	4.4	5.6	0

And distance between each Processing facilities is shown in table 7.3 all distances are in kilometers.

Figure 7.2 Location of Processing Facilities

Location of processing facilities have been shown in the map.

Table 7.4 PF and CC

Processing Facility	Collection Centers
P2	C8, C9
P3	C7, C10
P4	C11, C12
P5	C14, C15

From table 7.4 it is clear that Each Processing facilities have to handle waste from two collection centers. Each Processing facility has a big capacity vehicle, which collects waste from the assigned collection centers. Collection centers are shown in the figure 7.3.

Distance between all the fifteen collection centers are shown in table 7.5

Table 7.5 Distance between collection centers

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C1	0	1.5	3.2	11.4	9.4	11.4	6.8	5.2	7.3	10.6	10.8	8.6	13.1	13.4	13.8
C2	1.5	0	2.9	9.9	7.9	9.9	5.2	3.7	5.7	9.1	9.8	7.1	13.4	13.2	14.1
C3	3.2	2.9	0	8.5	7.5	9.5	7.2	6	7.7	13.1	11.6	10.3	14.5	14.7	15.3
C4	11.4	9.9	8.5	0	0.9	2	4.3	5.5	6.2	7.7	10.4	9.1	13.4	13.1	13.6
C5	9.4	7.9	7.5	0.9	0	0.9	3.3	4.6	5.3	6.8	9.5	8.2	12.4	12.2	12.6
C6	11.4	9.9	9.5	2	0.9	0	2.5	3.7	4.5	6	8.7	7.4	11.6	11.4	11.8
C7	6.8	5.2	7.2	4.3	3.3	2.5	0	1.6	1.7	5.9	7	5.1	11.8	11.5	12
C8	5.2	3.7	6	5.5	4.6	3.7	1.6	0	2.2	6.4	7.2	5.4	10.1	11.8	12.3
C9	7.3	5.7	7.7	6.2	5.3	4.5	1.7	2.2	0	5	6	4.2	10.7	10.4	10.9
C10	10.6	9.1	13.1	7.7	6.8	6	5.9	6.4	5	0	3.7	2.4	6.2	6	6.5
C11	10.8	9.8	11.6	10.4	9.5	8.7	7	7.2	6	3.7	0	1.9	3.9	3.7	4.1
C12	8.6	7.1	10.3	9.1	8.2	7.4	5.1	5.4	4.2	2.4	1.9	0	6.2	5.7	6.2
C13	13.1	13.4	14.5	13.4	12.4	11.6	11.8	10.1	10.7	6.2	3.9	6.2	0	0.6	1.1
C14	13.4	13.2	14.7	13.1	12.2	11.4	11.5	11.8	10.4	6	3.7	5.7	0.6	0	0.45
C15	13.8	14.1	15.3	13.6	12.6	11.8	12	12.3	10.9	6.5	4.1	6.2	1.1	0.45	0

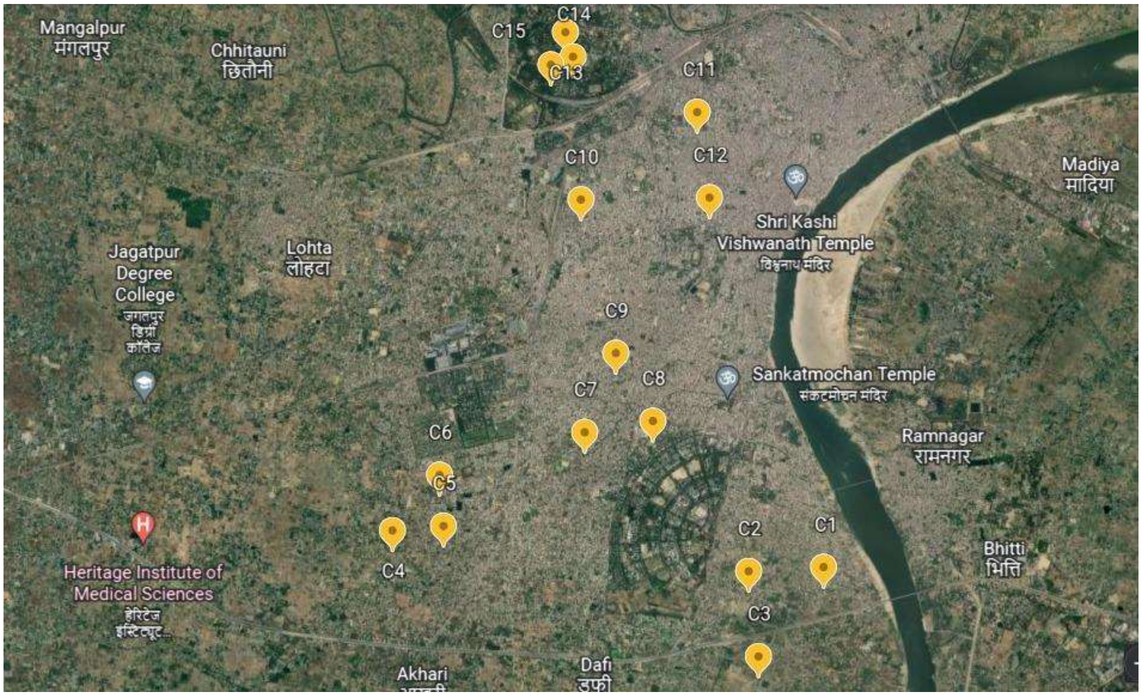

Figure 7.3 Location of Collection centers

Location of collection centers have been shown in the map.

7.11 Optimal waste Collection between Collection centers and Hospitals: For this case study as we have considered fifty-three hospitals (H1, H2, H3…..H53). Which have more than thirty beds. Eight collection centers will handle these fifty-three-hospital waste with the help of small capacity vehicles. The location of hospitals is shown in the figure 7.4

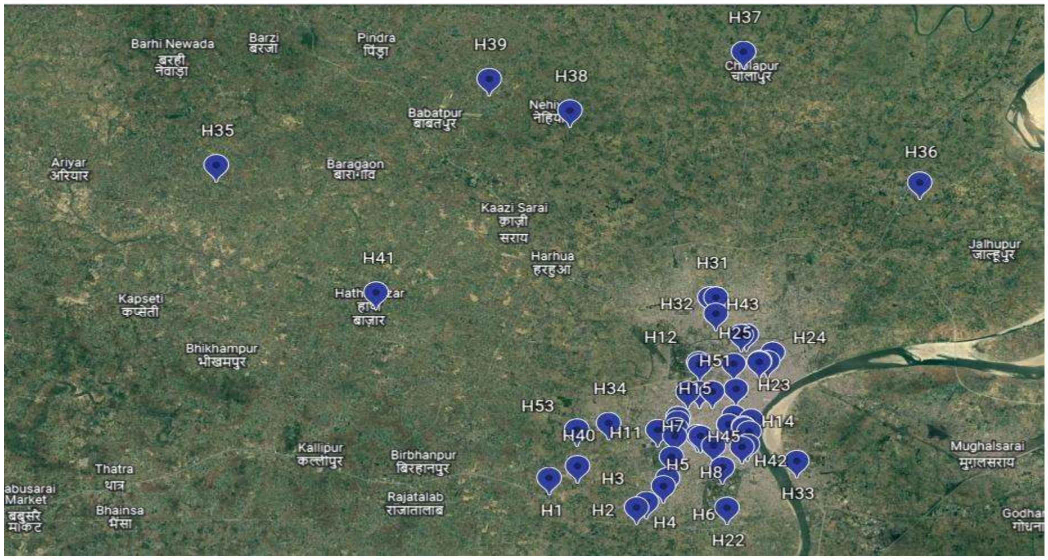

Figure 7.4 Location of Hospitals

The result of the current problem shows that total eight collection centers are assigned different number of hospitals, shown in table 7.6

Table 7.6 CC and Hospitals

Collection Centers	**Hospitals**
C7	H3, H4, H7, H47, H48
C8	H46
C9	H5, H6, H8, H9, H11, H18, H20, H21, H43, H49, H50, H51
C10	H1, H2, H14, H22, H28, H33, H40, H53
C11	H12, H13, H23, H24, H29, H30, H38
C12	H10, H15, H16, H17, H19, H42, H52
C14	H25, H26, H34, H35, H36, H37, H39, H41, H44, H45
C15	H27, H31, H32

In order to reduce the travelling distance different numbers of hospitals has been allocated to these collection centers on the basis of minimum distance between them. The amount of waste collected to each collection centers is shown in the table 7.7

Table 7.7 CC with amount of waste Collection

Collection Centers	Amount of waste Storage in Kg
C7	760
C8	850
C9	646
C10	663
C11	834
C12	496
C14	710
C15	505

Each processing facility have their vehicle in the current problem vehicle will start from P2 it will go to C8 and collect 1496 kg waste and return back to P2, after this vehicle again start it run and got to C8 and C9 to collect 646 kg of waste. In this manner Vehicle work is complete for processing facility 2. Similarly, vehicles routes for other facilities have been shown in table 7.8

Table 7.8 Vehicle route from PF to CC

Vehicle Route	Waste Collection(kg)
P2 → C8 → P2	1496
P2 → C8 → C9 → P2	646
P3 → C7 → P3	1423

P3 → C7 → C10 → P3	663
P4 → C12 → P4	1330
P4 → C12 → C11 → P4	834
P5 → C15 → P5	1215
P5 → C15 → C14 → P5	710

In the previous method Vehicle from the Processing facility had to visit each hospital individually. After introducing the concept of a collection center, it is clear that now Vehicle from the Processing facility have to visit only collection centers in place of each hospital. So, a large reduction occurs in terms of traveling distance in this new approach which finally reduces the waste handling cost. By introducing the concept of multiple processing centers and collection centers, we are preparing Varanasi to handle any pandemic-like situation because recent pandemic COVID has shown that we are not prepared to handle this type of situation.

If we summarize our findings, it will arrange as:

- Reduction in Waste handling and transportation cost.
- Hazardous waste has not to expose to human beings for long time.
- Pandemic-like situations in which huge amounts of waste will generate can be handled easily.
- Due to unstructured road conditions, big vehicles cannot travel to each hospital.
- Easy and convenient waste collection from the hospitals.

The connection between Processing facility (Red) to Collection centers (Yellow) and Collection centers to Hospitals (Green) is shown in the figure 7.5

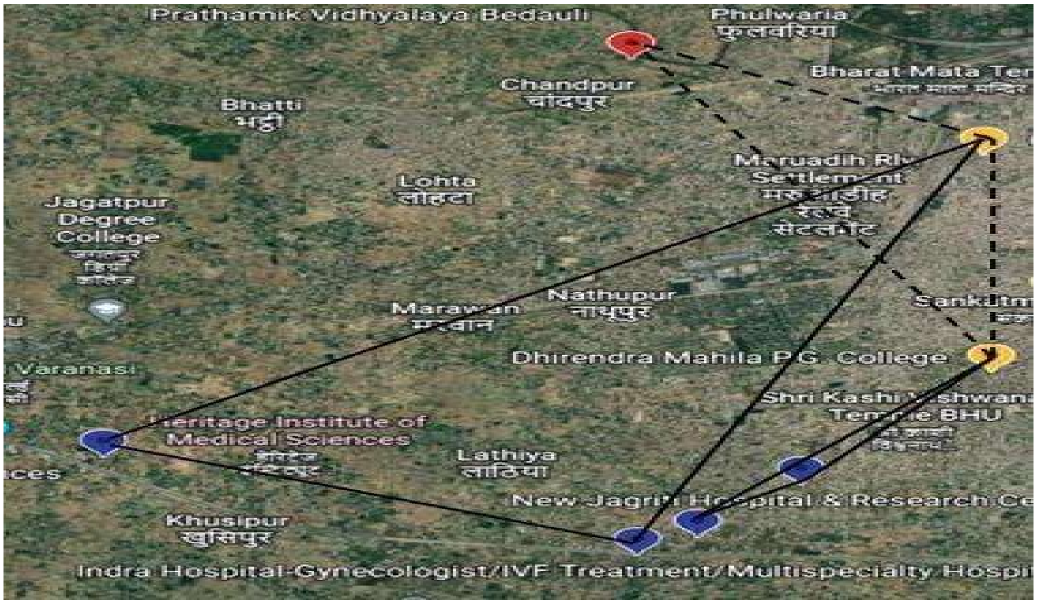

Figure 7.5 Connection between PF, CC, and Hospitals

7.12 Conclusion

The study reviewed the literature to establish the fact that healthcare waste management is critical to public health. Because of its inherited complexity and risk healthcare waste management needs customized planning. Alas that is not the case always. This study follows a case study approach to provide a descriptive and prescriptive approach for hospital waste management in the ancient city of Varanasi. The city has witnessed unplanned growth over the years and is densely populated. The healthcare facilities in the city have a large catchment area and attract patients from neighboring districts. The situation analysis based on secondary data and unstructured interviews of the stakeholders suggest that the ad hoc approach prevails in present hospital waste management in the city. The case selected hospitals having more than thirty wastes from the data published by the Indian medical association. The locations of collection and processing centers were decided based upon suggestions of the focus group. The study illustrated a 2-echelon approach for management of hospital waste in the city. The study's results suggested significant cost savings using the proposed approach, which makes the approach more sustainable. Apart from economic benefits, other associated benefits include reducing health hazards. The study has three implications for theory. First it establishes the fact that management of hospital waste management is a complex issue in unplanned cities. Secondly, hospital waste management should be managed separately from other urban wastes. Finally, hospital waste should be managed efficiently to make the effort sustainable. Similarly, the study has three implications for practice. First, operation research methods such as linear programing can be used to find optimal arrangements to reduce the cost of operation. Secondly, the model should be adaptive enough to adopt the changes in the future. Finally, the inclusive model can be utilized to perform situation analysis before committing investment.

Although this study provides an approach for managing hospital waste using a case study approach, there are certain limitations of the study which can be addressed in future studies. More focus on efficiency diverts attention from other objectives of hospital waste management and there may be some unintended consequences of the hard system thinking approach. Future studies can also utilize a soft thinking approach, such as system dynamics analysis to analyses the effect of proposed solution. As the complexity of the hospital waste management model increases, methods such as genetic algorithms and simulated annealing and other evolutionary algorithms are better suited. Though these algorithms do not guarantee an exact optimal solution, they give near-optimal solutions quickly.

7.13 Managerial Implications: The study has three implications for theory. First, it establishes that hospital waste management is a complex issue in unplanned cities. Secondly, hospital waste management should be managed separately from other urban wastes. Finally, hospital waste should be managed efficiently to make the effort sustainable. Similarly, the study has three implications for practice. First, operation research methods such as linear programming can be used to find optimal arrangements to reduce the cost of operation. Secondly, the model should be adaptive enough to adopt the changes in the future. Finally, the inclusive model can be utilized to perform situation analysis before committing investment.