SOLID WASTE MANAGEMENT PROJECT (ESE311)

OPTIMIZATION OF SOLID WASTE COLLECTION ROUTE

USING GIS MAPPING

Content

INTRODUCTION:

IMPORTANCE OF SOLID WASTE MANAGEMENT:

Population growth and economic changes drive increased waste production. Developing nations, such as India, struggles due to poor infrastructure and organization. Municipalities handle waste but spend most on inefficient collection (80%). Effective solid waste management encompasses collection, transportation, recovery, and safe disposal. SDG12: ensure sustainable consumption and production patterns.

OBJECTIVE

Optimization of allocation of bin and collection route for solid waste collection using GIS

1. GIS (Geographic Information System) plays a crucial role in optimizing collection routes and allocation bin by providing spatial data analysis and visualization tools.
2. With GIS, collection route optimization becomes more efficient and cost-effective.
3. By integrating various data layers such as road networks, traffic patterns, and waste generation points, GIS helps in determining the most optimal routes for waste collection vehicles.

BENEFIT OF OPTIMIZATION

01 Efficient route optimization helps minimize fuel consumption, vehicle maintenance costs, and labor expenses by reducing unnecessary travel distances and time spent on collection routes.

02 Optimized routes lead to reduced emissions from collection vehicles due to shorter travel distances and less idling time, contributing to lower carbon footprints and improved air quality in urban areas

03 Optimized routes and bin allocations streamline operations, allowing for higher productivity and throughput within the waste management system.

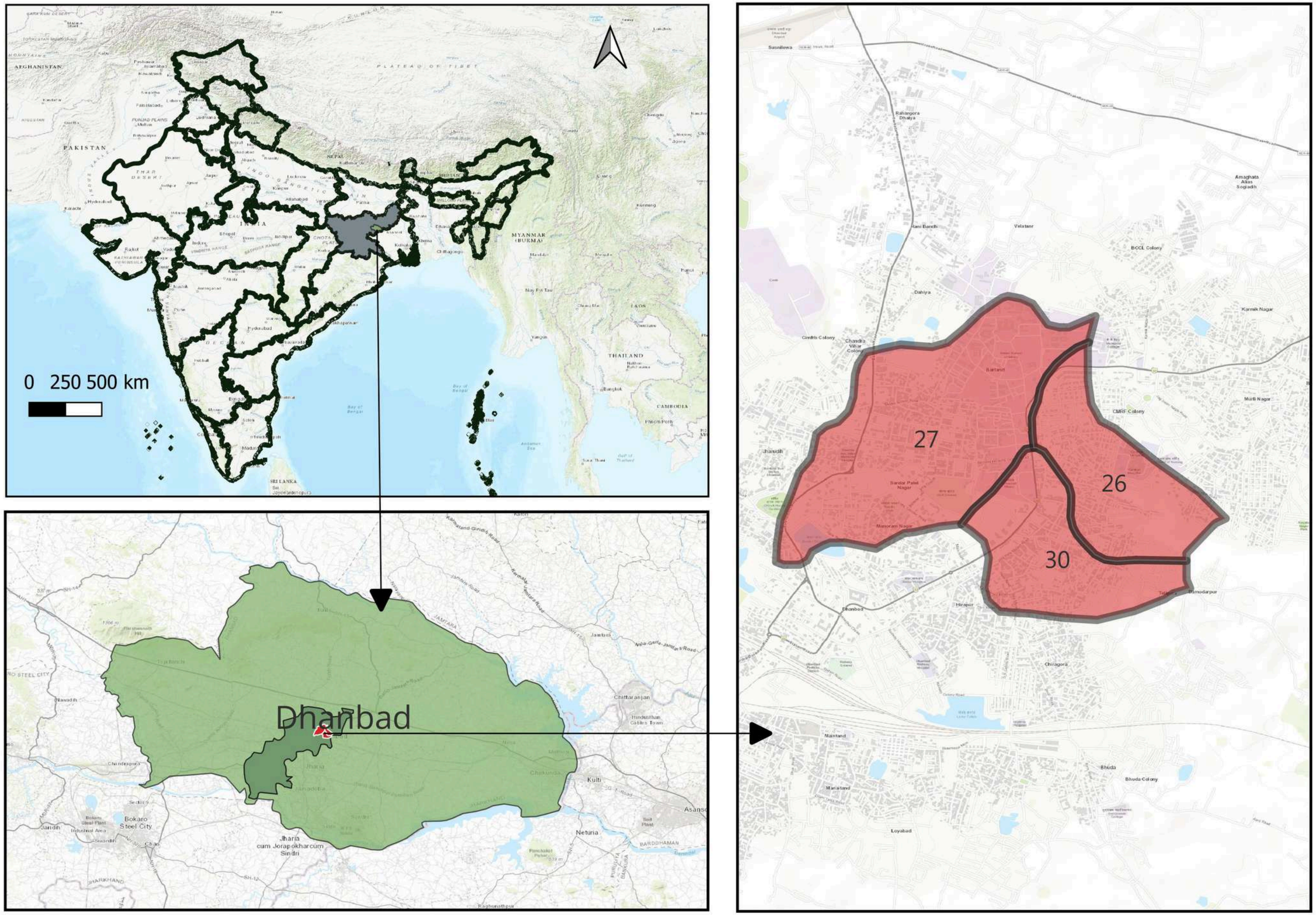
OVERVIEW OF STUDY AREA

01 The study area, Hirapur , Dhanbad, India, lies between latitude 86°06'11" E to 86°50'26" E and longitude 23°38'58" N to 24°03'30" N. It come under Dhanbad District in Jharkhand, India, which is renowned for its significant coal reserves.

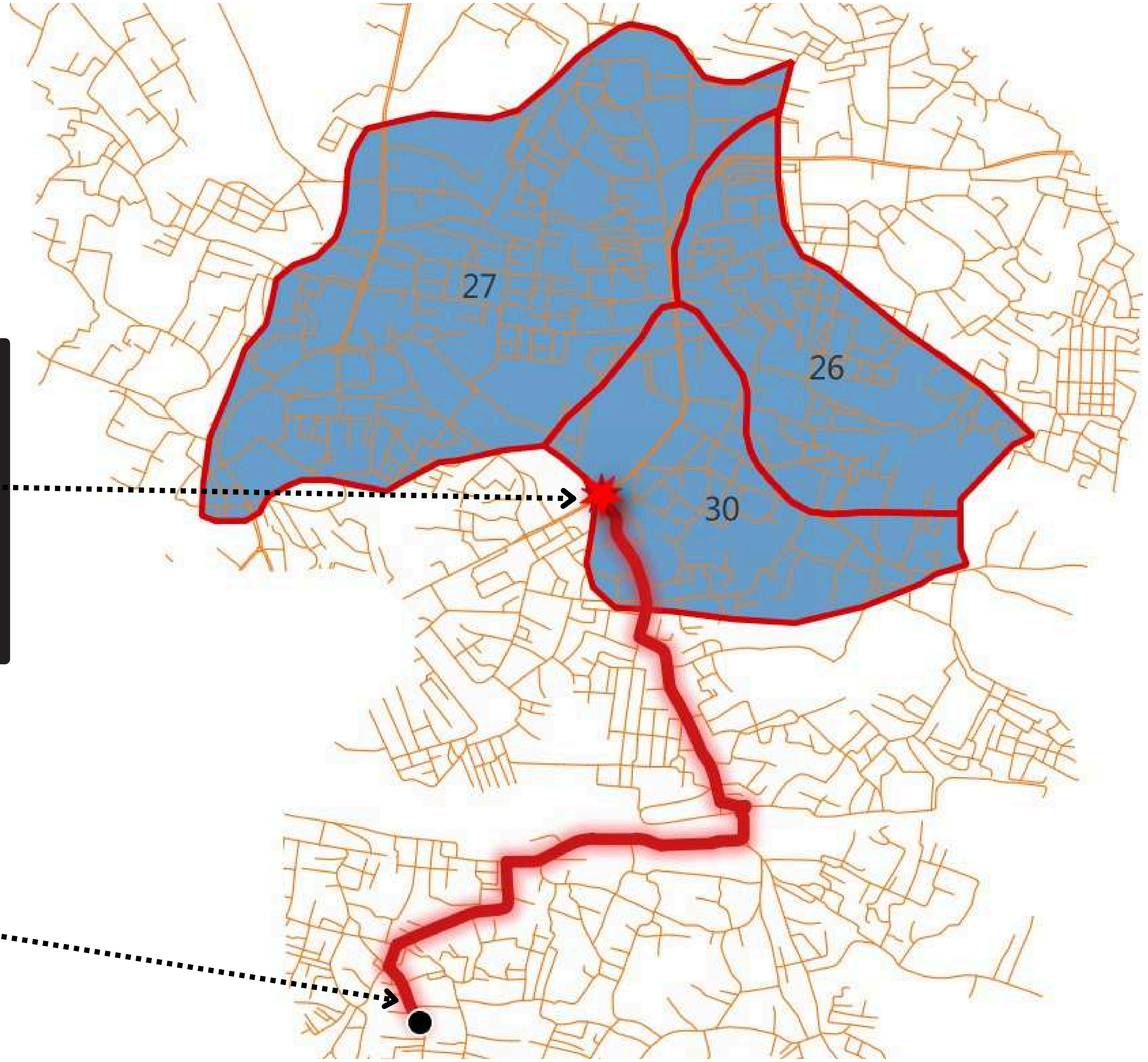
02 Dhanbad encompasses an urban region comprising 12 wards.

03 The 26th, 27th, and 30th wards, located within the Hirapur Area, Dhanbad have a combined population of 61,959 individuals within a 4 km^2 area. This area has been selected as the focus for the current study.

STUDY AREA



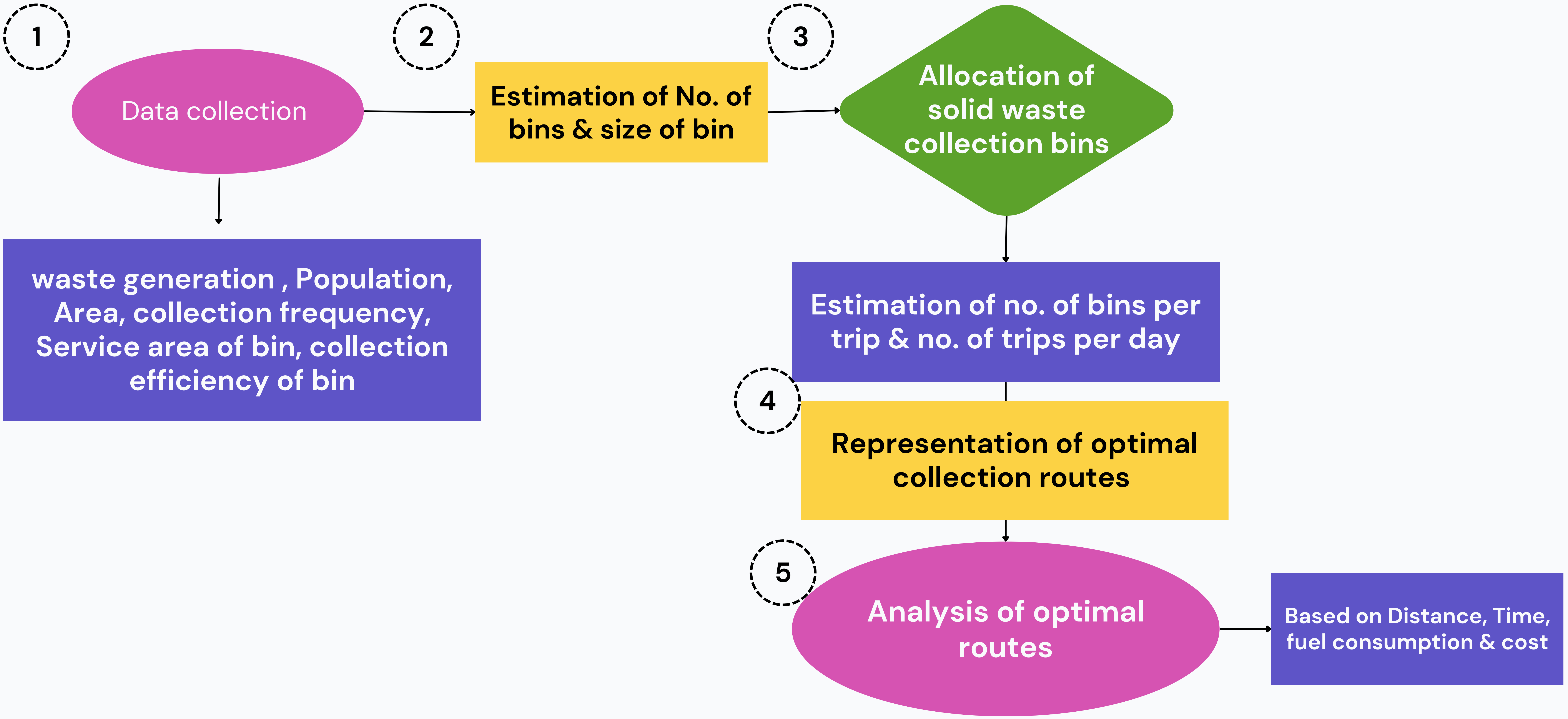
Study Area



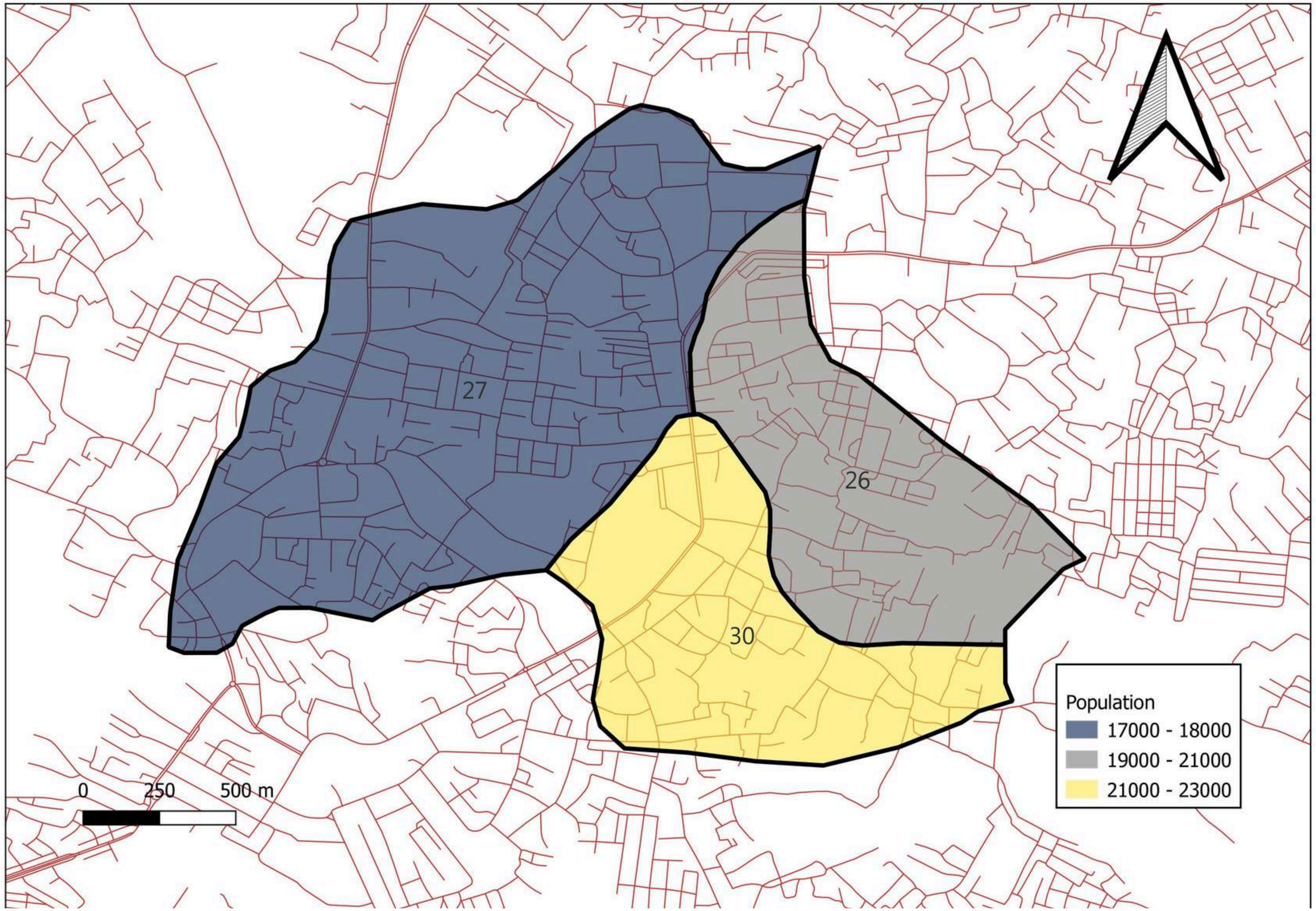
Compaction facility & Dispatch center

Landfill site: loyabad

Let's visualize flowchart of our project:

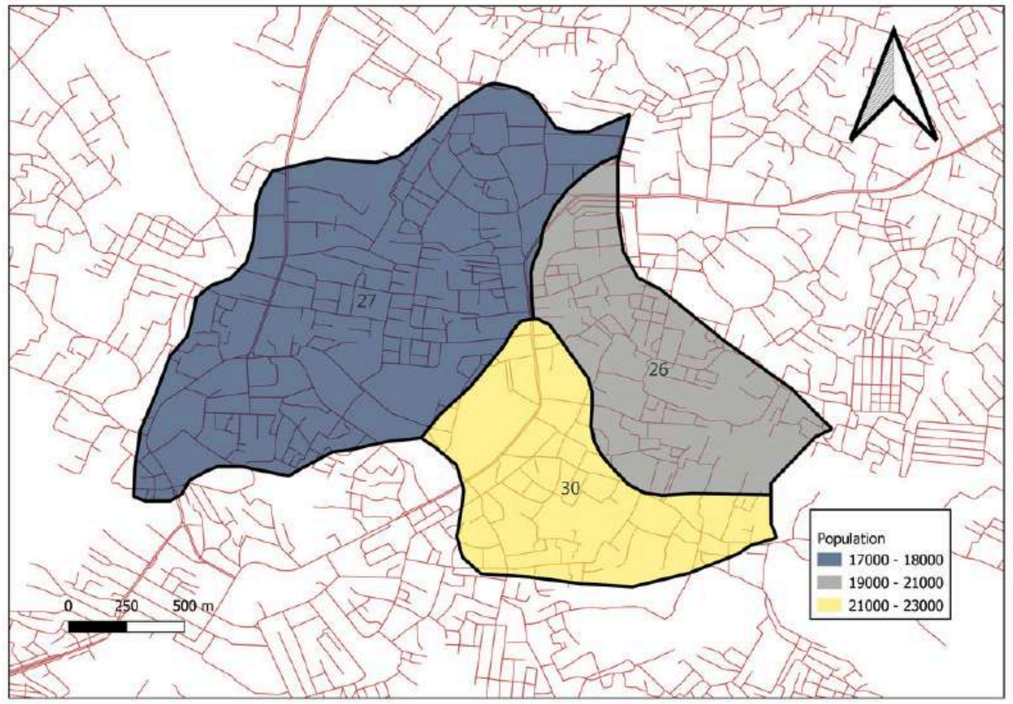


Study Area Based on Population



DATA

01. STUDY AREA



- Wards 26, 27, and 30 in Hirapur with Total pop. 61,959, Area 4 km^2 is Chosen as study area
- Ward 30 hosts Truck dispatch center& compaction facility
- Loyabad:landfilling site

02. WASTE CHARACTERISTIC

- Primarily residential with mixed commercial land use.
- Generates 146,244 kg of solid waste daily having average density of 400 kg/m^3.
- Lack of waste segregation at source results in Commingled waste.

03.BIN:

- Consider a stationary collection system.
- Service area of 100m radius around each bin.
- Having collection efficiency of 80%.

DATA

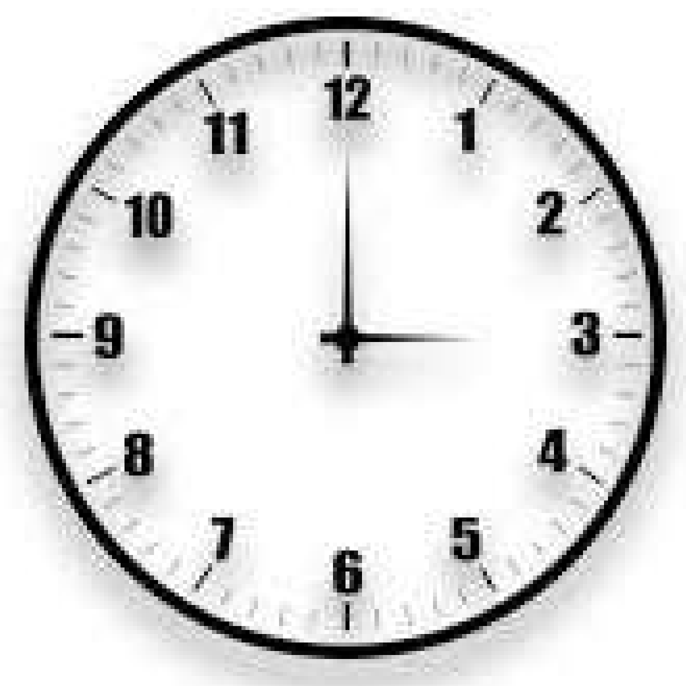
0.4 COLLECTION VEHICLE

- 2 mechanized vehicles estimated sufficient for efficient waste collection.
- With collection frequency of 2 days/week.
- Mechanical vehicles with 15m3 loading capacity reduce pickup and routing time with 35 km/h speed with fuel consumption 1.6L/km.

05. DUMPER TIPPER

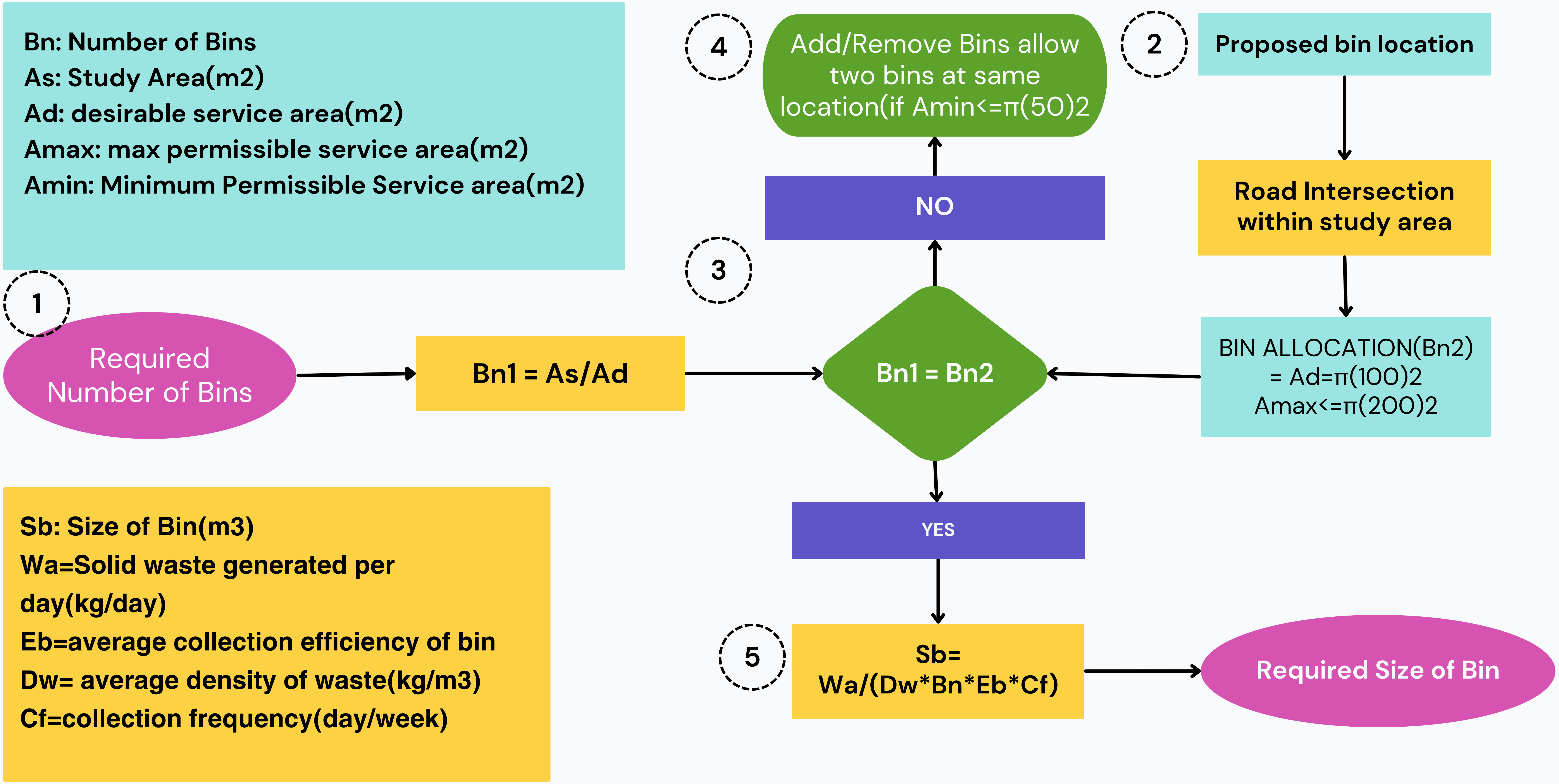
- 1 mechanized dumper tipper estimated for efficient waste transfer from compactor station to landfill site.
- With 25m3 loading capacity with 47 km/h speed with fuel consumption of 2.3L/km.

06.TIME



- Total working hours set at 8 hours per day, with 2 shifts with off-route time 30 min.
- 5 min unloading time assigned for each bin.
- 20 minute time allocated for landfill site unloading.

Let's visualize method for determination of the required number of bins and it's size



ESTIMATION OF REQUIRED NO. OF COLLECTION BINS AND ITS SIZE

WARD:26

- Area of ward = 931953.152 sq. m
- Area of service =3.14 x 100 x 100 = 31400 sq.m
- No of bin = $\frac{As}{Ad}$

  $= \frac{931953.152}{31400} = 29$

- Size of bin =Sb= Wa/(DwBnEbCf)

  $= \frac{57624}{(400 \times 29 \times 0.8 \times 2)}$

  = 3.1047 cu.m

WARD:30

- Area of ward = 931953.152 sq. m
- Area of service =3.14 x 100 x 100 = 31400 sq.m
- No of bin= $\frac{924945.691}{31400} = 29$
- Size of bin = $\frac{57624}{(400 \times 29 \times 0.8 \times 2)}$ = 2.6023 cu. m

WARD:27

- Area of ward = 2085996.392 sq. m
- Area of service =3.14 x 100 x 100 = 31400 sq.m
- No of bin= $\frac{2085996.392}{31400} = 66$
- Size of bin = $\frac{40320}{(400 \times 29 \times 0.8 \times 2)}$ = 0.9545 cu. m

Determination of the required number of bins:

Density of waste: 400kg/m3   Efficiency of bin: 0.8

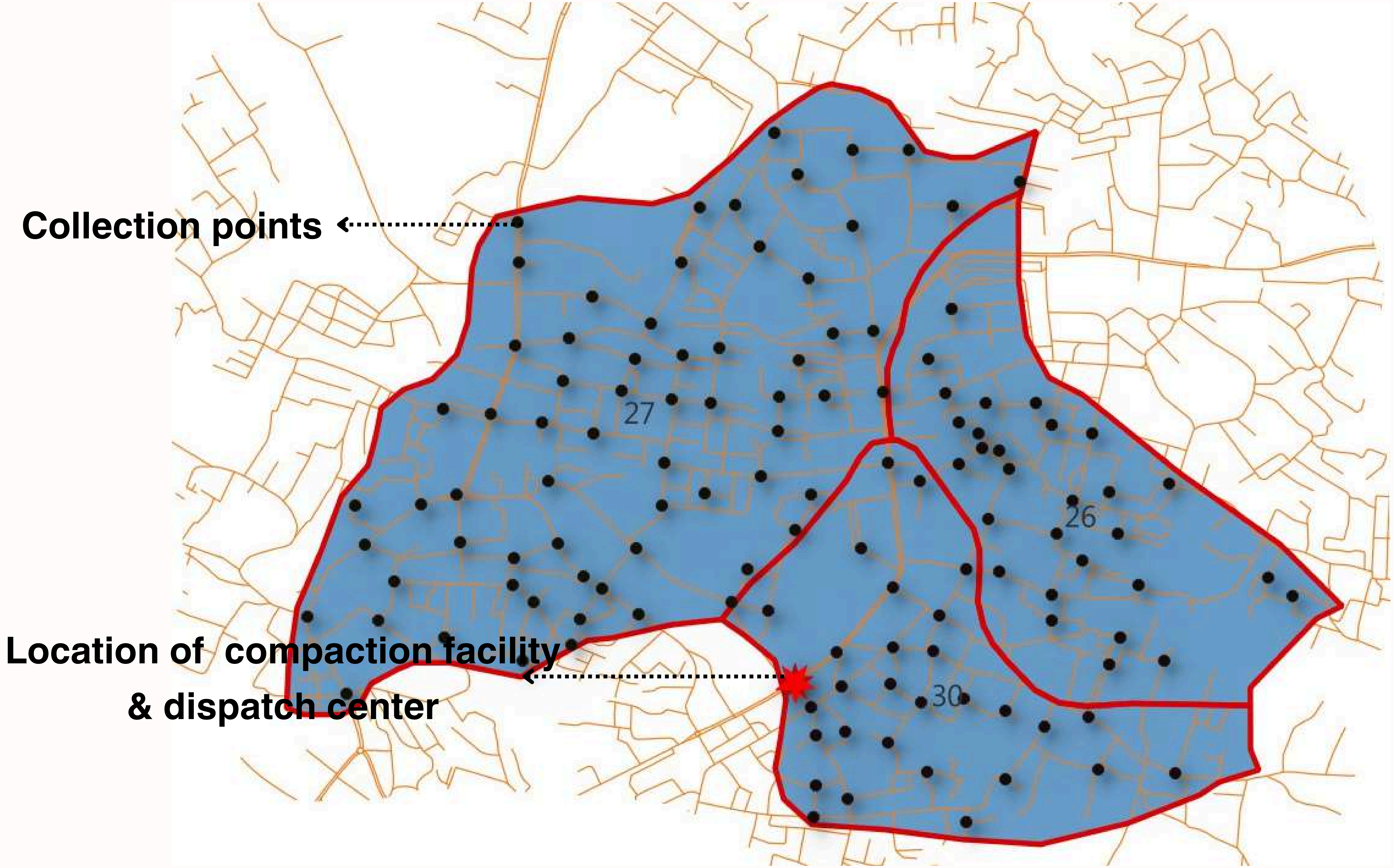
Collection frequency: 2day/week

WARD NO.	WASTE GENERATION(KG/WEEK)	POPULATION	AREA(M2)	NO. OF BINS	SIZE(M3)
26	57624	19872	931953.152	29	3.1047
27	40320	17132	2085996.392	66	0.954545
30	48300	24955	924945.691	29	2.602371
TOTAL	146244	61959	3942895.235	124	1.842792

GIS Mapping of Allocation of Bins

1. **Ancillary data integrated into GIS for base map creation, including ward, topographical, and municipality maps.**
2. **Residential areas and road networks digitized using OpenStreetMap and ESRI Topographic imagery.**
3. **Bin allocation based on road characteristics, waste generation rates, and population.**
4. **Detailed road network data crucial for informed bin placement decisions, slope consideration omitted as plain terrain.**
5. **Allocating solid waste collection bins along road intersections when feasible observing the density of residential and commercial areas and the population of the area**

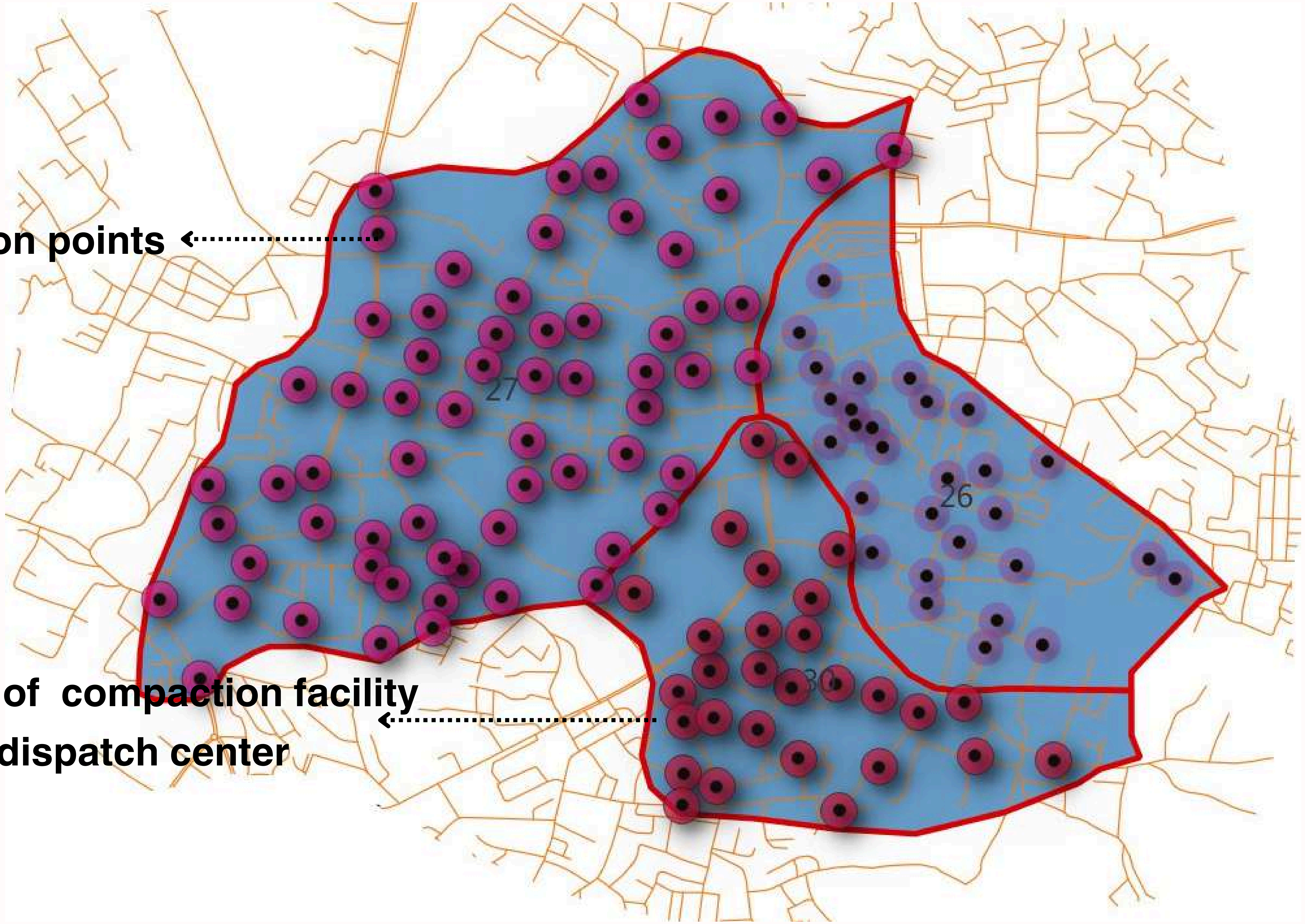
ALLOCATION OF BINS



BUFFER:

Collection points

Location of compaction facility
& dispatch center



COMPACTING STATION AND DEPOT:

ESTIMATION OF REQUIRED NO. OF COLLECTION BINS PER TRIP & NO. OF TRIPS PER WEEK

- Density of waste = 400kg/m3
- Total waste per week = 146244 kg/week
- Total volume of waste per week = $\dfrac{\text{Total waste per week}}{\text{density of waste}}$

  $= \dfrac{146244\ (\text{kg/week})}{400\ (\text{kg/m3})}$

  $= 365.61\ \text{m3/week}$

- Volume of 1 vehicle = 15m3
- Volume of 1 bin = 1.84 m3
- Collection efficiency of bin = 80% = 0.8
- No. of trips per week = $\dfrac{\text{Total volume waste per week}}{\text{volume of vehicle}}$

  $= \dfrac{365.61\ (\text{m3/week})}{15\ (\text{m3})} = 24.374$

ESTIMATION OF REQUIRED NO. OF COLLECTION BINS PER TRIP & NO. OF TRIPS PER WEEK

- Collection frequency= 2 days/week
- No. of trips per day= $\dfrac{\text{No. of trips per week}}{\text{Collection Frequency}}$

  $= \dfrac{24.374}{2} = 12.187 \sim 13$

- No. of bins empty per trip = $\dfrac{\text{Volume of vehicle (m3)}}{\text{volume of bin (m3)} \times \text{collection efficiency of bin}}$

  $= \dfrac{15\text{m3}}{(1.82\text{ m3}) * 0.8} = 10.3022 = 10$

GIS Mapping of optimal Routes

1. **Ancillary data integrated into GIS for base map creation, including ward map, road network and location of allocated bins.**

2. **We used Vehicle Routing Problem (VRP) based on Traveling Salesperson algorithm (TSP). This involves finding the fastest route for a salesperson to visit multiple cities, starting from one point and optionally ending at another.**

3. **Instead of dealing with a large number of points, we grouped them into smaller clusters based on ward. This helped to manage the complexity as the number of routes would increase exponentially with the number of points.**

4. **We determined the longitude and latitude of each location, then prepared a distance matrix. This matrix allowed us to compare the distance between each pair of points and identify the shortest paths.**

5. **Utilized VRP solver for route optimization, ensuring efficiency by selecting optimal locations per trip. Analyzed distances and travel times to choose fastest paths, depicted on road network for practical implementation.**

Back to Agenda

ALTERNATIVES ANALYSED FOR SHORTEST ROUTE:

01. ORS TOOLS

- PROVIDES ACCESS TO THE FUNCTION OF OPEN ROUTE SERVICE. THIS TOOL INCLUDES ROUTING FROM POINT FILES WHICH REQUIRE
- WE NEED TO MANUALLY SELECT THE POINTS USING ORS TOOLS AND ONLY THEN WILL IT CREATE THE ROUTES WHICH TURNS OUT TO BE QUITE INEFFICIENT.
- THIS INTRODUCES A SIGNIFICANT ELEMENT OF SUBJECTIVITY AND POTENTIAL ERROR INTO THE ROUTING PROCESS

02. NETWORK ANALYSIS

- NETWORK ANALYSIS CONSTITUTES A FUNDAMENTAL TOOL IN GIS FOR OPTIMISING TRANSPORTATION SYSTEMS.
- IT PRIMARILY CATERS TO POINT-TO-POINT TRANSPORTATION SCENARIOS, WHICH MAY NOT ALIGN WITH THE OPERATIONAL DYNAMICS OF STATIONARY COLLECTION SYSTEMS.
- RATHER IT REQUIRES AGGREGATION OF RESOURCES FROM VARIOUS COLLECTION POINTS TO A CENTRAL FACILITY

03. VRP SOLVER

- VRP SOLVER IS AN OPEN SOURCE TOOL FOR REPRESENTING, SOLVING AND VISUALISING RESULTS OF VEHICLE ROUTING PROBLEM.
- IT CREATES DISTANCE MATRIX WHICH SOLVES OUR MAJOR PROBLEM. IT IS ALSO HIGHLY TRANSPARENT AS EACH STEP IS VISIBLE TO US.
- IT CATERS TO TRANSPORTATION ALONG VARIOUS COLLECTION POINTS TO A CENTRAL FACILITY AS NEEDED.
- THEREFORE, IT IS USED AS THE BASIS FOR OUR ANALYSIS

VEHICLE ROUTING PROBLEM

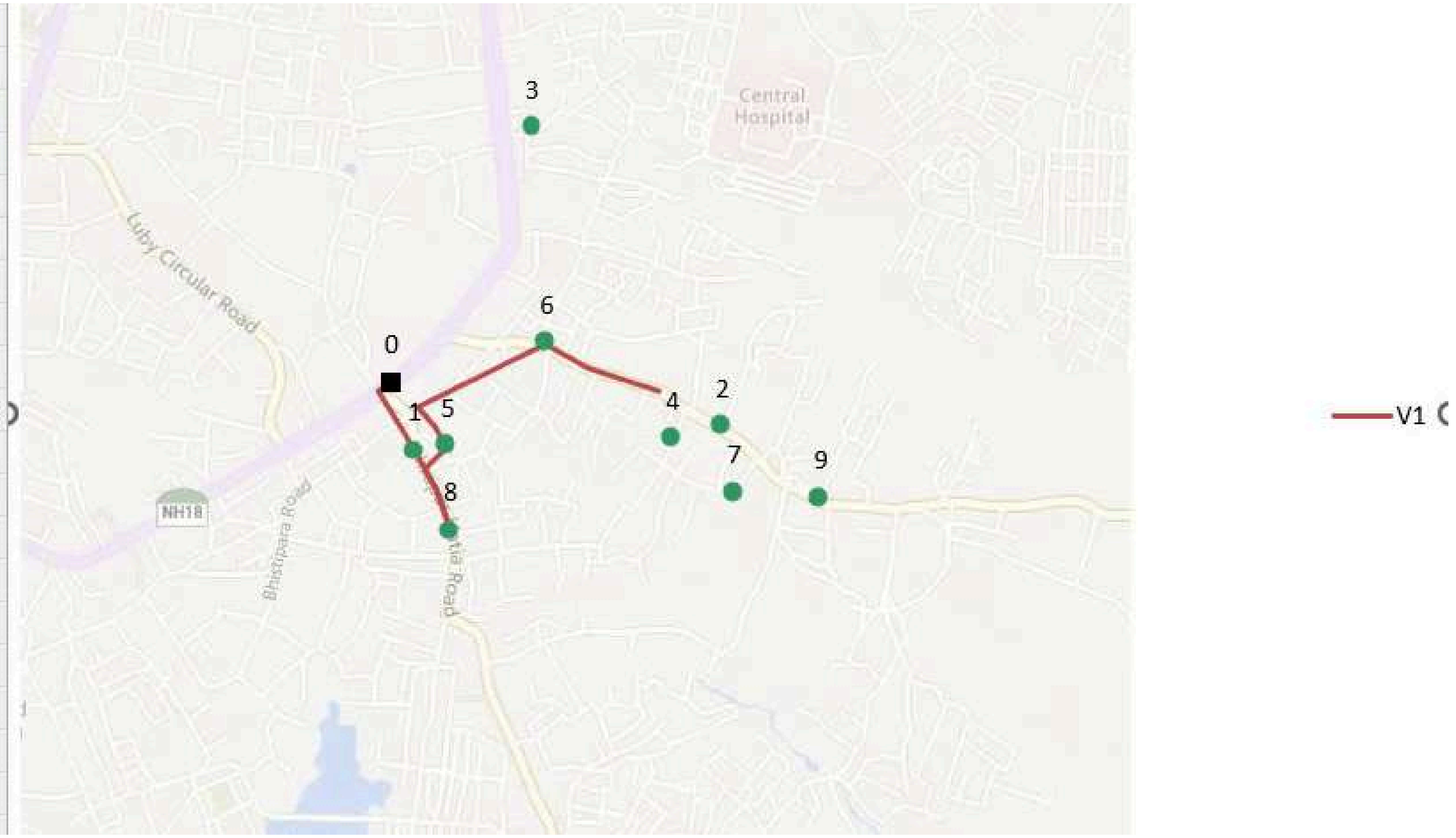
- The Vehicle Routing Problem (VRP) is a combinatorial optimization and integer programming problem aimed at determining the optimal set of routes for a fleet of vehicles to deliver goods to a set of customers from a central depot.
- VRP generalizes the Travelling Salesman Problem (TSP) and is often applied in logistics and transportation management scenarios.
- The primary objective of VRP is to minimize the total route cost, considering factors like distance traveled, time taken, or fuel consumption.
- VRP variants include capacity constraints, where vehicles have maximum carrying capacities, time windows specifying when each location must be visited, and minimizing the length of the longest single route among all vehicles.
- Determining the optimal solution for VRP is NP-hard, which means finding the most efficient solution becomes increasingly difficult as the problem size grows.
- Despite its computational complexity, VRP has direct applications in various industries, including retail, e-commerce, waste management, and public transportation.
- Vendors of VRP routing tools often claim significant cost savings ranging from 5% to 30%, making them valuable assets for businesses aiming to optimize their delivery operations.

COLLECTION ROUTES:

For Ward 30:

- **Total no. of Bins:** 29
- **Maximum no. of collection bins emptied per trip =** 10
- **No of trips in ward 30= 29/10 =** 3

Trip 01:



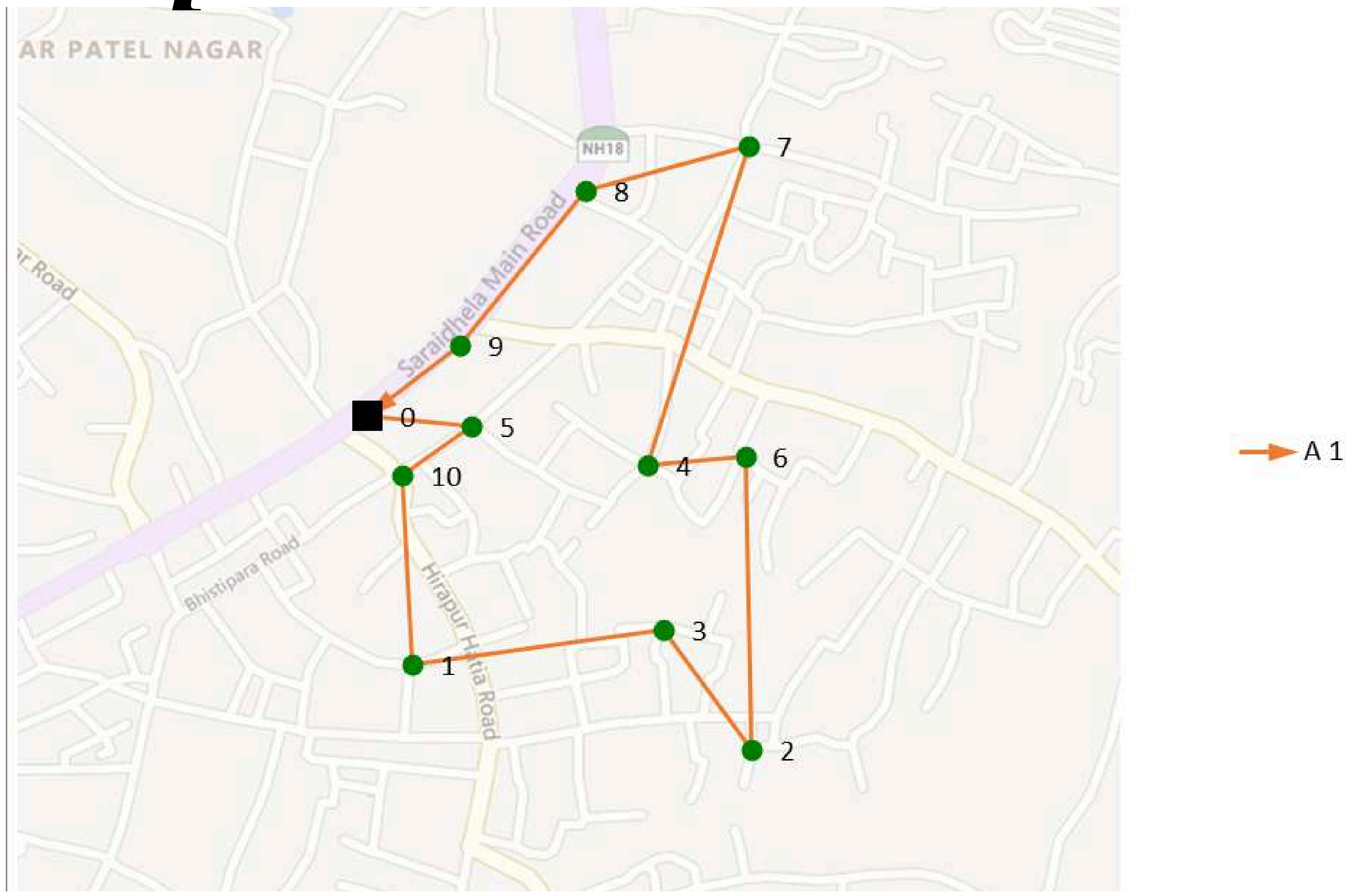
Location Name	Distance travelled
Depot	0.00
Bin 1	0.23
Bin 8	0.45
Bin 5	0.70
Bin 6	1.20
Bin 2	1.70
Bin 9	2.00
Bin 7	2.31
Bin 4	2.57
Bin 3	4.10
Depot	4.89

DISTANCE MATRIX

Collection path:

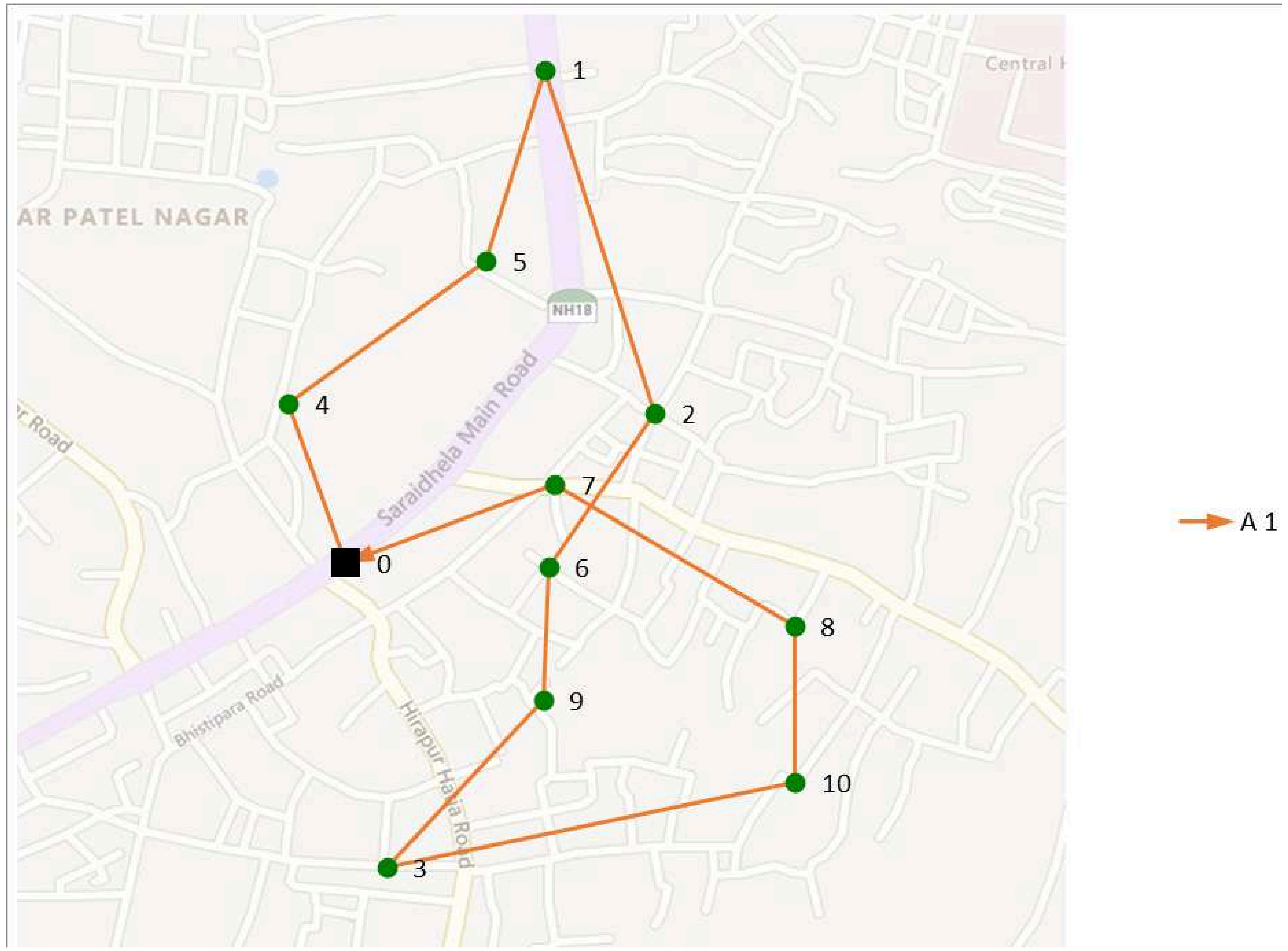
Depot->B1->B8->B5->B6->B2->B9->B7->B4->B3->Depot

Trip 02:



Collection path:
Depot -> B5->B10->B1->B3->B2->B6->B4->B7->B8->B9->Depot

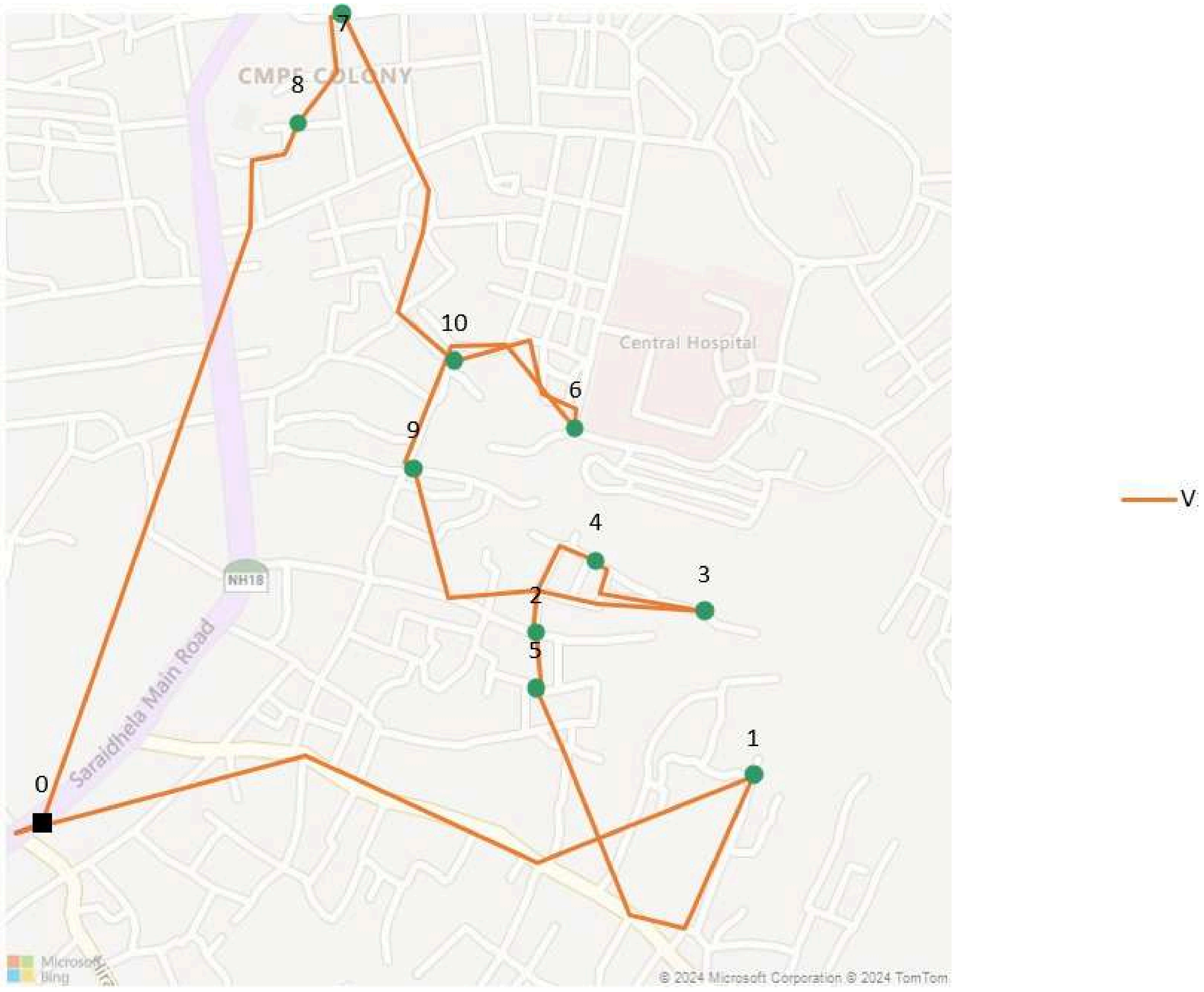
Trip 03:



Collection path:
Depot -> B4->B5->B1->B2->B6->B9->B3->B10->B8->B7->Depot

For Ward 26:

Trip 01:



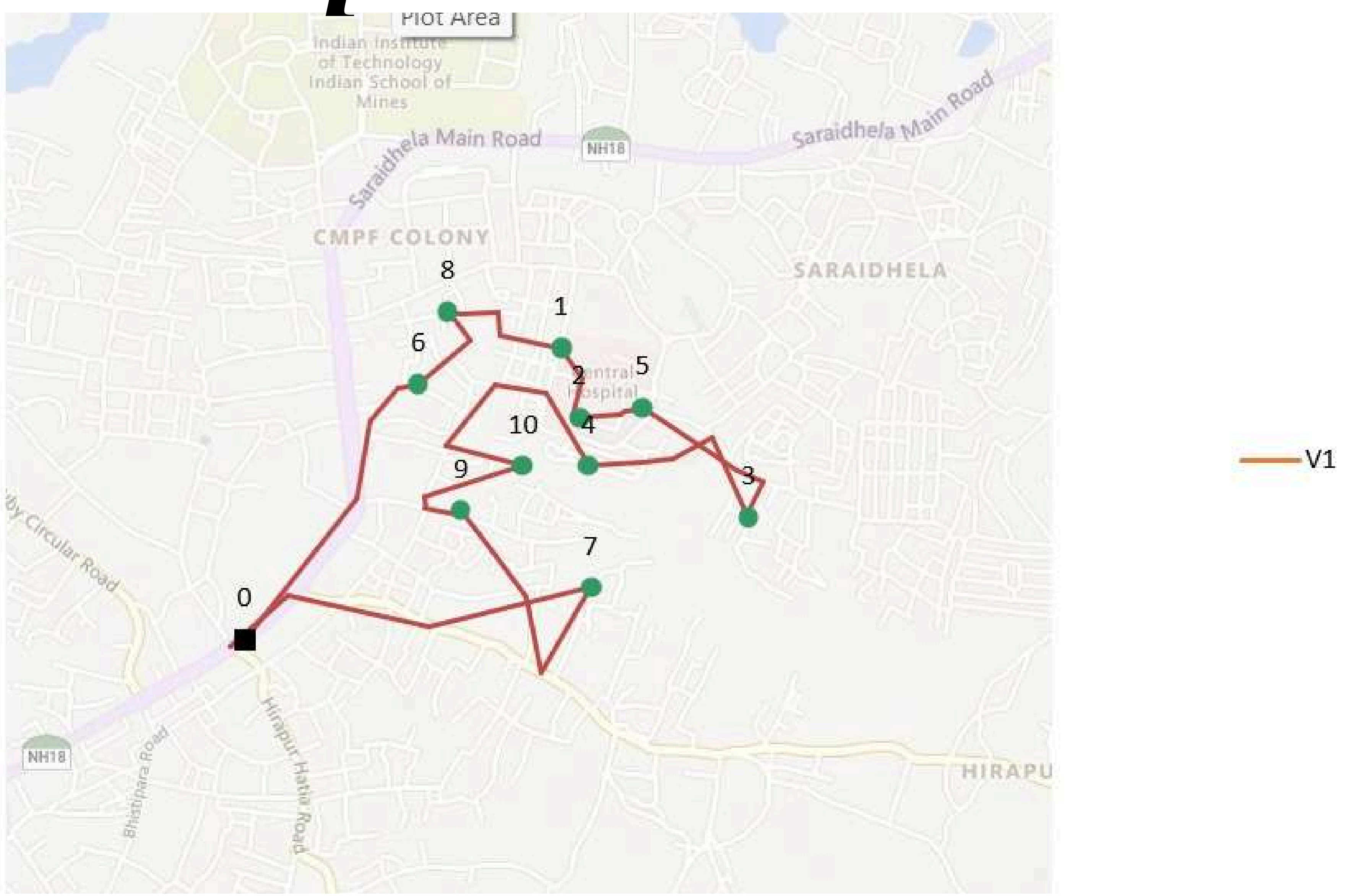
- **Total no. of Bins:** 29
- **Maximum no. of collection bins emptied per trip =** 10
- **No of trips in ward 26 = 29/10 =** 3

Collection path:

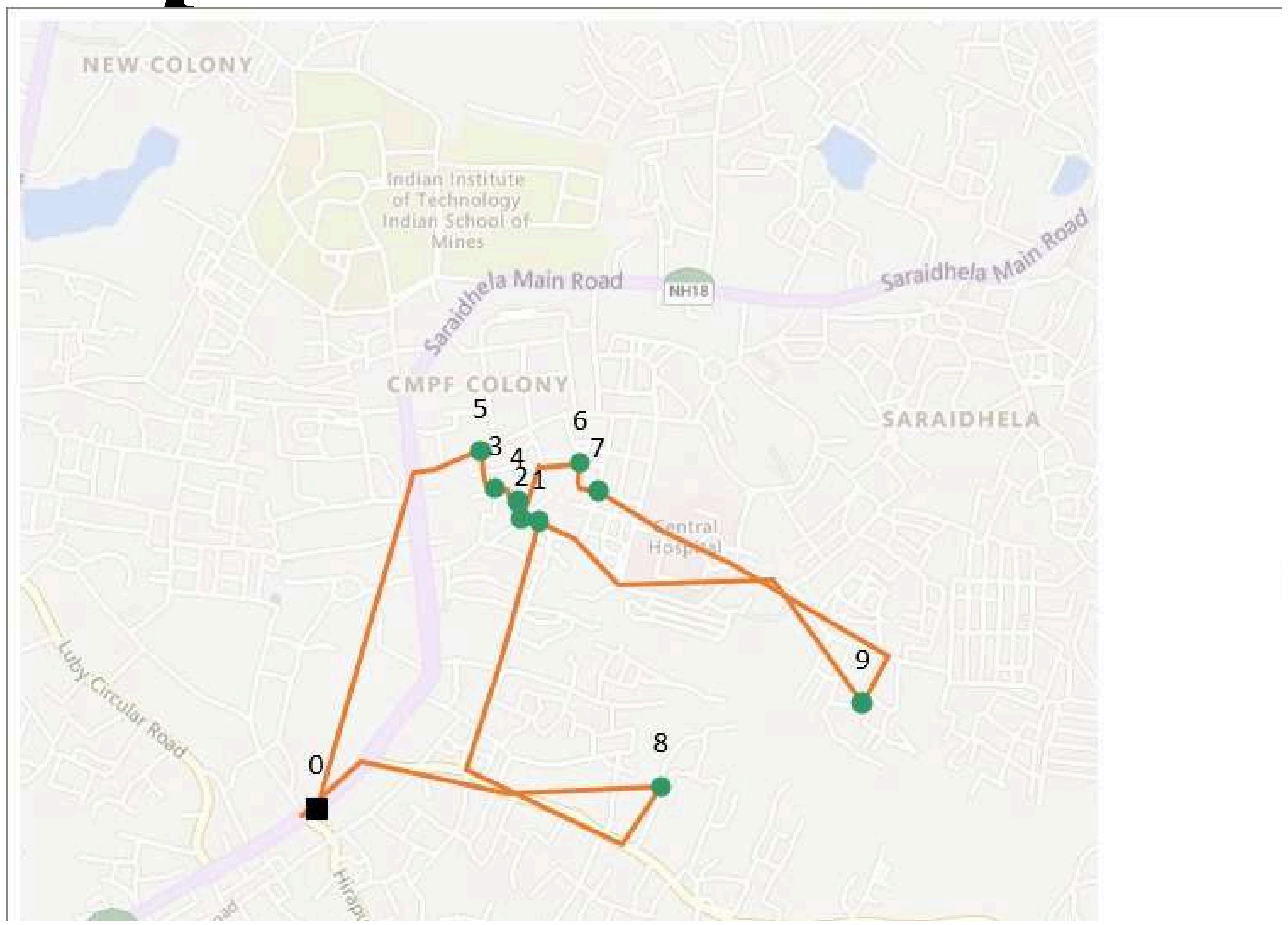
Depot->B1-> B5-> B2-> B4-> B3-> B9-> B6-> B10 ->B7->B8->Depot

^

Trip 02:



Trip 03:



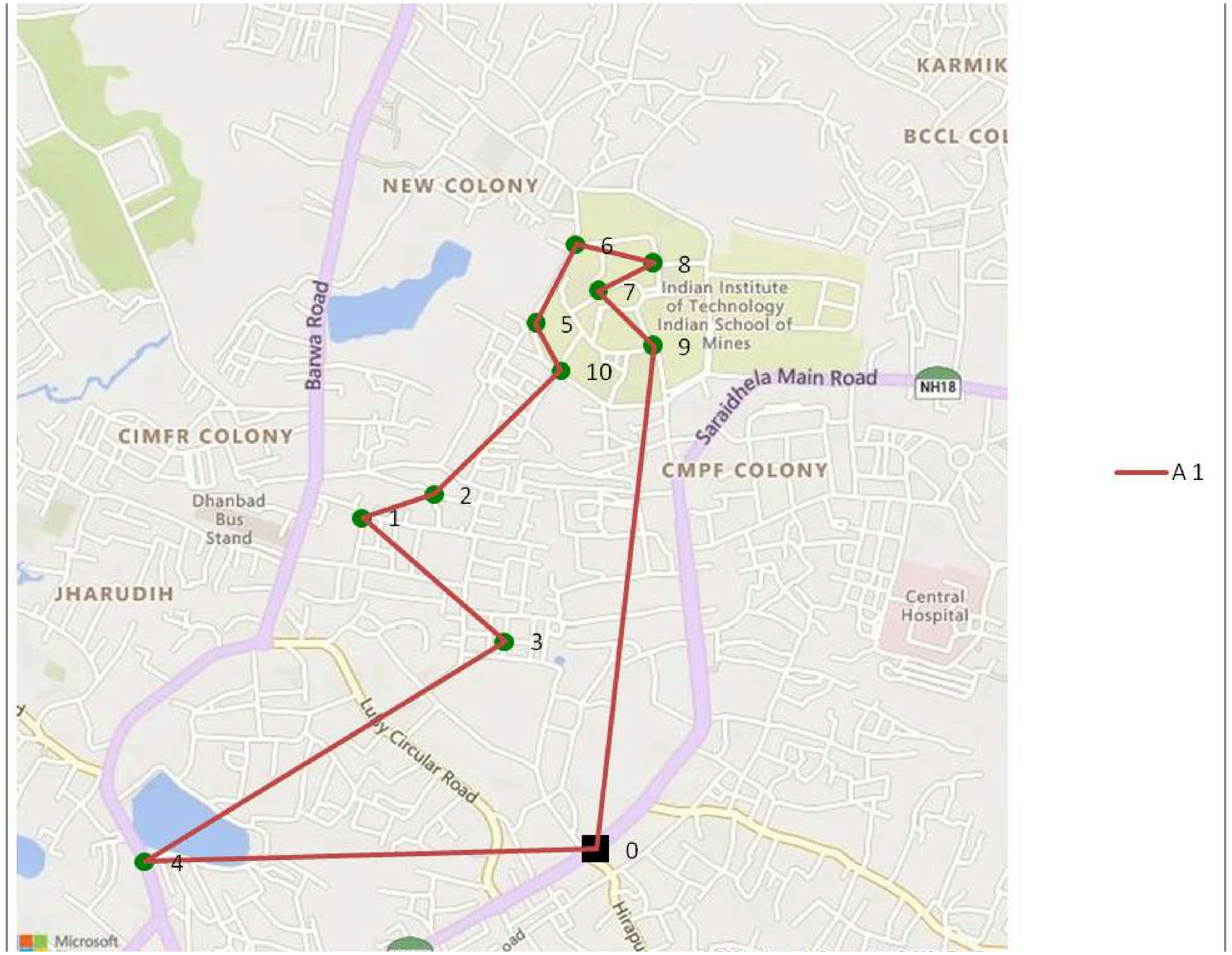
Collection path direction:
Depot->B17->B19->B20->B14->B13->B15->B12->B11->B18->B16->Depot

Collection path direction:
Depot->B28->B21->B29->B27->B26->B22->B24->B23->B25->Depot

For Ward 27:

Trip 01:

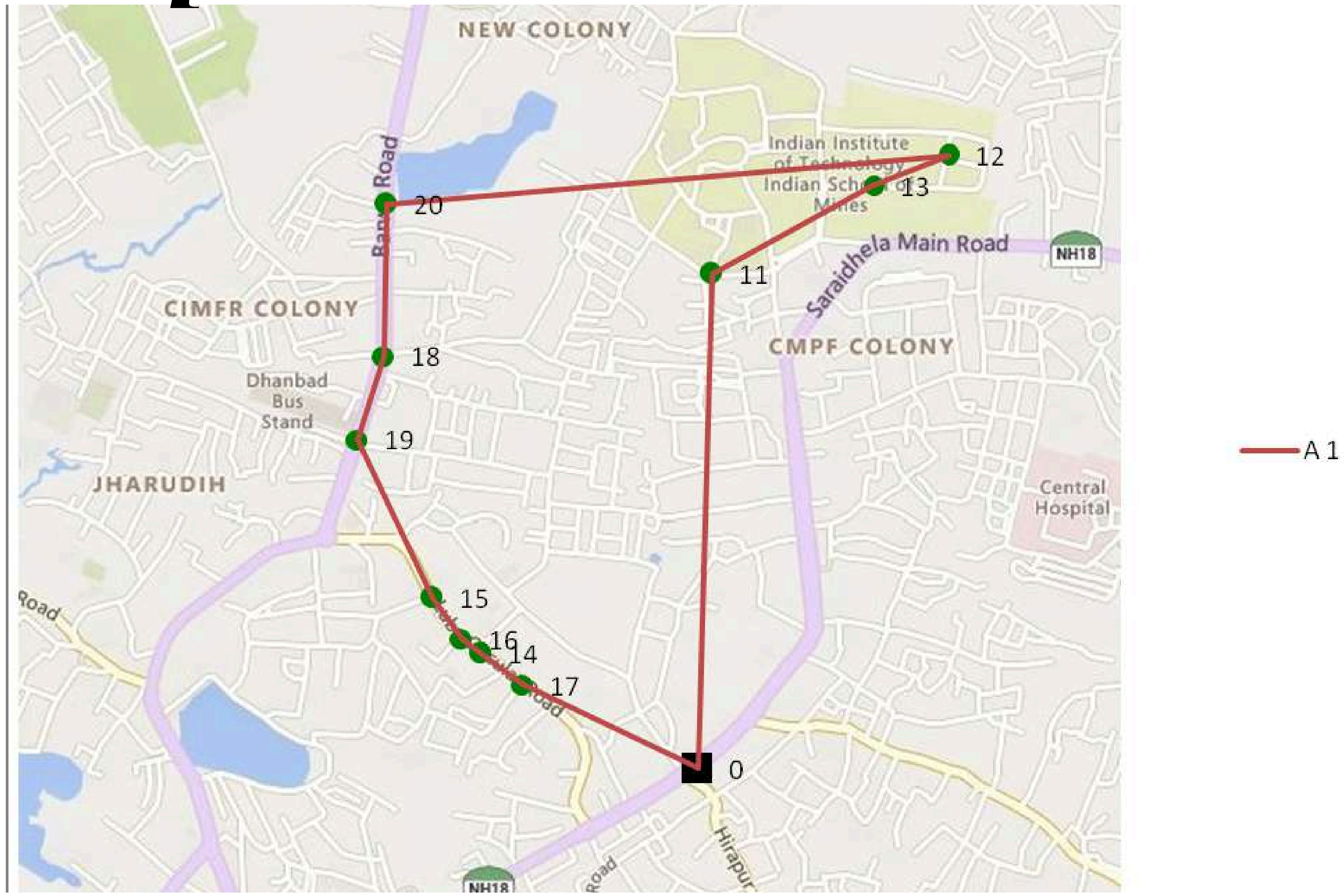
- **Total no. of Bins: 66**
- **Maximum no. of collection bins emptied per trip =** 10
- **No of trips in ward 26 = 66/10 =** 7



Collection path:

Depot->B9->B7->B8->B6->B5->B10->B2->B1->B3->B4->Depot

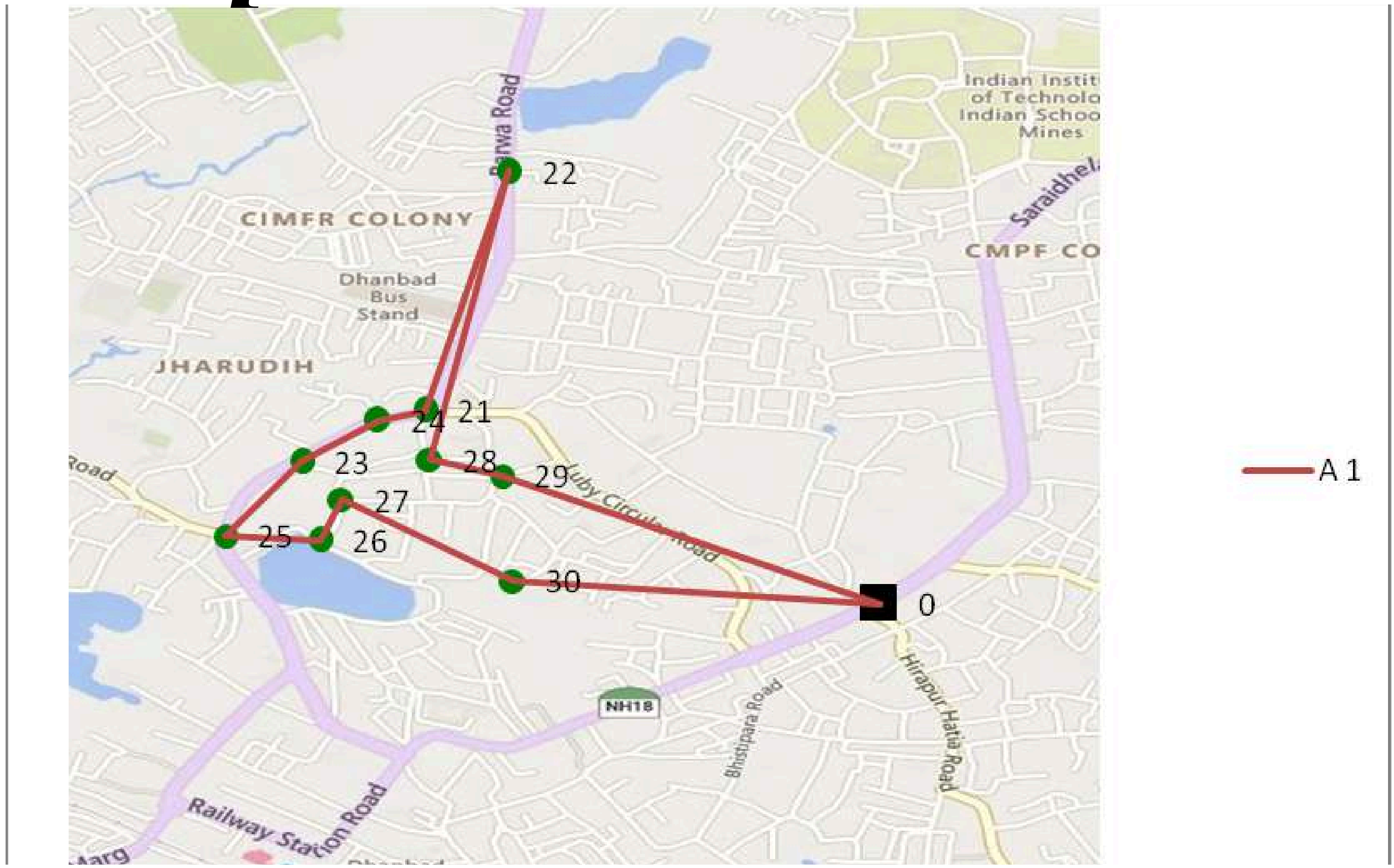
Trip 02:



Collection path direction:

Depot->B11->B13->B12->B20->B18->B19->B15->B16->B14->B17->Depot

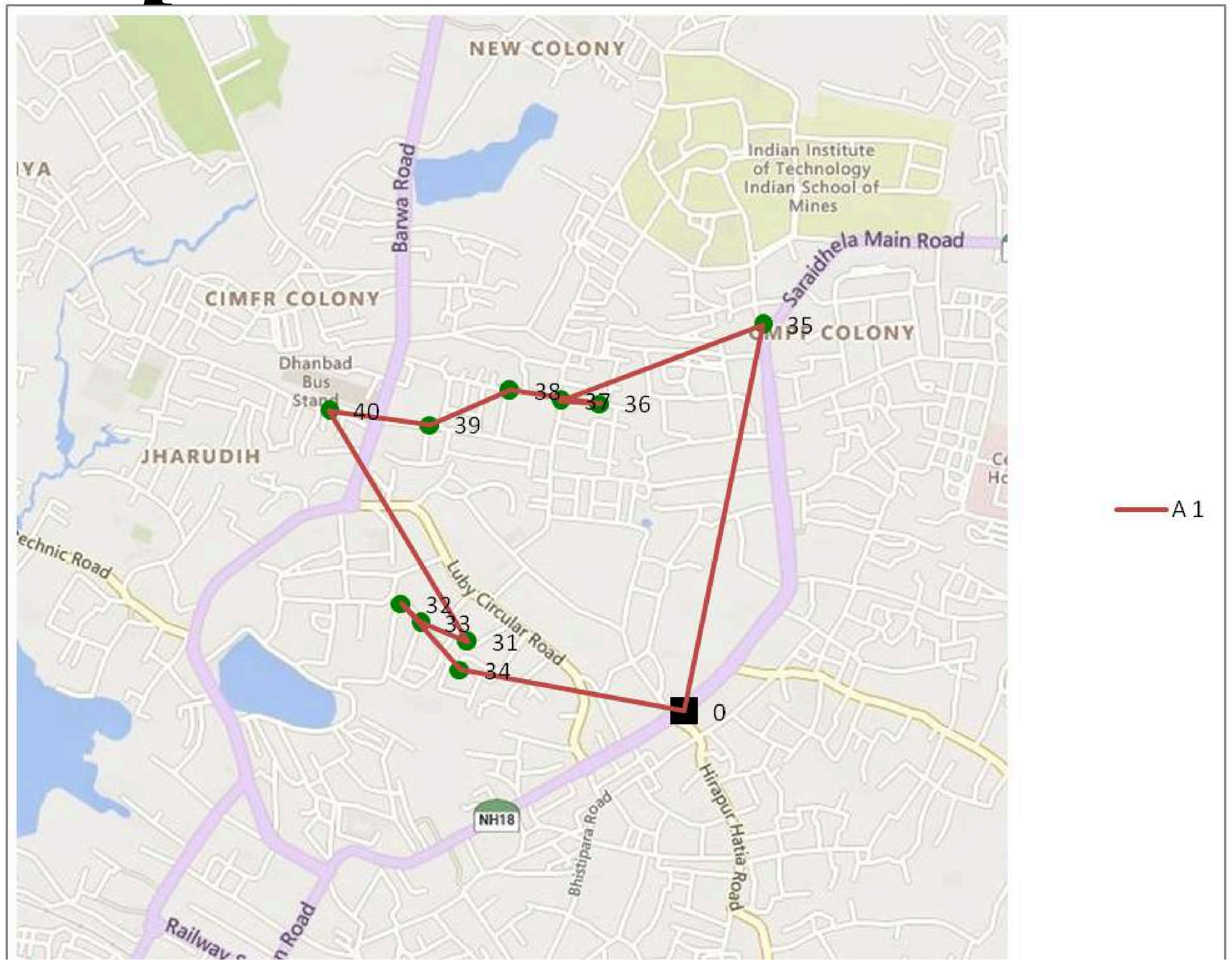
Trip 03:



Collection path direction:

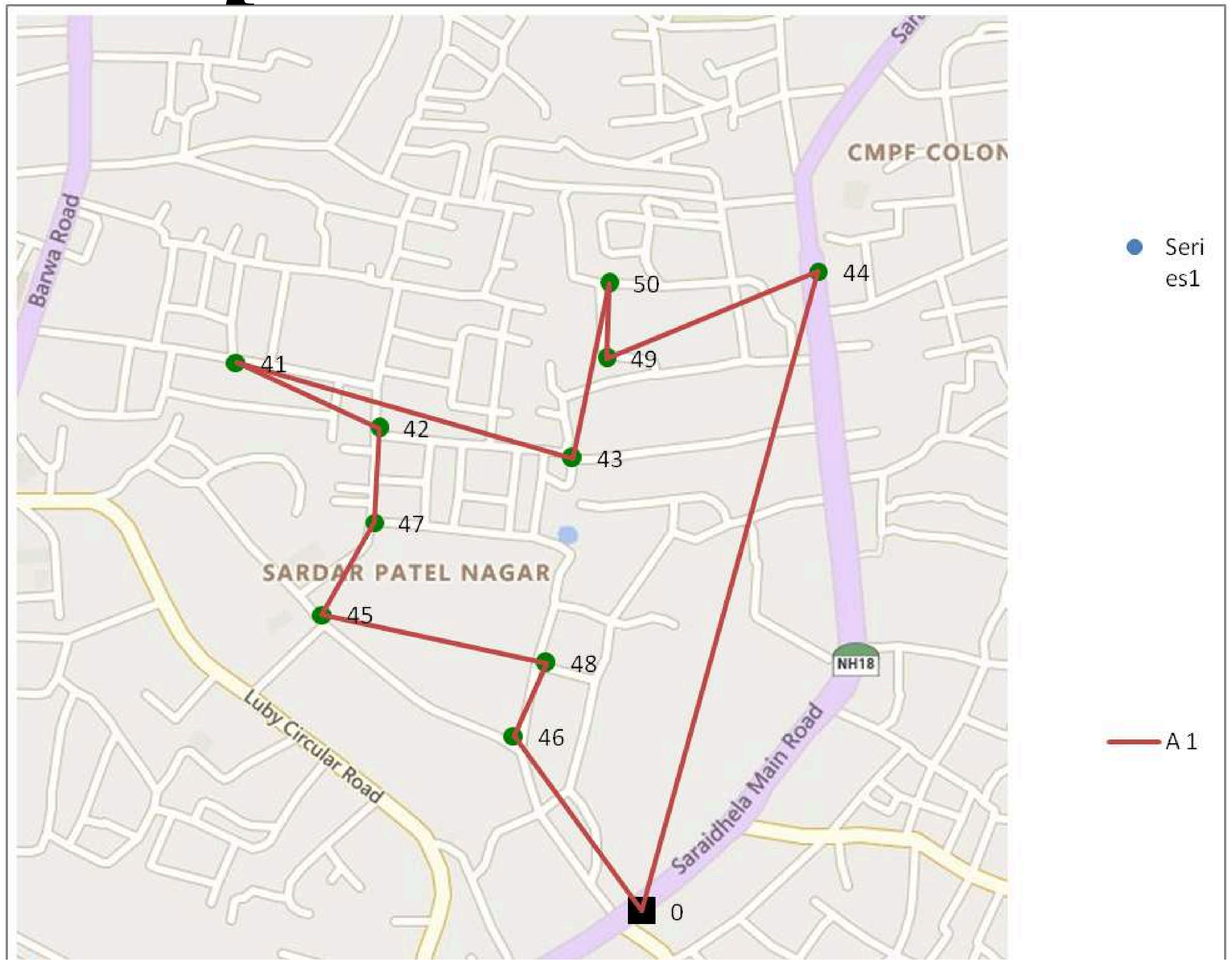
Depot->B30->B27->B26->B25->B23->B24->B21->B22->B28->B29->Depot

Trip 04:



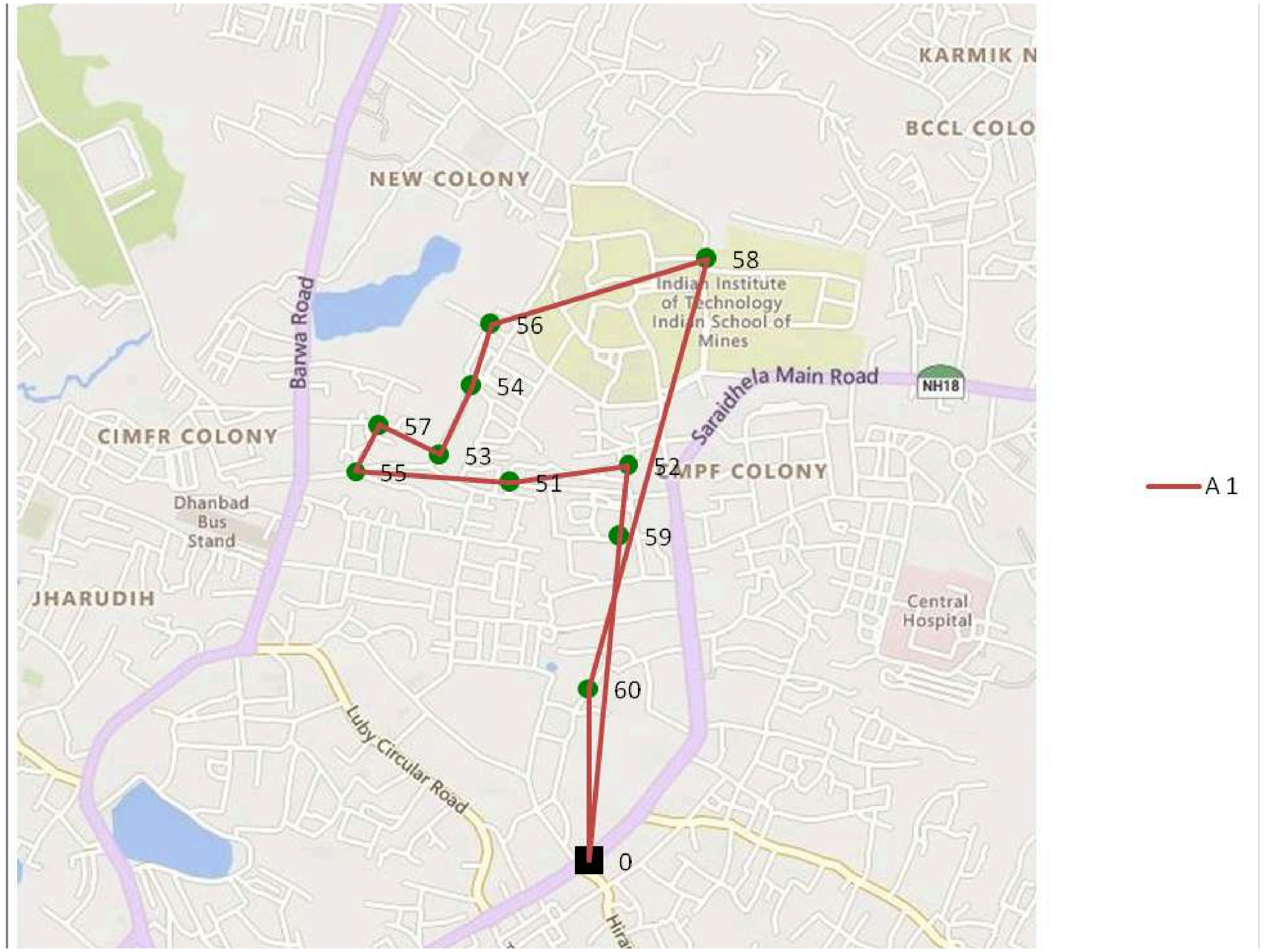
Collection path direction:
Depot->B34->B32->B33->B31->B40->B39->B38->B36->B37->B35->Depot

Trip 05:



Collection path direction:
Depot->B46->B48->B45->B47->B42->B41->B43->B50->B49->B44->Depot

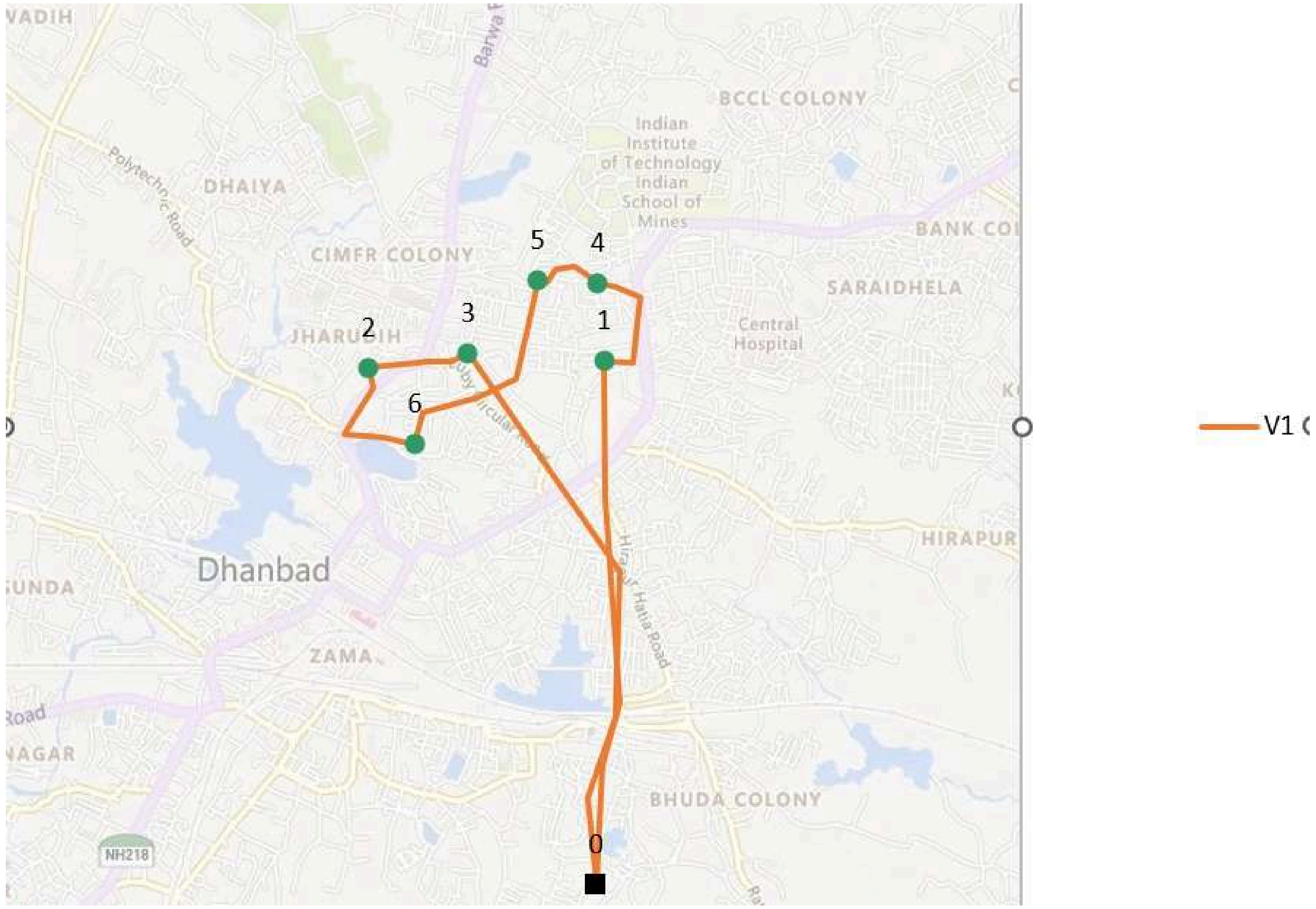
Trip 06:



Collection path direction:

Depot->B60-B58->B56->B54->B53->B57->B55->B51->B52->B59->Depot

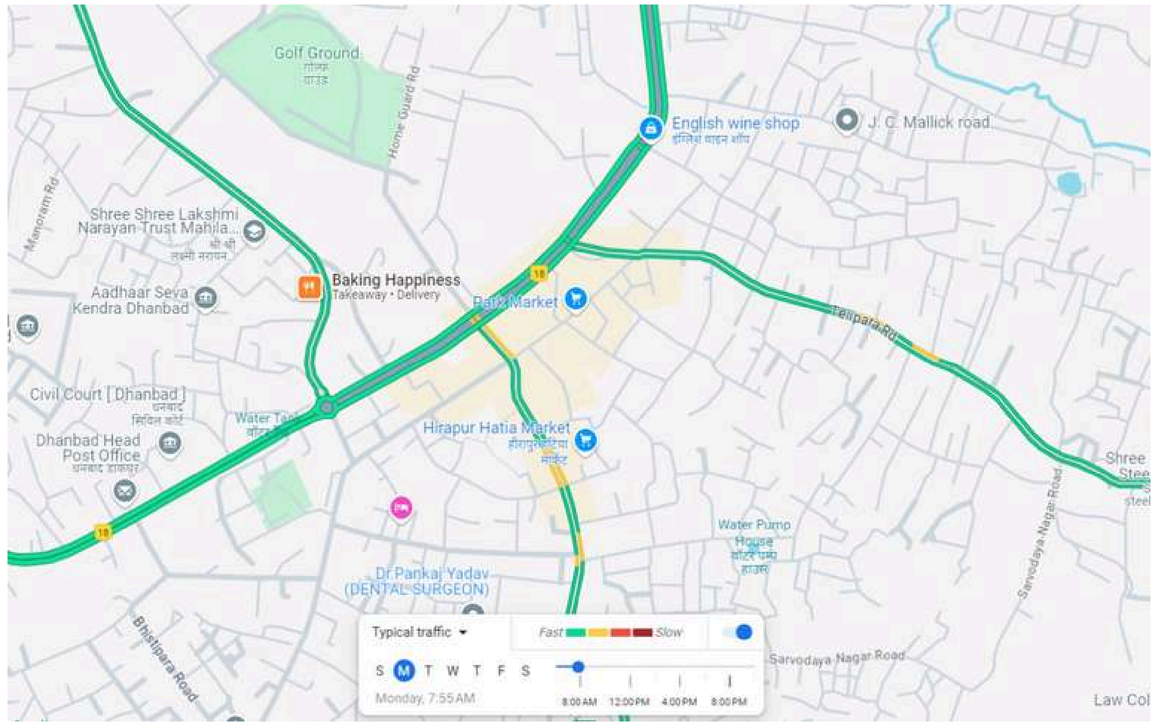
Trip 07:



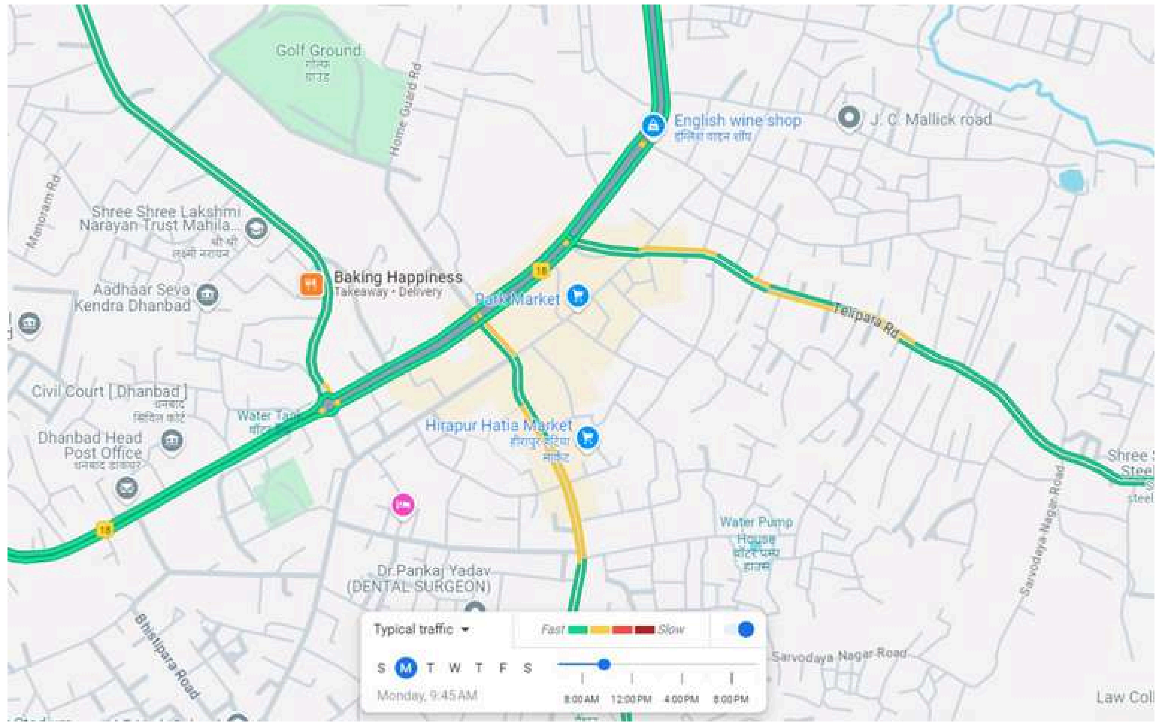
Collection path direction:

Depot->B63->B62->B66->B65->B64->B61->Depot

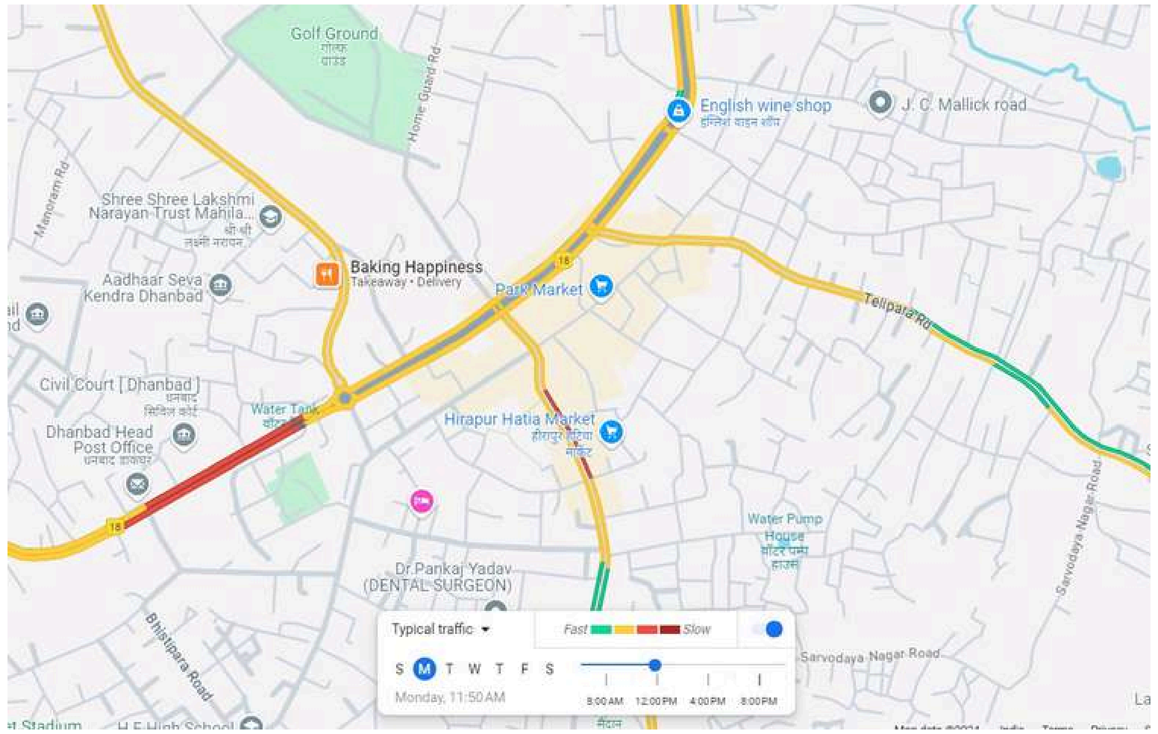
SUITABILITY OF TIME OF COLLECTION WITH RESPECT TO TRAFFIC



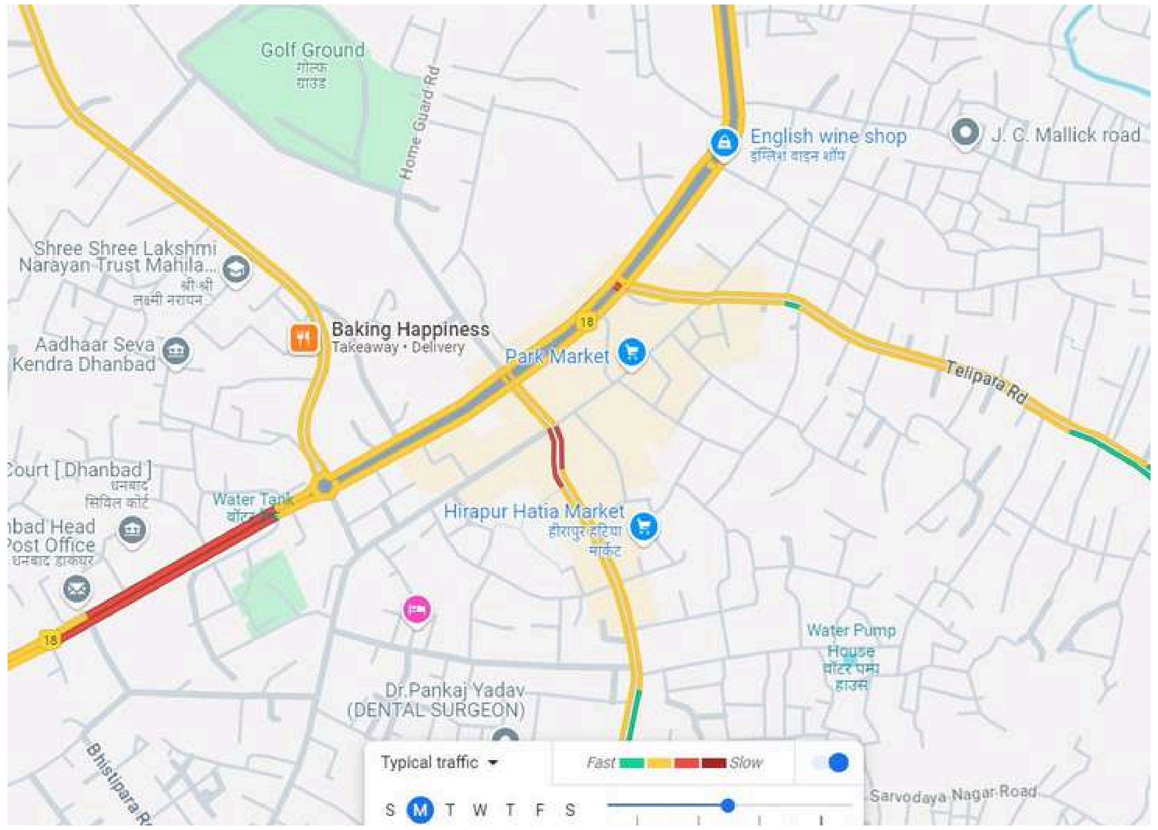
AT 8 A.M.



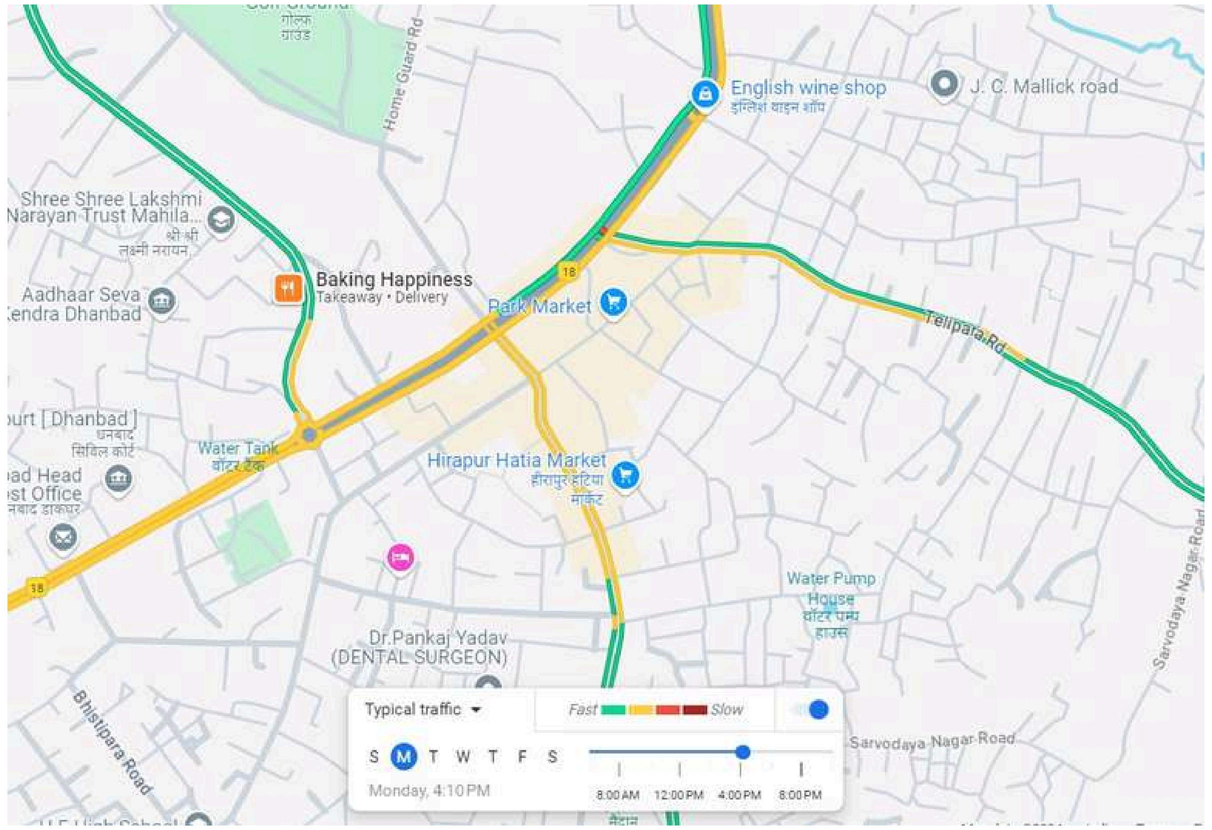
AT 10 A.M.



AT 12 NOON



AT 2 P.M.



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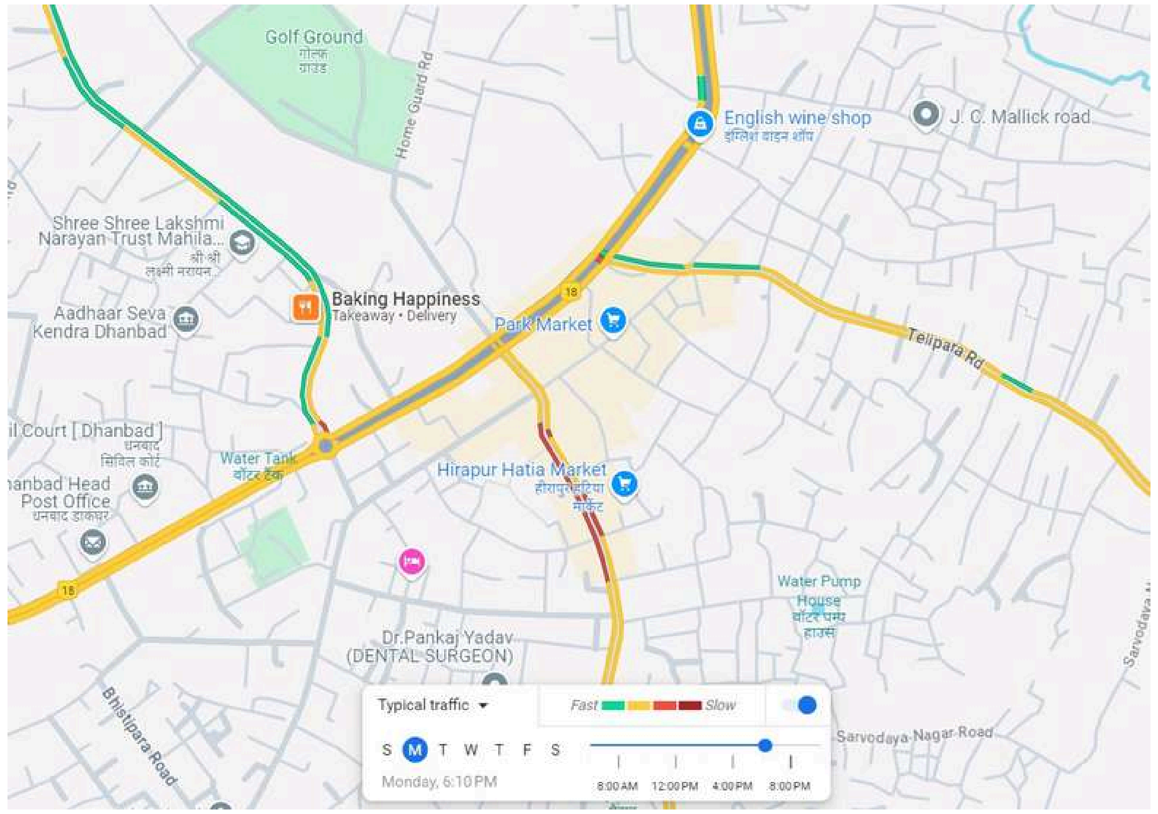


AT 7 P.M.

SUITABILITY OF TIME OF COLLECTION WITH RESPECT TO TRAFFIC

AFTER THE ANALYSIS OF THE TRAFFIC DATA IT WAS FOUND THAT THE TIME OF COLLECTION BY SOLID WASTE COLLECTION TRUCKS IS FAVOURABLE TO BE FROM 6 A.M TO 10 A.M FOR THE FIRST SHIFT & 7 P.M TO 11 P.M IN THE SECOND SHIFT

Results of Optimised Routing

VEHICLE	TRIP:01			TRIP:02			TRIP:03			TRIP:04		
	Time (Hr)	No. of bins	Distance (Km)	Time (Hr)	No. of bins	Distance (Km)	Time(Hr)	No. of bins	Distance (Km)	Time(Hr)	No. of bins	Distance (Km)
01	1.022	10	6.61	1.029	10	6.86	0.95	9	7	1.081	10	8.7
02	1.036	10	7.12	0.956	10	4.32	1.021	10	6.6	1.214	10	13.33

VEHICLE	TRIP:05			TRIP:06			TRIP:07			TOTAL	
	Time (Hr)	No. of bins	Distance(Km)	Time (Hr)	No. of bins	Distance(Km)	Time(Hr)	No. of bins	Distance (Km)	Time(Hr)	Distance (Km)
01	1.040	10	7.26	1.021	10	6.58				6.145	43.01
02	0.601	6	3.56	0.980	10	5.15	0.889	9	4.89	6.701	44.97

Data for Collection vehicle:

SPEED OF EACH COLLECTION VEHICLE	35 KM/HR
COST OF FUEL (DIESEL)RS/ L	92.51
HOURLY SALARY OF CREW MEN	153 RS/HR
FUEL CONSUMPTION PER KM	1.6 L/ KM
NO. CREW MEN PER TRUCK	1
COLLECTION FREQUENCY	2DAY/WEEK

Cost analysis for Collection vehicle:

TOTAL TIME(HR/DAY)	(6.65+7.20)= 13.85
TOTAL DISTANCE(KM/DAY)	(43.01+44.97)=87.98
COST OF FUEL (RS/DAY)	(1.6LDIESEL/KM)*(87.98KM/DAY)*(92.51 RS/DIESEL)= 13022.44 RS
COST OF CREW (RS/DAY)	(13.85 HR)*(153 RS/HR)= 2118.59RS
TOTAL COST/DAY	(13022.44+2118.59= 15141.05
COST OF FUEL (RS/WEEK)	13022.44*2=26044.88
COST OF CREW (RS/WEEK)	2118.59*2=4237.18
TOTAL COST/WEEK	15141.05*2 = 30282.09

Data for Dumper Tipper

NO. OF DUMPER TIPPER	**1**
DUMPER TIPPER SPEED (KM/HR)	**47**
HOURLY SALARY OF CREW MEN	**153 RS/HR**
COLLECTION FREQUENCY (DAY/WEEK)	**2**
DISTANCE FROM COMPACTOR STATION TO LAND FILL	**3.416KM**
VOLUME OF DUMPER TIPPER, M3	**25**
FUEL CONSUMPTION PER KM	**2.3 L/KM**
NO. OF CREW TAKEN BY DUMPER TIPPER	**1**
COMPACTOR VOLUME REDUCTION	**15%**

Cost analysis for Dumper Tipper

VOLUME AFTER COMPACTION (M3/WEEK)	(365.61*0.15)=310.25
TOTAL DISTANCE PER DAY	(6*2*3.416)=40.992
NO OF TRIP PER WEEK	(310.25/25)= 12 TRIP/WEEK
NO OF TRIP PER WEEK	6 TRIP/DAY
TOTAL TIME PER DAY(HR/DAY)	(((3.416/47)*12)+0.5+((20/60)*0.5))=3.3721
COST OF FUEL (RS/DAY)	40.992KM/DAY*2.3L/KM*92.51RS/L = 8721.99
COST OF CREW (RS /DAY)	153RS/H*3.3721H/DAY = 515.94
TOTAL COST PER DAY	8721.99+515.94 = 9237.93

Cost for Dumper Tipper per week

COST OF FUEL(RS/WEEK)	8721.99*2=17443.98
COST OF CREW (RS/WEEK)	515.94*2=1031.88
TOTAL COST/WEEK(RS/WEEK)	18475.87

Total Cost of Optimised Routing

TOTAL COST OF WHOLE ROUTE PER DAY	(15141.05+9237.93)=24378.98
TOTAL COST OF WHOLE ROUTE PER WEEK	24378.98 RS PER DAY * 2DAY/WEEK =48757.96
MAXIMUM WORKING HOUR FOR EACH TRUCK ON COLLECTION ROUTE (HR/DAY)	7.201

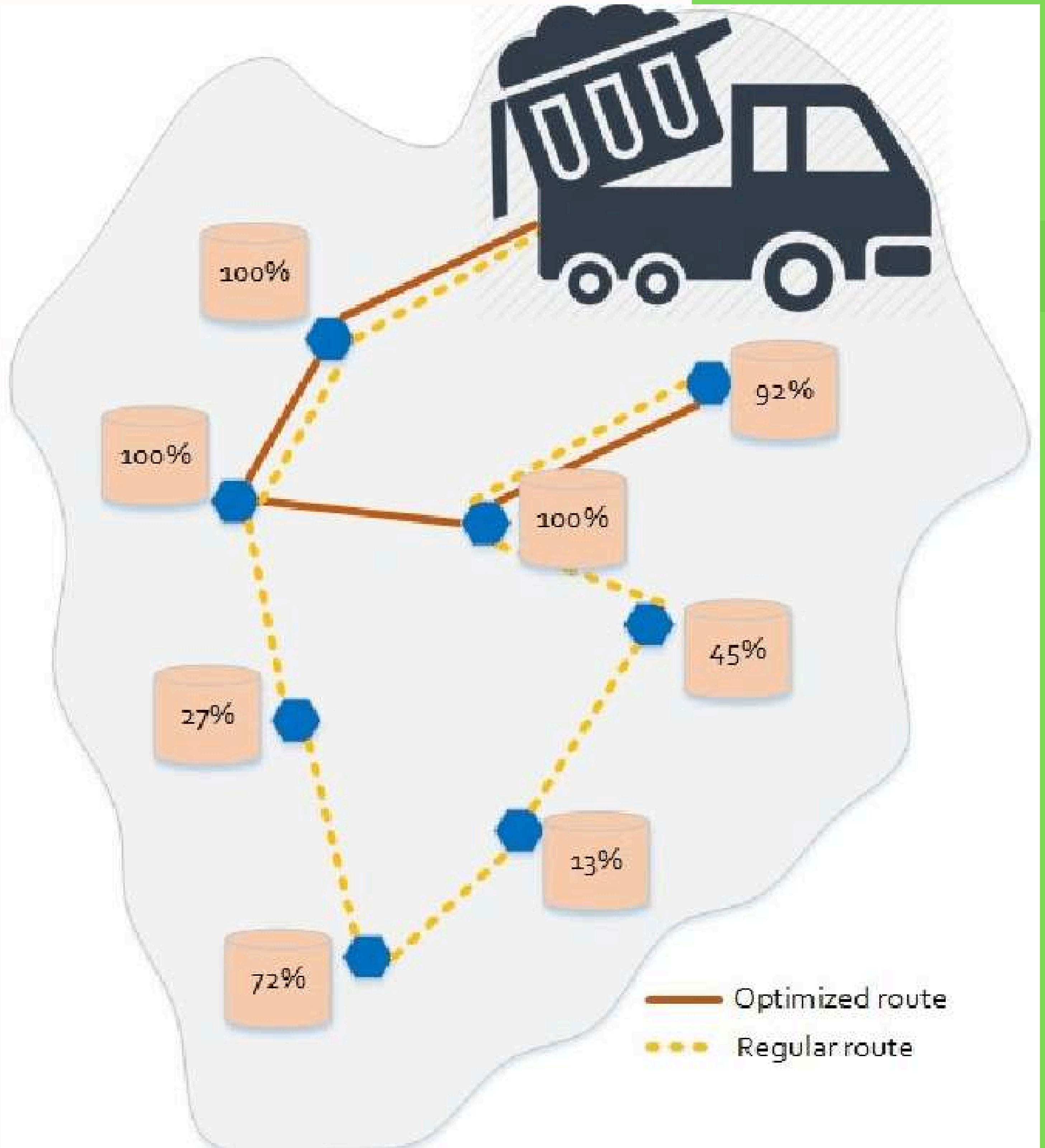
CONCLUSION:

- At presently, Dhanbad Municipal Corporation is solely responsible for the collection and disposal of solid waste. Presently, the systems applied by the municipal authorities are unscientific, outdated and inefficient. Solid waste is littered wherever possible. The municipal authority does not have adequate provisions to deal effectively with the ever-growing problem of solid waste management.
- The study will be helpful for providing an organised and optimum solid waste management operation in cities where no, or limited, facilities are available at present. This study will help the policy makers to formulate solid waste management strategies. Keeping the similar base work, there are many future scopes in altering the options for further improvements

FURTHER SCOPE

- **Optimising routes using slope through triangular networking involves breaking down terrain into triangles, calculating slope within each triangle, and using algorithms to find the most efficient paths.**

- **Ground verification as it ensures proposed routes align with actual terrain conditions, facilitating safe and practical navigation.**



REFERENCES:

- https://journals.sagepub.com/doi/full/10.1177/0734242X16649679?casa_token=f2Zhqau63FQAAAAA%3AHNn-BDfipsN8I-xMAf9oyGjvu-8pYa0HOJl7egTwKf6Oj_x12fmzbtD8AJy6VVVFG7FrYGkMcy5nYg
- https://journals.sagepub.com/doi/epub/10.1177/0734242X14554644j
- https://www.routific.com/blog/travelling-salesman-problem
- http://opensolver.org/
- https://www.semanticscholar.org/paper/Location%E2%80%93allocation-of-bins-in-urban-solid-waste-a-Rathore-Sarmah/4b2271523230561f91d44b57e475cd873235fcaa
- http://www.census2011.co.in/
- http://sedac.ciesin.columbia.edu/
- http://www.openstreetmap.org/