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Optimal Drinking Water Distribution System Designing using Network Analysis and Geospatial Technology

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I. Introduction

GIS has been regarded and proven as an efficient and powerful tool in the water distribution industry. American "Water Works Association" reported that near about of the 90% of water agencies are in United States are now partially using GIS to assist their daily operation (Venkatarao 2014). GIS is a state-of-the-art technology capable of efficiently performing all these data related processes. The first water company to implement GIS was Denver Waters (Deb and Agrawal, 1999). It wasn't really a GIS as known now days, in real it was an Automated Mapping/Facility Management (AM/FM). Anyway, it was the initiativestep in the use of computerized mapping information management system within the water works (Alperovits and Shamir, 1977; Bhave, 1985).

Nowadays the need of linking spatial, economic and physical information together is more frequent. This will be possible only because of the proper implementation of GIS techniques. The GIS system make us able not only to link geographical or spatial data with another alphanumeric data sets, but also helping us in updating it in a simple way to included data, through and appropriate graphic interface. The water pipe networks are obviously the imperative structures in urban and industrial areas and these networks are composed by a set and subset of elements e.g. pipes, motor pumps or compressors, valves etc. and all these are interconnected in order to transport fluid from supply sites to demand locations(Wu and Walski, 2005; Wu and Simpson, 2002). Remote sensing (RS) and GIS method on the contrary have updated the maps latest remote sensing data sets, integrates them in thematic cost layers in GIS environment and then computes all possible best fit routes along with associated costs (Coley, 2003). Apart from the shortening of 5-15 percent of the route length, the method also has the potential benefits like cadastral overlays on route for the gadget notification, precise location data on installations and organization of O & M (Fujiwara and Khang, 1990; Gessler, 1985).

GIS provides functionality for the development and effective preparation of accurate spatial information for input into the network design optimization models. It includes the network layout, connectivity, pipe characteristics and cost, pressure gradients, demand patterns, cost analysis, network routing and allocation, Connections and the effective color graphic display of results. GIS technology is increasingly being relied as a veritable capable tool of assisting decision makers and planners in selecting an optimal route when setting new pipelines in an area. This helps to reduce construction and operational costs, as well as minimize negative impacts to the environment during construction (Van et al., 2005; Dandy et al., 1996).

Traditional methods of designing of MC water distribution systems are limited because system parameters are often generalized; spatial details such as installation cost are reduced to simplified values expressing average tendencies; and trial and error procedures are followed, invoking questions as such as whether the optimum design has been achieved or not? In support of this an optimal design of drinking water distribution system must concentrate on two things first minimize the construction cost as well as maximize reliability of the final resolution. During the designing of water pipelines two steps are to be developed first is the optimal layout of the pipe network. Secondly, it is

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necessary to calculate the expected demand of the user consumers. Both steps can be done with the help of GIS (Niklesh and Khedikar, 2011; Eiger et al., 1994).

II. Study Area

Patna is located at 25.6155 °N latitude, 85.1355 °E longitude in typical tropical climate region of India. Patna district is in the eastern region of India, bordering Nepal in the North side, West Bengal in the eastern side, Uttar Pradesh in the West, and Jharkhand in the South (Fig. 1). Patna is located at an altitude of 53 meters and the total population of PMC accordingly to 2011 census is 16, 83200.The urban settlements covers roughly an area of 175 sq. km. Patna is a large city with a considerable population. Patna is famous for its glorious past, especially the period of Magadha and the Mauryan rule. Patna is hot and humid summer and cold in winters. Temperature range varies from a maximum of 43°C in summer to a minimum of around 5°C in the winters. Relative humidity can go up to 100% during summer. It receives medium to heavy rainfall in the monsoon.

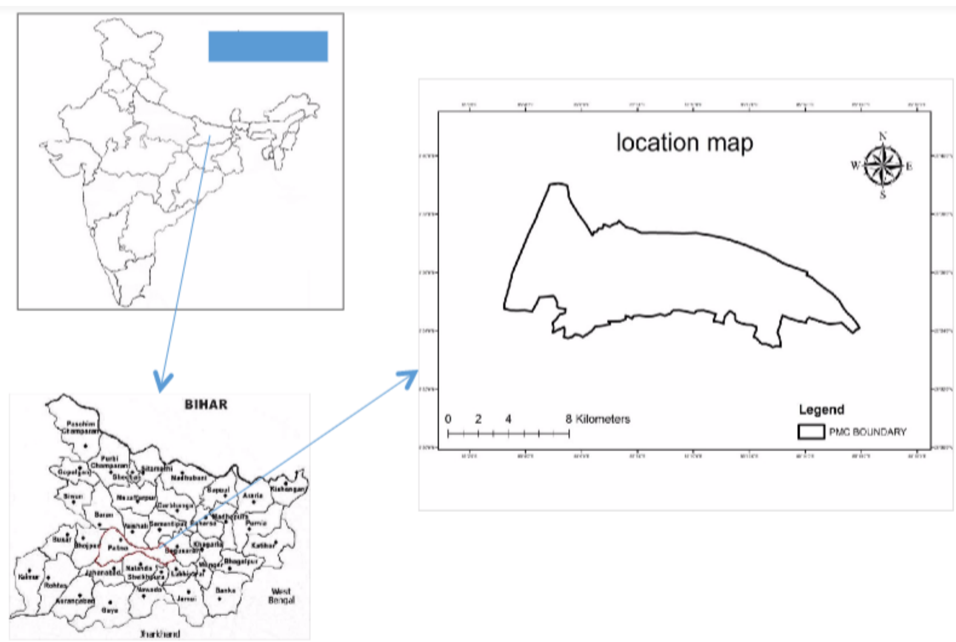

Figure 1: location map of the study area

III. Methods and Materials

a) Data Used

Geo Eye provides 0.41m (16 inch) panchromatic and 1.65m multispectral imagery in 15.2 km (9.4 mi) swaths. The vehicle or spacecraft is projected for a sun-synchronous orbit at an altitude of 681 km (423 mi) with an inclination angle of 98 degrees, with a 10:30 a.m. equator crossing time. Geo Eye can image up to 60 degrees off nadir.

LANDSAT has the tremendous ability to collect and transmit up to 532 images per day. It is deployed in a polar, sun-synchronous orbit and because of this it can scans across the entire globe's surface at an altitude of 705 kilometers +/- 5 kilometers. In this process it takes 232 orbits, or 16 days. It have the weighs of 1973 kg, is 4.04 m long, and 2.74 m in diameter. Unlike its predecessor satellites, Land sat 7 has a solid state memory capacity of 378 gigabits (roughly of 100 images). The main instrument equipped on board on Landsat7 is the Enhanced Thematic Mapper Plus (ETM+).Data from the LANDSAT satellites is collected in a continuous stream of data along with a near vertical path as the satellite moves from north to south directions. The LANDSET data is arbitrarily divided into nominal scenes which are about 24 second increments of spacecraft time apart, corresponding to a spacing of approximately 160km. This path/row designation is referred as the LANDSAT Worldwide Reference System (WRS). The rows have been positioned in such a way that the Row 60 coincides with the equator.

b) Network Analysis

Water distribution network comprise a plannar system of pipes or links (through that the water flow happened), connected together at nodal points which may be at different elevations. In general the complex system will also include pumps, reservoir and valves and more. A network node commonly has one of the two key functions; either it receives a supply for the system or it may delivers the demand required by consumers on the other hand. As a special case, it may satisfy neither of these requirements but merely serve as a junction between two or more pipes. The pressure head at the supply node is established by the presence of the pump or a reservoir. Resistance to flow (friction loss) which are the function of length ,diameter, flow rate and pipe material and roughness occur in the links as the fluid water around the network from supply node to demand nodes. The effect of minor losses may be including as equivalent pipe lengths. It is usual to specify a minimum acceptable residual pressure head at demand nodes and the pressure heads at the supply nodes must be of sufficient magnitude to satisfy these requirements. The differences between the total heads (measured with reference to a common horizontal datum) at a supply node and a demand node is equal to the algebraic sum of the head losses taken along any path of the network (Fig. 2).

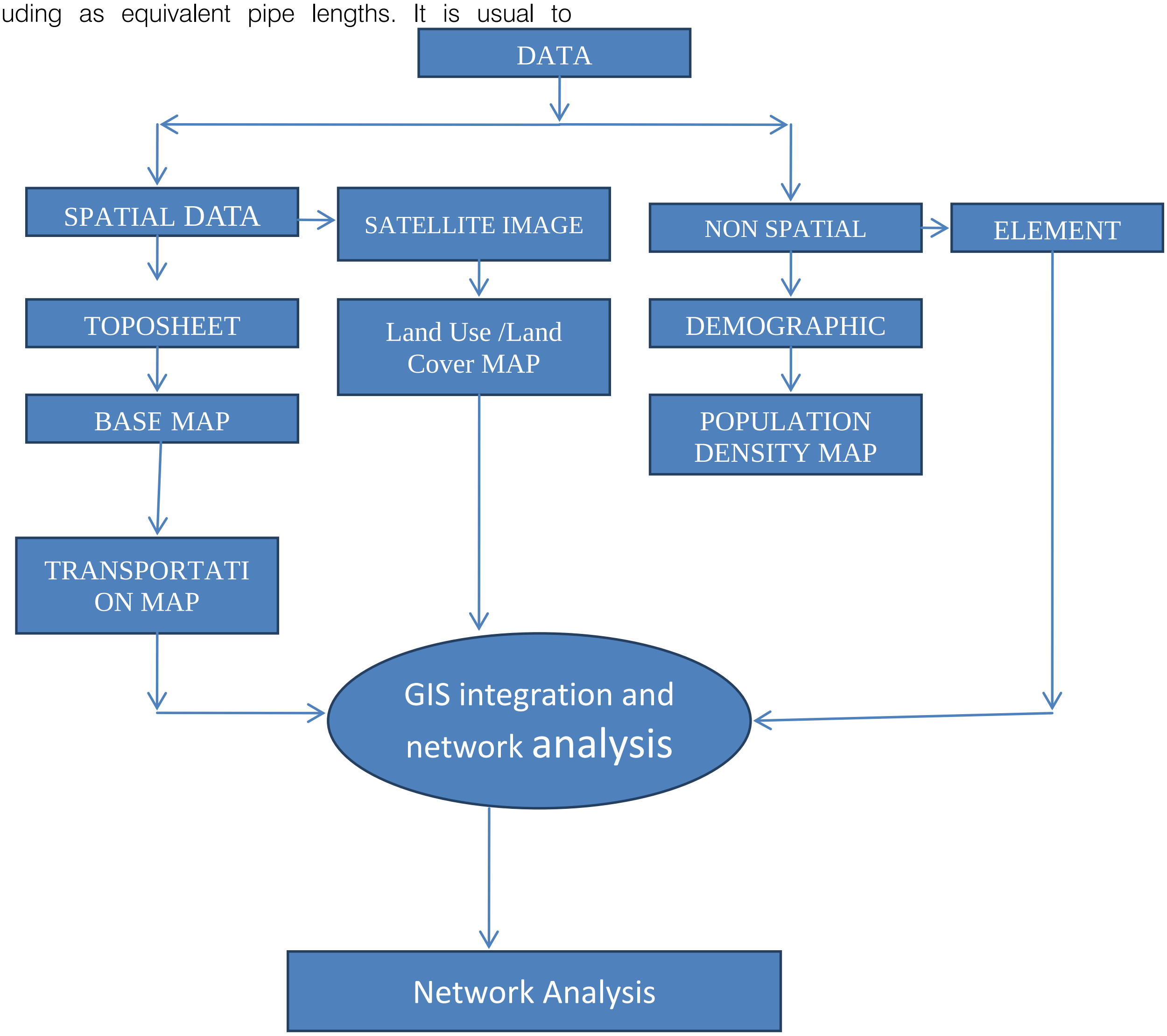

Figure 2: Flowchart for the methodology

Current study use the street network system which is created hierarchically based on levels of the roads, such as small roads, main roads, inter district and highway. Supplied water pressures may vary in different locations of a distribution system due to varied reasons. Water mains below the street may operate at a higher pressures and a water pressure reducer could be located at each point where the water enters a building or a house. In some poorly managed and maintained water supplies water pressure could below to limit that result only in a trickle of water or it may on so high level that it led to damage the plumbing fixtures. These fractures in fixtures ultimately cause the wastage of water and shortage at connection sites. Pressure in an urban water system is typically maintained either by a pressurized water tank serving an urban area and further by pumping the water up into a high tower which commonly rely on the gravity to maintain a constant pressure in the system or solely by pumps at the water treatment plant and repeater pumping stations.

Continuous water supply is taken granted to the masses in mostly developed countries but it is a severe problem in almost of the developing countries, where sometimes water supply is only provided for a few hours every day or somewhere it is a few days per week. It is estimated that the half of the population of developing countries receiving water on an intermittent basis. Conditions are worst in poor and backward countries.

c) Hazen Williams Equation

The Hazen–Williams equation is an empirical formula which relates the flow of water in a pipe with the physical properties of the pipe and the pressure drop caused by the friction. It is used in the designing of water pipe systems. It is named after Allen Hazen and Gardner Stewart Williams. The Hazen–Williams equation has the advantage that the coefficient C is not a function of the Reynolds number, but it has the disadvantage that it is only valid for water. Also, it does not account for the temperature or viscosity of the water. The results for the formula are acceptable for cold water at 60 of (15.6 oC) with kinematic viscosity 1.13 CST. For hot water with a lower kinematic viscosity (0.55 CST at 130 of (54.4 oC) the error will be significant.

$$hf = 0.002083 . L (100/C)^{1.83} . gpm^{1.85} / d^{4.8655}$$

Where,

C = friction factor

D = Inside diameter of the pipeline

gpm = gallons per meter of water

L = length of the pipe (ft)

hf = friction head loss (ft)

As for the calculation of Hazen William equation the Hazen William roughness constant the coefficient of c is been taken as 100 for the existing pipeline where cast iron is used to deliver the water whereas for the new water pipeline Hdpe pipes are used for long life plan and the coefficient of c for Hdpe pipe is 150. After the calculation for the existing pipe dia.3, 6, 8, 12, 16 inch total specific head loss (mm h20/100m pipe) is 47143691.7. Whereas for the designed one the specific head loss (mm h20/100m pipe) is 18506273.67.

IV. Result and Discussion

Patna Municipal Corporation (Patna Nagar Nigam), abbreviated PMC, is the main nodal agency for the governance and administration of Patna, entrusted with the development and management of about 110 km2area. The whole area is divided further into 72 wards, which accommodates the population size of 1.6 million. (Census, 2011). Municipal Commissioner is the executive administrative head of the Corporation, who is assisted by a large number of officers, belonging to different departments in the Patna municipal Corporation. The distribution system is the final barrier before the delivery to the consumer's tap.

a) Land Use/ Land Cover Map

Land use is the human use of land. Land use involves the management and modification of natural environment or wilderness into built environment such as fields, industries, parks and settlements. It has also been defined as the special arrangements, activities and inputs people undertake in a certain land cover type to produce, change, reshape or maintain it. Land use map is divided into seven classes such as water bodies, agriculture land, scrub land, high moisture land, settlements, vegetation and fallow land. In PMC area most of the part is covered by urban settlement and natural vegetation area along with agriculture field. In PMC area the upper part is classified as the high moisture land because of the river Ganges.PMC area is having very less fallow land and scrub land (Fig. 3).

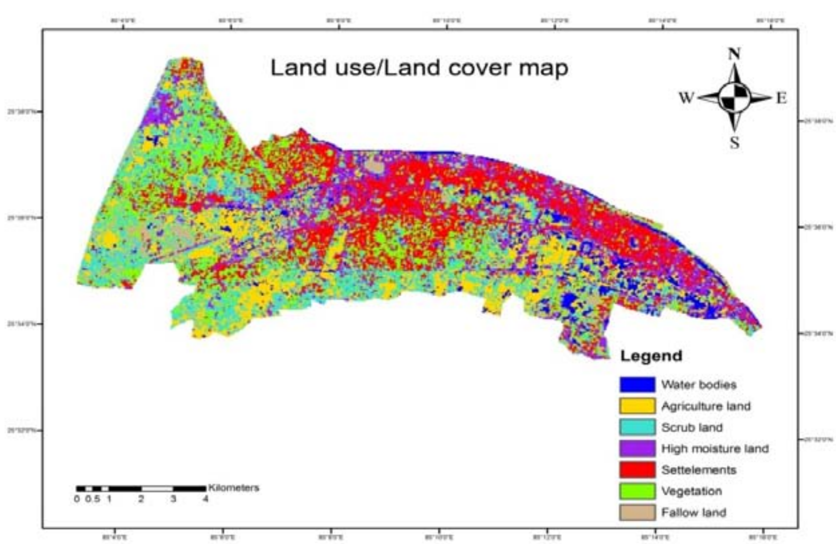

Figure 3: Land Use/ Land Cover Map

b) Population Density Map

Population density map is been prepared by Topo sheet. The variation of population can be seen from this map. Total population of 72 wards is 16, 83,200.The lighter shades of the area shows the less population whereas the dark one shows more populated area .The most populated ward is ward no.3 who's population is 21,539.The least populated ward is ward no.12 who's population is 1974.On an average rest of the ward is having population around 18,000-20,000 (Fig. 4).

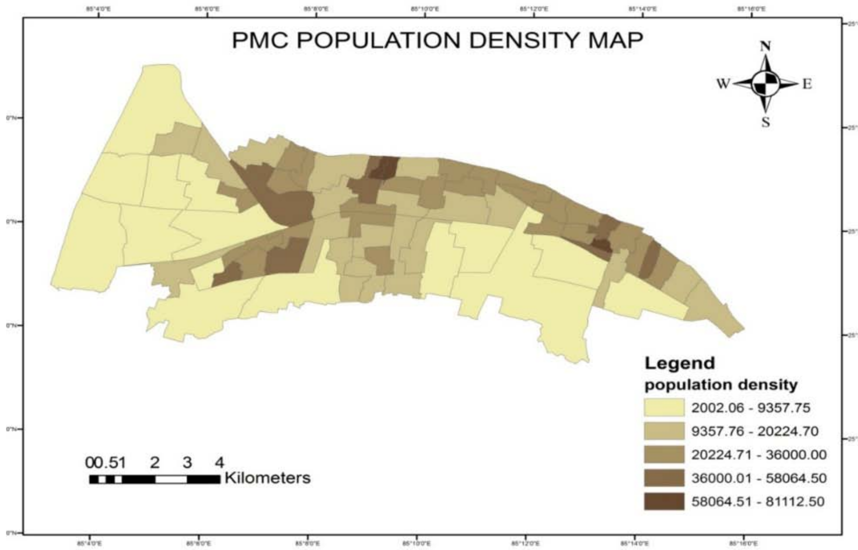

Figure 4: Population Density Map

c) PMC Water Distribution Map

Water pipe line map is been prepared from the high resolution image of GEO EYE 2012. Water distribution network consist of a plannar system of the pipes or links (over which the water flow), connected each other at nodes which may be at different elevations. The various number of pipes is been used for making the networking of water pipe line. The existing water supply systems of Patna city is based on the sources from the groundwater sources. It does not utilize the water of three rivers in the vicinity-Ganga, Sone and Punpun at all. Bihar Rajya Jal Parishad has developed and implemented the existing water supply system(Fig. 5).It is currently operated and managed by Patna Municipal Corporation. Distribution systems are composed of water mains, valves, hydrants, service lines, and storage facilities. This infrastructure is expensive in cost but long-lived. Because it is largely out of sight, distribution infrastructure tends not to be a top priority in the management and financing of water systems. But as populations shift and pipes corrode, substantial ongoing investments are necessary.

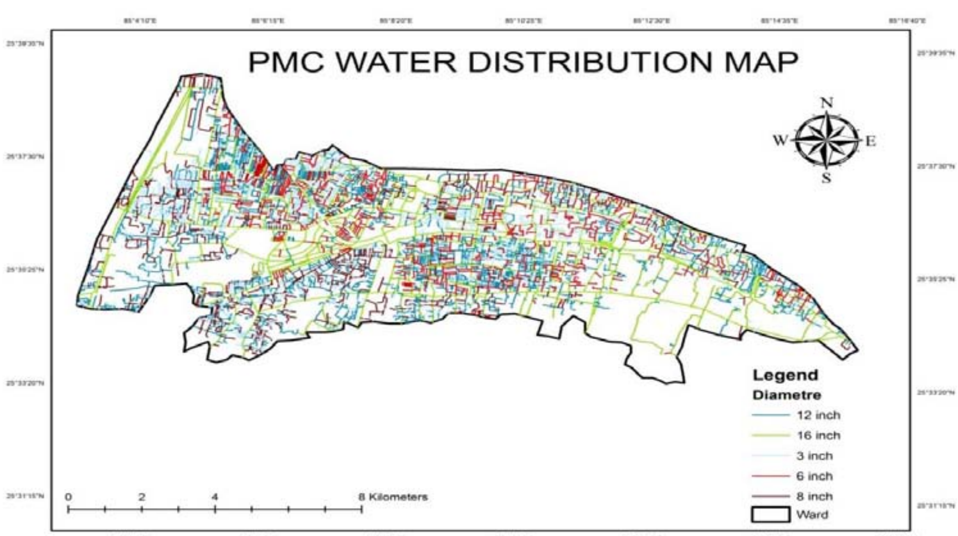

Figure 5: PMC water distribution

Global Journal of Human-Social Science (B) Volume XVII Issue II Version I Year 2017

d) Shortest Path Analysis Map

The shortest path analysis map has been prepared with the help of the high resolution image of GEO EYE 2012.Here, the shortest path analysis used to find out the quickest, shortest, or even the most scenic route, depending on the impedance we choose to resolvethe issue. If the impedance taken as time, then the best fit route will be the quickest route but if the impedance is a time attribute with live or historical traffic, then the best fit route is the quickest route for a given time of day and date. Hence, the best fit route can be defined as the route that has the lowest impedance, or the least installation cost. The shortest path analysis has been done to find the shortest path between the supplier tanks to the last node the consumer tap. Shortest path analysis can be defined as the network analysis tool which will help to find the shortest path to deliver the water to the tap.The shortest route between source and destination points is searched iteratively over corridors of narrowing width using network analysis approach. The cost is computed as weighted sum of material cost of pipeline and the access cost of approaching the route. Thus the first rough route is obtained over entire rectangular area encompassing start and end points. The subsequent route search is limited to a broad buffer zone around the previous route.

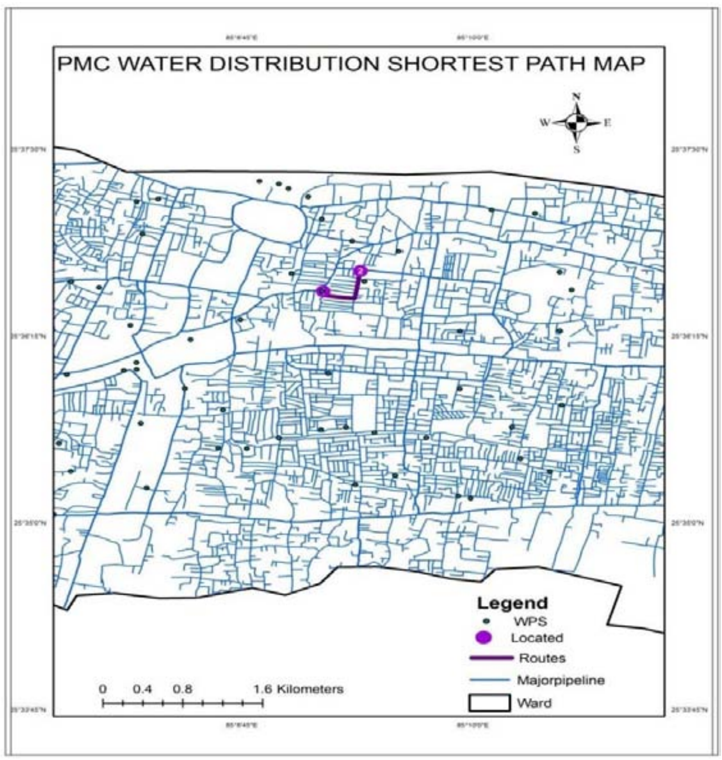

Figure 6: Shortest path analysis map

The shortest path analysis map (Fig. 6) shows the minimum distance from the pump to the consumer tap. The analysis helps to find the shortest path to deliver the water to the tap.

V. Conclusion

Water pipe line design of PMC area using geo-spatial technology has been done to provide the drinking water 24*7 at the consumer end. By incorporating the GPS location of the overhead tank in ARC GIS 9.3 and the details of the tank such as their pumping capacity, date of installation and their distribution pattern in the ward help to make an upgraded information about the existing water distribution. The specific head loss is calculated by Hazen William equation for existing pipe line as well as for design one shows the better result for the design one. After the calculation for the existing pipe dia.3, 6, 8, 12, 16 inch total specific head loss (mm h20/100m pipe) is 47143691.7. Whereas for the designed one the specific head loss (mm h20/100m pipe) is 18506273.67.An approach has been done to meet the demand supply gap as by removal of the pipelines which were very old and most of them are having leakage problem. Per capita demand of water supply has been calculated as157 lpcd. After 38% leakage loss only 97 lpcd is transported through pipes as old pipes are busted or having leakage problem due to excessive pressure. Removal of old pipes and installation of hdpe pipe help to fulfill the demand supply gap only 2 lpcd has to be achieved after the new installation. The pumps are not running to their full capacity after using new pipes 2 lpcd is achieved (increase of running hours of pumps). shortest path analysis has done to find the shortest path between the pump to the consumer tap as well as it will help to reduce the cost of the piping.

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