Design and Mapping of Underground Sewerage Network in GIS, a Case Study of Islampur Town

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Abstract: ***The infrastructure of a city, mainly the water supply and sewerage system are vital for urbanization, wastewater generated from urban area is a result of domestic and industrial activities, and domestic wastewater contains organic and inorganic matter in suspended, colloidal and dissolved form. The municipal wastewater management is a critical issue in an urban environment. If the municipal wastewater is not properly collected, treated and disposed, the related effects pose serious threat to the environment. Many small cities do not have proper drainage system, Islampur, Dist. Sangli; Maharashtra, India is one such. As on date all the domestic waste water is either send in open drain or in open area around the houses. This is resulting in hygienic problems and to cater for; Municipal Corporation of Islampur town has come up with underground sewage collection plan. This study aim at designing collection system for Islampur town, the work undertaken uses, GIS as a tool for mapping the collection system (primary and secondary) in order to facilitate further works.***

Keywords: Wastewater, suspended, colloidal, municipal, underground, hygienic, environment, sewage, network and GIS.

1. Introduction

A sewerage system is composed of various sewer lines terminating at the junction of a large sewer line. The large sewer line also terminates at the junction of a still larger sewer line. Finally, the main sewer line terminates at the outfall. Thus, a sewerage system can be viewed as a set of sewer lines collecting discharges at their nodal points and emptying into another set of sewer lines.

In this paper attention is focused on the design of a sewer line and mapping of sewer network in GIS tool, with also a location of Sewage Treatment Plant (STP). GIS has been regarded and proven as an efficient and powerful tool in the wastewater industry. According to American Water Works Association, 90% of water agencies are now partially using GIS to assist their daily operation [9].

Islampur town is an important central town in the vast rural hinterlands of Walwa Taluka in Sangli District. The town is situated on **17^{0}20' N** Latitude and **74^{0}20' E** Longitude. It is located 40 Kms to the North-West of Sangli (a district headquarter), 29 Kms to the South-East of Karad and 48 Kms to the North of Kolhapur. The town situated at a distance of about 7.5 Kms from the right bank of river Krishna.

There is no underground sewerage scheme in Islampur town. All domestic wastewater generated in the basin is discharged through open channels in to the nallas. This open surface drain system has got many problems such as very easy for foreign matter to have entry in the open drains which hampers. The flow and creates stagnation of the sewage, creates odor nuisance, creates mosquito and files problems and deterioration of river water quality.

2. Previous Research Works

1) **Urban Development on Sewerage and Sewage Treatment (1993) by CPHEEO manual.**
In this manual provides objectives, planning of sewerage system, also show design consideration, population forecast, design criteria, parameters. It provides standard assumptions, tables, and design period for various systems. It provides design of sewer, type of pipe materials, velocity flow and also provides STP process, design and related standard considerations.
2) **Swamee, P. K. (2001). "Design of Sewer Line". *Journal Environmental Engineering.***
In this paper provides the major portion of the cost of a wastewater system. In the design of a sewerage system the sewer line is the basic unit occurring repeatedly in the design process. Any savings during the design of this unit will affect the overall cost of the sewerage system. The literature shows that the present status of sewer line designs algorithms use linear programming and dynamic programming. This literature provides the various formulas such as resistance equation, diameter equation, depth equation, maximum velocity and discharge equation and optimization of the equations. Remedial measures are given on minimum cover, self cleansing velocity. In the description of algorithm, the procedure is stepwise given, design example and its solution. An algorithm for optimal design of a sewer line has been described. The resistance equation was used for elimination of design variables.
3) **Charalambous, C. and Elimarn, A. A. (1990), "Heuristic Design of Sewer Networks". *Journal Environmental Engineering.***
This paper is presented a Heuristic approaches for the design of sewer networks and the use of standard diameters. This Heuristic provides good and logical (rather than optimal) designs of sewer networks. The necessary and sufficient conditions to determine positions of a lift station are presented in a theorem.

Based on this theoretical result, a heuristic design algorithm, using either Manning or the modified Hazen-Williams hydraulic equation, is developed. The proposed heuristic design algorithm takes into account all the structural and hydraulic requirements. In this paper also gives the diagram of geometry of sewer line, shows the level of the pipe. The CPU time for designing sewer networks using the proposed heuristic is less than 10% of the time required for the optimization procedure. Such application indicates the effectiveness of the heuristic in rapidly providing "good" sewer network designs that are comparable to the optimal ones.

4) **Greene, R., Agbenowosi, N. and Loganathan, G. V. (1999). "GIS-based approach to sewer system design". *Journal Environmental Engineering.***
In this paper, planning and design of sewer networks, most decisions are spatially dependent because of the right-of-way considerations and the desire to have flow by gravity. The geographic information system- (GIS-) based approach takes advantage of the spatial analysis capability of GIS in combination with a sewer design program to develop an integrated procedure for the design of sewer systems. The program that was developed uses the user specified manholes' locations to generate the sewer network. The GIS is used to analyze the area's topography, surface features, and street network to delineate sub-watersheds, to locate pump stations, and to determine the path for the force main.

3. Objectives of Study

- Data collection required for design of domestic sewage collection system.
- Design of underground sewage collection system.
- Location of Sewage Treatment Plant (STP).
- Mapping sewage network using GIS.

4. Data Collection

The field data required for the design of the sewerage system such as details of exiting water supply, the ward wise and road wise population as per census, development plan etc. were collected from the Islampur Municipal council. Also the Geographical Information of the town is essential to find out the general slope of the ground which helps in finalizing the alignments and directions of the sewers.

Table 3.1: Sample Collected Data from Islampur Town

Sr. No.	*Way points*		*Ground Level in M*		*Length in M*	*Population*	*Type of Sewer Line (probable)*	*Remark*
	From	To						
1	1	2	574	573	37.9	0	Sub-main	Near Rajaram bapu Petrol Pump
2	2	3	573	574	31.6	0	Sub-main	
3	3	4	574	576	36.5	0	Sub-main	
4	4	5	576	575	33.1	15	Lateral	
5	4	6	576	572	31.1	10	Sub-main	
6	6	7	572	573	36.0	15	Sub-main	
7	1	7	574	573	31.2	15	Main	
8	7	8	573	577	29.0	10	Sub-main	
9	8	9	577	573	27.4	0	Lateral	
10	9	10	573	571	20.7	10	Lateral	
11	8	11	577	573	33.0	35	Sub-main	
12	11	12	573	576	30.2	15	Lateral	

5. Population Projection

1. General Considerations
Sewerage projects considering the overall economy and replacement criteria are recommended to design to meet the requirements over a 35 years period after its completion. The period between design and completion is taken as 1 year (i.e.) 2015 year. Hence it is required to forecast the population of the Islampur town for the next 35 years (viz.) 2050 year. Design population i.e. population after 35 years should take into consideration certain such as scope of future growth and development in industrial, commercial, educational, administration and social circles etc.

2. Population Details
Population data from year 1951 to 2011 is available as shown in figure no. 1 and table no. 1 with the help of this data; population forecasting has been done and three years such as 2015, 2030 and 2050 of population also shown in figure no. 1.

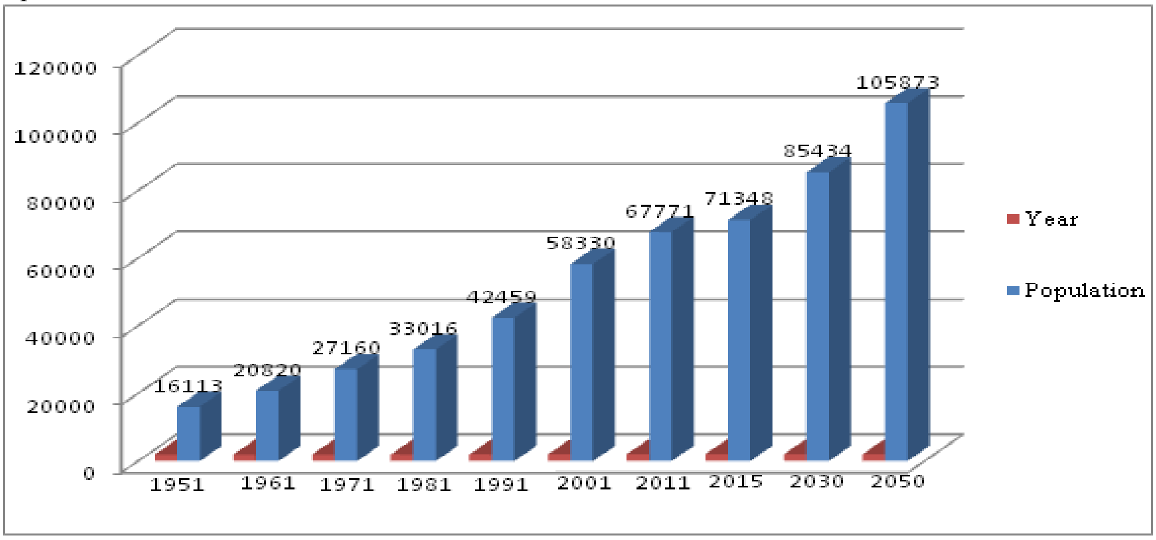


Figure 1: Population of Last Decades and Forecasting

The design period for the project is taken as 35 years. Considering 2015 as the year of commissioning of the scheme, the ultimate year for design of sewerage scheme is taken as 2050.

Table 1: Population of Islampur Town in the Previous Decades

Sr. No.	*Year*	*Population*	*Arithmetrical Increase*	*Incremental Increase*	*Rate of Growth*
1	1951	16113			
2	1961	20820	4707		0.292
3	1971	27160	6340	1633	0.305
4	1981	33016	5856	-484	0.216
5	1991	42459	9443	3587	0.286
6	2001	58330	15871	6428	0.374
7	2011	67771	9441	-6430	0.162
Total =		**265669**	**51658**	**4734**	**1.634**
Average =		**37953**	**8610**	**947**	**0.272**

(Ref.: Development Plan of Municipal Council of Islampur Town)

6. Methods of Population Forecasting

There are many methods for the population forecasting suitable for the town. From that some methods are given below:

1. Arithmetical Increase Method

In this method, the average increase of population per decade is calculated from the past records and added to the present population to find out population in the next decades. This method gives low value and is suitable for well settled and established communities. Formulae of this method as below:

$$P_n = P_1 + n*X$$

Where,
P_n = Population in the n^{th} Decades
P_1 = Population in the latest Decades
n = No. of Decades
X = Avg. Arithmetical Increase (from table no. 1)

Sample Calculation:
Data:
Year = 2015, P_1 = 67771, n = 0.4, X = 8610 and P_n =?
P_n = 67771 + 0.4* 8610
P_n = **71215** …… *(i)*

2. Incremental Increase Method

In this method the increment in arithmetical increase is determined from the past decades and the average of that increment is added to the average increase. This method increases the figures obtained by the arithmetical increase method. Formulae of this method as below:

$$P_n = P_1 + n*X + n*(n+1)*(Y/2)$$

Where,
P_n = Population in the n^{th} Decades
P_1 = Population in the latest Decades
n = No. of Decades
X = Avg. Arithmetical Increase (from table no. 1)
Y = Avg. Incremental Increase (from table no. 1)

Sample Calculation:
Data:
Year = 2015, P_1 = 67771, n = 0.4, X = 8610, Y = 947 and P_n =?
P_n = 67771 + 0.4* 8610 + 0.4*(0.4+1)*(947/2)

P_n = **71480** …… *(ii)*

3. Geometric Progression Method

In this method the percentage increase is assumed to be the rate of growth and the average of the percentage increase is used to find out future increment in population. This extension has to be done carefully and it requires vast experience and good judgment. This method gives much higher value and mostly applicable for growing towns and cities having vast scope for expansion. Formulae of this method as below:

$$P_n = P_1 * (1 + Z)^n$$

Where,
P_n = Population in the n^{th} Decades
P_1 = Population in the latest Decades
n = No. of Decades
Z = Geometric Mean (from table no. 1)

Sample Calculation:
Data:
Year = 2015, P_1 = 67771, n = 0.4, Z = 0.272 and P_n =?
P_n = $67771*(1+0.272)^{0.4}$
P_n = **74625** …… *(iii)*

Take the average of these three answers as below manners:
Avg.1 = (*i + ii) / 2* = (71215 + 71480) / 2 = 71348
Avg.2 = (*i + iii) / 2* = (71215 + 74625) / 2 = 72920
Avg.1 = (*ii + iii) / 2* = (71480 + 74625) / 2 = 73052

Select a minimum value ***i.e.*** **P_{2015} = 71348** *(see also in figure no 1)* of these three averages and same calculations of remaining years.

7. Design of Sewer Line

1. Components

The Sewerage system consists mainly of:-

- Collection system (sewer, sewer appurtenances
- Conveyance system (pumping station, pumping main etc.)
- Sewage Treatment Plant (STP)

2. Planning

- **Objective**
  The objective of a public waste water collection and disposal system is to ensure that sewage or excreta and sullage discharged from communities is properly collected, transported, treated to the required degree and finally disposed of without causing any health or environmental problems.

- **Need for planning**
  Planning is required at different levels; national, state, regional and community. Though the responsibility of various organizations in charge of planning public waste water disposal systems is different in each case, they still have to function within the priorities fixed by the national and state governments and to keep in view overall requirements of the area. The waste water disposal projects formulated by the various State sponsoring Authorities at present do not always contain all the

essential elements for appraisal. When projects are assessed for their cost benefit ratio and for institutional or funding purposes, they are not amenable for comparative study and appraisal. Also at times different standards are adopted by the Central and State agencies regarding various design parameters. It is necessary therefore to specify appropriate standards and design criteria and to avoid different approaches.

- **Design considerations**
  In designing waste water collection, treatment and disposal system, planning generally begins from the final disposal point going backwards to give an integrated and optimum design Co suit the topography and the available hydraulic head, supplemented by pumping if essential.

3. Design Period

Sewerage projects may be designed normally to meet the requirements over a thirty five year period after their completion. The period between design and completion should also be taken into account which should be between three to six years depending on the type and size of the project. Design periods for the project components may be designed to meet the periods mentioned below in table no 2:

Table 2: Deign Periods [15]

Sr. No.	*Component*	*Recommended Design period in years*	*Clarification*
1.	Collection System i.e. Sewer Network	35	The system should be designed for the Prospective population of 35 years, as its replacement is not possible during its use.
2.	Pumping Stations (Civil Works)	35	Duplicating machinery within the pumping station would be easier/cost of civil works will be economical for full design period.
3.	Sewage Treatment Plant (STP)	35	The construction may be in a phased manner as initial the flows may not reach the designed levels and it will be uneconomical to build the full capacity plant initially.

4. Design Parameters

- **Population**
  The population is very important parameter because of water supply quantity is predominating.

- **Rate of Water Supply**
  Wastewater quantity may be assumed to be 80% of the quantity of water supply. The sewers should be designed for a minimum of 150 lpcd.

- **Slope/Gradient**
  Slope depends upon the topography of ground and levels. Slope is also another important parameter because the rate of flow is depends upon the amount of slope.

- **Peak Factor**
  The peak factor or the ratio of maximum to average flow depends upon contributory population and the following values are recommended. These peak factors will be applied to the projected population for the design year considering an average wastewater flow based on allocation.

Table 3: Peak Factor [15]

Sr. No.	*Contributory Population*	*Peak Factor*
1.	Up to 20000	3.5
2.	20000 to 50000	2.5
3.	50000 to 750000	2.25
4.	Above 750000	2.0

5. Velocity

The sanitary sewer is designed to obtain adequate scouring velocities at the average or at least at the maximum flow at the beginning of the design period for a given flow and slope. Velocity is little influenced by pipe diameter. The recommended slope for minimum velocity is 0.75 metre/sec. and maximum velocity is 3.00 metre/sec.

- **Pipe Size**
  The pipe size should be decided on the basis of ultimate design peak flow and the permissible depth of flow. The minimum diameter of public sewer may be 150 mm. In hilly areas, where extreme slope are prevalent, the size of sewer may be 100 mm [15].

- **Depth of Cover**
  1 m cover on pipeline is normally sufficient to protect the pipe lines from external damage [15].

6. Manholes

Manholes are interconnecting between two or more sewers and to provide entry of sewers. Manholes are used to building connections and junction chambers.

7. Hydraulic Design Equation

Normally, The Manning's equation is used most commonly for the design of sanitary sewers because it is efficient, popular and fully satisfied the experimental results [1] and same is used for this design.

The Manning's Equation is as below,

$$V = (1/n) \times R^{(2/3)} \times S^{(1/2)}$$

Where,
V = Velocity in metre/sec
n = Friction Factor
= 0.011 (For Plastic smooth pipe)
= 0.013 (For Cement-concrete pipe)
R = Hydraulic Radius in metre

$$= \frac{\text{C/s area of flow in sq. metre}}{\text{Wetted perimeter in metre}}$$

S = Slope of Energy Grade Line
Wastewater = 80 % of water supply per person

Sample Calculation

Consider, one primary line of sewer network which is waypoint no 770 to 773 (thick line), and the location is at right side of Sambhuappa Math in Islampur town.

Data:

Population (P) = 535, Peak Factor (PF) = 2.25, Slope (S) = (591.50 - 590)/110.70 = 0.01, Wastewater Quantity = 80%*150 = 120 lpcd and Design Flow (Q_d) and Velocity of Flow (V) =?

Q_d = 535*2.25*120*0.05

= 1.44 MLD or

Q_d = 0.017 cum/sec

But, $Q_d = q_{act}$

$(q_{act}) / (Q_{full}) = 0.5$ (From table no 4)

$(0.017) / (Q_{full}) = 0.5$

Q_{full} = 0.033 cum/sec

$Q_{full} = V \times A$

$= (1/N) \times (D/4)^{(2/3)} \times S^{(1/2)} \times (\square/4) \times D^2$

D = 0.20 m (or 250 mm provided)

∴ V = 1.21 m/sec and A = 0.05 Sqm

Same procedure and calculations of other lines of network and all these lines of calculated values are shown in table no. 4.4 as below:

∴ Q_{full} = 0.06 cum/sec

Then, $(q_{act}) / (Q_{full}) = (0.017/0.06) = 0.281$

By using Interpolation Formulae,

$(Y-Y_0)/(X-X_0) = (Y_1-Y_0)/(X_1-X_0)$

Where,

X_0 and Y_0 = Lower Value

X and Y = Middle Value

X_1 and Y_1 = Higher Value

Compare between Velocity and Discharge of Hydraulic Elements and find out X (Vel. of Flow)

X_0 =	0.776	Y_0 =	0.196
X =	?	Y =	0.281
X_1 =	0.902	Y_1 =	0.337

(0.281–0.196) / (X–0.776) = (0.337–0.196) / (0.902–0.776)

X or v/V = 0.85

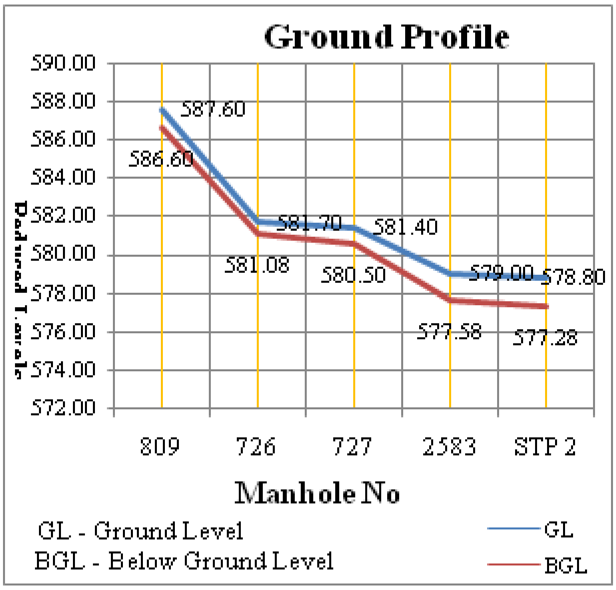
∴ Velocity of Flow, (V) = 1.03 m/sec > 0.75 m/sec (Hence, OK)

Table 4.6: Calculated Values of Sewerage Networks

Sewer Line	From	To	U/s RL, m	D/s RL, m	L, m	P	Q, cum/sec	D, m	Velocity, m/sec	Slope	PF
Primary Lines											
770-773	770	773	591.50	590.00	110.70	535	0.033	0.25	1.03	0.010	2.25
773-775	773	775	590.00	589.00	80.10	595	0.037	0.25	1.07	0.010	2.25
832-773	832	773	590.25	590.00	175.60	265	0.017	0.20	0.86	0.010	2.25
851-847	851	847	587.35	582.00	123.90	450	0.113	0.25	2.38	0.040	2.25
831-858	831	858	590.00	582.30	242.80	765	0.143	0.30	2.27	0.030	2.25
827-821	827	821	585.60	583.00	191.80	605	0.057	0.25	1.39	0.015	2.25
812-818	812	818	590.00	582.20	259.20	975	0.183	0.35	2.41	0.030	2.25
809-726	809	726	587.60	581.70	220.80	905	0.283	0.35	3.26	0.025	2.25
2575-821	2575	821	583.90	583.00	84.80	150	0.014	0.20	0.95	0.015	2.25
2580-818	2580	818	583.00	582.20	120.10	140	0.013	0.20	0.93	0.015	2.25

781-776	781	776	591.70	588.20	181.80	1090	0.123	0.30	1.81	0.018	2.25
767-760	767	760	592.20	585.90	157.20	640	0.100	0.30	1.93	0.025	2.25
754-760	754	760	592.70	585.90	197.70	685	0.150	0.30	2.43	0.035	2.25
Secondary Lines											
776-775	776	775	588.20	588.00	27.80	3045	0.190	0.40	1.61	0.010	2.25
873-775	873	775	588.35	588.00	118.20	1555	0.097	0.35	1.36	0.010	2.25
775-843	775	843	588.00	583.70	179.30	5405	0.676	0.55	2.88	0.020	2.25
867-843	867	843	587.90	583.70	140.90	8960	1.120	0.70	3.26	0.020	2.25
843-844	843	844	583.70	583.20	42.00	14365	0.898	0.70	2.38	0.010	2.25
2213-844	2213	844	584.00	583.20	160.70	175	0.011	0.20	0.76	0.010	2.25
882-776	882	776	590.75	588.20	185.40	1955	0.159	0.35	1.71	0.013	2.25
760-719	760	719	585.90	583.75	82.90	1490	0.233	0.40	2.39	0.025	2.25
Tertiary Lines											
1061-844	1061	844	584.75	583.20	210.30	5310	0.332	0.50	1.85	0.010	2.25
844-847	844	847	583.20	582.00	104.60	20025	1.252	0.80	2.59	0.010	2.25
847-858	847	858	582.00	582.30	52.80	20565	0.643	0.70	1.69	0.005	2.25
858-821	858	821	582.30	583.00	159.30	22000	0.688	0.75	1.71	0.005	2.25
821-818	821	818	583.00	582.20	81.60	22500	1.406	0.85	2.66	0.010	2.25
818-727	818	727	582.20	581.40	65.10	23000	1.438	0.85	2.68	0.010	2.25
727-2583	727	2583	581.40	579.00	106.20	23000	1.438	0.85	2.68	0.010	2.25
738-2583	738	2583	580.00	579.00	50.70	9430	0.884	0.65	2.76	0.015	2.25

723-726	723	726	582.70	581.70	132.30	3350	0.105	0.40	1.07	0.005	2.25
719-723	719	723	583.75	582.70	187.50	3290	0.103	0.35	1.07	0.005	2.25
726-727	726	727	581.70	581.40	28.80	4195	0.524	0.50	2.71	0.020	2.25
2583-STP No. 2	2583	STP No. 2	579.00	578.80	30.00	32430	2.027	0.95	2.92	0.010	2.25



Graph of Geometry of Sewer Line (From 809 to STP)

This graph shows the ground profile of the one sewer line from the network.

8. Data Representation

The most common form of presentation of project work data is in image form for continuous information (e.g. classified data). Presentation of data in a GIS in tabular or diagram form is desired. A GIS makes it possible to link or integrate information that is difficult to associate through any other mean.

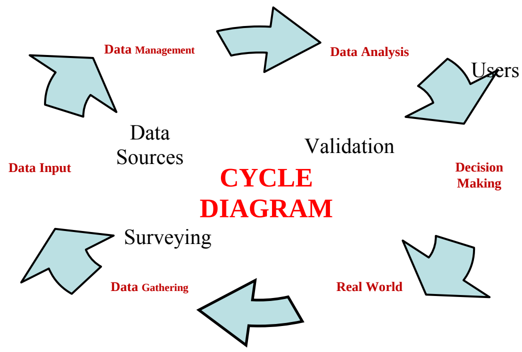


Figure 2: GIS as a Management Tool

9. Mapping of Sewerage Network

Data was collected in the form of Way Points using GPS; each point was taken at 30 m interval on straight path and at every change in connection point. GIS was used to generate a map which is shown in figure no 3 as below:

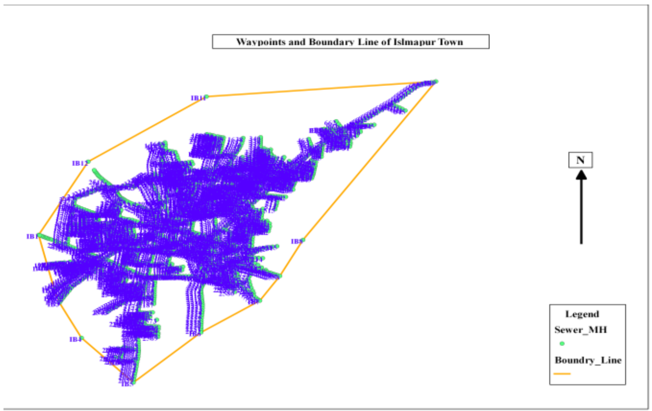


Figure 3: Map of Islampur Town

Figure no. 4 shows the selected yellow lines, these yellow lines indicate the sequence of network. It means from House Sewer to Lateral Sewer to Sub-main Sewer to Main Sewer to STP.

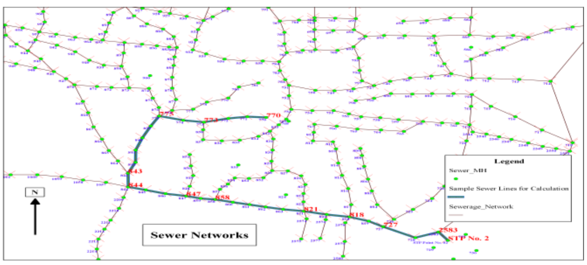


Figure 4: Sewer Network of Islampur Town

10. Results and Discussion

In this project, design of sewer line is one part of work which is done. And another part is mapping in GIS software. The main objective of this project is to prepare a base map of Islampur town, contour road network which is also useful for sewer line as sewer lines are located in the centre of road. Calculated total length of sewer line is 95.005 Kms and the range of diameter of sewer line is about 200 – 1000 mm. and also calculated total discharge quantity of wastewater of Islampur town is 34.13 cum/sec. The proposed STP locations are five in Islampur town. In that five STP, two STP such as STP Point No. 1 and 4 are more economical than other because it's in low area, more space and existence of the town and also covered more area to collect wastewater. And the STP Point No. 1 is near to Krishna River as compare to other STP Points. It means treated of wastewater is poured into the river also.

11. Conclusion

- The available population data of Islampur town from year 1951 to 2011, the population growth rate is 0.272.
- Do not have proper drainage system, so underground sewerage system is required due to less pollution and diseases.
- As per design and analysis, the total sewage of all STP's generated is about 34.13 cum/sec.
- Five STP's are required for collection of wastewater.
- Total length of sewer line is 95.005 Kms and the range of diameter of sewer line is about 200 – 1000 mm.
- Sewerage System of Islampur Town map is attached.

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