A Raster GIS Model for Water Supply Tower and Source Option Prioritisation in Community Based Water Supply Schemes at Attanagalla, Sri Lanka

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ABSTRACT

Optimum location identification for the water tower and source is very important for any water supply scheme mainly due to storage capacity, elevation, landuse, yield of the source throughout the year, and the costs for transmission and distribution system. Towers need water from several alternative sources. Construction of distribution pipe lines is expensive due to physical features, terrain, water and urbanisation. Considering these factors design option prioritisation can be carried out by using Raster GIS. To demonstrate the potential of Raster GIS a case study was undertaken for the prioritisation of source locations for a Community Based Water Supply Scheme (CBWSS) to deliver safe and reliable drinking water for rural community living in approximately 64 km² within Attanagalla of Gampaha District. A Raster GIS model was developed to prioritise the community based water supply scheme by using terrain features with the resolution of 10 m. Base layers for the key parameters of population, roads, elevation, land use, soil, rainfall and streams were prepared and analysed to obtain the final output. Four options of two tower and two source locations for CBWSS were evaluated and Ihalagama & Algama were selected for water tower & source respectively. This paper demonstrates the weighted overlay for the cost surface (60% Road +30% Slope+10% Soil) and the least cost path for transmission and distribution (5,486,173.50 in Cost units) and close proximity to the urban area was selected. Raster GIS can overlay the layers easily, has terrain modelling capability and incorporates cost functions. Therefore Raster GIS is a great facilitator for spatial modelling for the prioritisation of planning and management of water supply schemes.

KEYWORDS: Prioritisation, Community Based Water Supply Scheme, Raster GIS, Spatial Modelling

1. Introduction

1.1. General

Safe water, suitable for human consumption is a scarce resource which is indispensable for the sustenance of life on the planet. This contributes health, social development and overall economy of the country. Access to safe drinking water is considered as an inalienable right of people. Rural communities face many hardships due to lack of access to safe drinking water.

In Sri Lanka the piped water supply coverage is reported as 47 % (NWSDB 2016). Out of the rural areas only about 22.8% has been covered. Sri Lanka urgently needs to provide potable pipe borne water to rural communities. This causes many problems, such as, i) rural areas have lower population densities, ii) coverage extents are large and iii) available funding is limited. Therefore, in order to provide potable water to all, the planners and designers need to find the optimum design ensuring that the stakeholder needs are well looked after. GIS is a very powerful tool to carryout planning and management of spatially distributed resources and it provides the strength for the engineers to evaluate options for the optimum design. There are two GIS formats that can be used for modelling. They are vector and raster formats.

1.2. Vector GIS

Advantages of Vector GIS are data can be represented at its original resolution and form without generalisation, graphic outputs is usually more aesthetically pleasing, since most data is in vector form and no conversion is required and accurate geographic location of data is maintained.

Disadvantages of Vector GIS are location of each vertex needs to be stored explicitly, for efficient analysis, vector data must be converted into a topological structure, algorithms for manipulative and analysis functions are complex and may be processing intensive, continuous data is not effectively represented in vector form and spatial analysis and filtering within polygons is impossible.

In real life problems decision making involves in many types, layers and attributes. Therefore, when vector data are used for overlay modelling, it is inherent that the data bases need to grow exponentially leading to errors and loss of speed of operations.

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1.3. Raster GIS

Raster GIS is the most suitable data format for spatial modelling. Main factor is the comparatively big advantage in the data handling technique which requires less space while enabling easy computing. Hence this format is ideally suited for mathematical modelling and quantitative analysis. In Raster format geographic location of each cell is implied by its position in a regular cell matrix. Accordingly, other than origin point no geographic coordinates has to be stored. In raster, discrete data is accommodated equally well as continuous data and grid cell systems are highly compatible with output devices. Though the spatial data storage technique has tremendous advantages in handling, if the modeller is not careful then the raster data causes accuracy problems.

Though these differences are known in theory, there are no detailed case study examples of using raster models for real life applications and especially in the planning and design of Water Supply and Drainage projects in Sri Lanka. However there are raster application to real life problems and demonstration of advantages in other parts of the world (Al-Sabhan et.al, 2003, Joerin et al., 2001).

Though NWSDB with its mandate needs to execute rational planning and design of potable pipe borne water systems, there is a void in demonstrating the potential of GIS when decision making is challenging. Hence a community based case study application was undertaken.

The coverage of existing water supply schemes of NWSDB is limited for town areas in Attanagalla. Available capacity of these urban systems are not sufficient to cater the adjacent rural communities. Hence the need to provide optimal drinking water supply systems for the rural community has become a very important task.

1.4. Study Area

Rural hilly areas of the Attanagalla, Mirigama, Warakapola and Ruwanwella Divisional Secretariet Divisions with an overall extent of 64 km2 were the study area falling within the Gampaha and Kegalle Districts (Figure 1). Study area which consisted of 41 Grama Niladari Divisions having Gampaha as the closest major city had a total Population of 41511 with a mixed culture including middle and low income families.

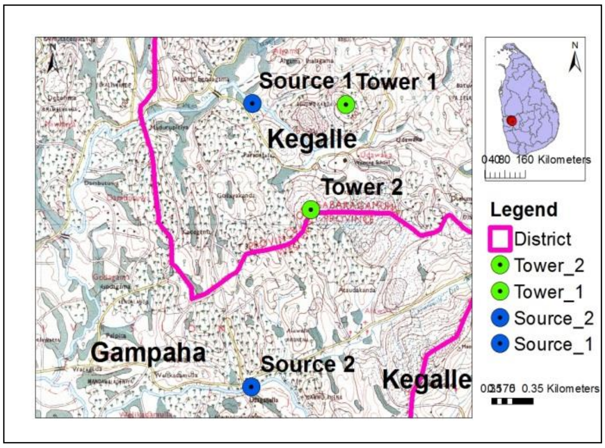

Figure 1: Study Area Map

Table 1: Data

No	Data Layer	Layer Type	Resolution
1	Project Area	Polygon	1: 50,000
2	DSDs	Polygon	1: 50,000
3	Population	Polygon	1: 50,000
4	Water Tower	Points	1: 10,000
5	Water Source	Points	1:10,000
6	Land use pattern	Polygon	1:10,000
7	Contours	Polylines	1:10,000
8	Elevation spot	Points	1:10,000
9	Soil layer	Polygon	1:10,000
10	Road Network	Polylines	1:10,000
11	Stream Network	Polylines	1:10,000

1.5. Data

Spatial data, format of base data and the resolution used for the study are in the Table 1.

Land use pattern has 05 types (Built-up area, Cultivation area, Forest area, Rock area and Water area) and road raster has 03 types. Slope raster consist of 09 classes and soil raster consists of 03 classes.

2. Methodology

Parameters selected for objective function were water demand, water source capacity and the Cost (Transmission cost, Distribution Cost, Treatment cost, Cost for construction of water Tower) as shown in table 2.

Water demand is very important factor when designing a Community Based Water Supply Scheme. Therefore, water demand for the project area is calculated using the population density of the area and according to that capacity of the water source is evaluated.

Water source capacity is based on the catchment area, rainfall intensity of the area and the water quantity extracted. Locations for water sources were selected with the same capacity. Therefore, it is necessary to ensure that those two locations which have the equal catchment area and the same rainfall intensity. And also this capacity would meet the water requirement. Watershed delineation for the source location was used as the outlet for the catchment.

Cost is depending on the length of the road, slope of the area and the soil type. Supply and laying cost of pipes were represented by the road length for transmission and distribution cost. Construction cost of water tower and the treatment cost were assumed constant for locations with same elevation and land use.

Table 2 : Objective Function

No	Objective	System Concept and parameters
1	Selection of a Water Source	f (Water Demand, Water Source Capacity, Cost)
2	Water Demand	f (Population)
3	Source Capacity	f (Rainfall, Catchment area)
4	Cost (Transmission cost, Distribution Cost, Treatment cost, Cost for construction of water Tower)	f (Road Length, Slope, Soil)

Base layers for the key parameters namely, population, roads, elevation, landuse, soil, rainfall and streams were prepared using GIS operations to convert from vector format to raster format. Digital Elevation Model (DEM) shown was created by using Triangular Irregular Network (TIN) with the use of contours and spot heights of the area. 10m contour interval and raster resolution of 10m was used.

Environmental settings is the workspace into which to place results, the cell size, processing extent or output coordinate system to apply to results and a mask to limit the area that will be processed. The settings for GIS were established at three levels; for the working application so that settings apply to all processes within the model and for a particular process within a model.

Possible combinations for water tower and source are as follows to optimize the cost of pipelines.

Water Tower location at Tower_1 and Source location at Source_1

Water Tower location at Tower_2 and Source location at Source _1

Water Tower location at Tower_1 and Source location at Source_2

Water Tower location at Tower_2 and Source location at Source_2

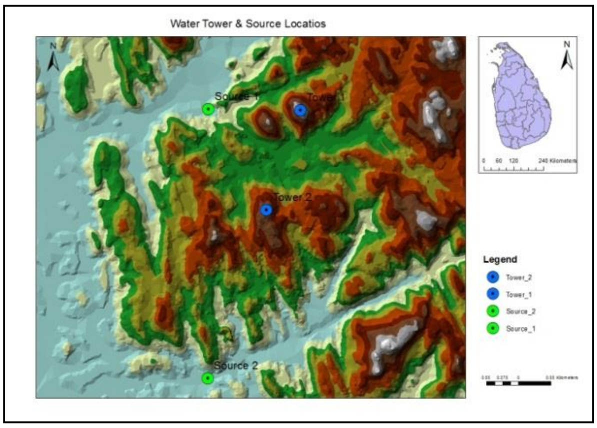

Figure 2: Digital Elevation Model

Two water tower locations (Ihalagama and Uduwaka) which having same elevation and landuse of the area were selected by using GIS operations. (Overlay elevation layer & landuse layer and reclassify).

Flow direction raster was created by using GIS with the DEM. Sinks were identified and filled then flow direction was created again. Sinks were found after the flow direction has created and then flow accumulation raster was created. Actual streams raster was burned to the DEM to find the Sinks again using raster GIS and again flow accumulation raster was created. After that Stream network has been identified with the threshold value to match with the physical stream network in the area. Watersheds were delineated along the streamline and find out two locations for sources which having the same catchment area.

IDW, one of the rainfall interpolation methods in GIS was used for the study area to ensure that the two water source locations which having same rainfall intensity.

Two water source locations (Algama and Uduwaka) which having same catchment area and rainfall intensity were selected by using GIS operations.

Road raster was created and reclassified by using GIS operations to find the cost for pipe laying and road reinstatement.

Slope raster was created by using GIS with DEM to identify the slope in the area, which affects to the pipe laying cost for transmission lines and distribution lines.

Soil raster was created and classified to find the excavation cost for pipe laying.

In GIS, weighted overlaying was used to overlay the three layers of road, slope and the soil rasters. Then the Cost surface raster which incorporates cost was created by using road length, slope of the terrain and soil type.

Cost surface = Road layer * 60% +
Slope layer * 30% +
Soil layer * 10%

These percentages decided by considering rates involved in the NWSDB rate book 2014. Cost distance raster from each water tower location to

the delivery points (centroid of each DSD areas) and cost distance raster from each water source location to tower locations were prepared. Cost distance tool take into account that distance can also be measured in cost.
Cost paths from each tower to delivery points and from each source location to tower locations. Alternatives were evaluated to find the locations for water tower and the source.
Economical route is identified by comparing path costs shown in Figure 3 .

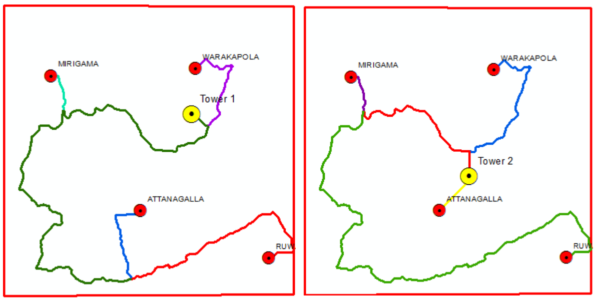

Figure 3: Cost paths from tower locations to Centre of the DSDs

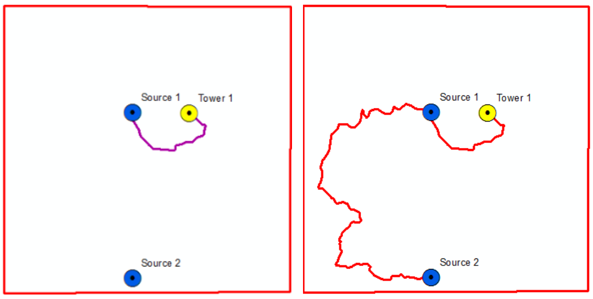

Figure 4 : Cost paths from source locations to tower 1

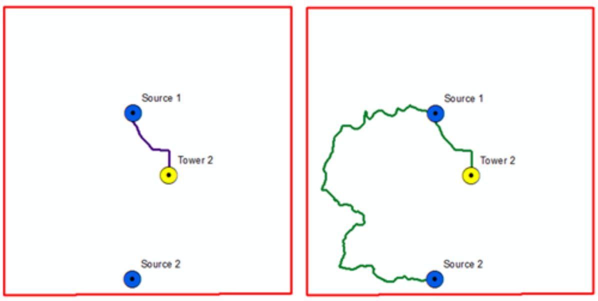

Figure 5 : Cost paths from source locations to tower 2

Vector to raster conversion was verified by overlaying.

3. Results

Identified key parameters were population, roads, elevation, landuse, soil, rainfall and streams in the study area.
Cost for transmission and distribution were calculated and tabulated in table 3.1.

Table 3.1 : Cost for Transmission and Distribution

Options	Locations	Total Cost, in million cost units
1	Water Tower location at T1 and Source location at S1	5.49
2	Water Tower location at T2 and Source location at S1	5.64
3	Water Tower location at T1 and Source location at S2	5.50
4	Water Tower location at T2 and Source location at S2	5.66

From the above table, two options were selected and then considering close proximity to urban areas was selected.
The Tower 1 at Ihalagama and Source 1 at Algama were selected as the water tower and water source locations for the community based water supply system in Attanagalla area. Results verified with the field data.

3.1. Assumptions made

Both source locations have same capacity with the required water quantity and the water quality throughout the year
Both Water Tower locations have similar construction cost and water treatment cost. For that tower locations are selected those having the same elevation and landuse type. Because the construction difficulties due to elevation and the landuse is similar when the tower locations are having the same characteristics.
Therefore cost will depend only on the transmission cost from Source location to the Tower location and distribution cost from Water Tower location to the delivery points.
Material cost for pipe laying were constant for both locations.

4. Discussion

The cell size determines the resolution at which the data is represented. Cell size = 10 is used for the study due to the easiness of calculations and match with the contour interval = 10 m.
Water demand is very important factor when designing a Community Based Water Supply Scheme. Therefore, water demand for the study area is calculated using the population density of the area and according to that capacity of the water source is evaluated.
Water demand = Population x Percapita consumption of water per day
Percapita consumption of water per day = 120 l/ day

Population = Population density of each DSD x area of relevant DSD
Water Supply System is designed to provide the water demand of each DSD to its centroid. Water demand for each DSD is applied to its centroid.
Two water tower locations were selected by overlaying elevation and road layer which has the same elevation and road condition.
Water source locations are selected with the similar capacity with the required water quantity and the water quality. Therefore, it is necessary to ensure those two locations which have the equal catchment area and the same rainfall intensity. IDW method was used for Rainfall interpolation. Rainfall interpolation method was selected on the lowest rainfall for those locations from the above three methods for worst case. Watershed delineation for the source location was used as the outlet for the catchment.
There were four alternatives for optimize the cost of pipelines. Transmission and distribution cost depends on the length of the road, slope of the area and the soil type. Supply and laying cost of pipes were represented by the road length for both situations.
Assuming both Water Tower locations have similar construction cost and water treatment cost, tower locations were selected those having the same elevation and landuse type. Because of the construction difficulties due to elevation and the landuse is similar when the tower locations are having the similar characteristics.
Therefore cost depends on the transmission cost from Source location to the Tower location and distribution cost from Water Tower location to the delivery points.
Cost distances from tower locations and two source locations were calculated by using cost distance tool. Three parameters used to calculate the path cost were Road length (distance), Slope and Soil layers. Road distance is the most important directly affects to the path cost factor when consider the pipe laying. Road distance is two times important than the slope of the terrain. Laying cost of pipes in sloping terrain is higher than the flat terrain and Soil type affects to the path cost. Therefore slope was taken in to consideration due to laying cost of pipe is varied with the soil type. Soil type is the least important factor comparing the other two.
GIS Learning Objectives are Vector to Raster conversion, Raster to Vector conversion (Point, Line ,Polygon), Reclassification, Spatial interpolation (IDW), Spatial overlaying (Weighted overlaying), Raster analysis, creating Triangular Irregular Network (TIN), Digital Elevation Model (DEM), Slope raster, Soil raster, Cost distance raster, Cost path Generation of stream network and Watershed delineation.
Vector to Raster and Raster to Vector conversions are used for the verifications.
Do you think your objective function is fully addressing the problem or you later realized that you had missed something out ? Say that and discuss how to do it in the next occasion.
Raster resolution selected for the study was 10 m and the extent of the study area was 64 km2. Contour interval used for the study was 10.
For example;
If we use cell size = 1, It is very accurate but it takes more time consuming comparatively. i.e. high resolution
If we use cell size = 20, It is less accurate compared to cell size = 1 and less time consuming comparatively. i.e. low resolution
Cell size = 10 is used for the study due to the easiness of calculations and match with the contour interval = 10 m.
When doing this type of studies in future the finer resolution would be recommended to improve the accuracy of the study.
Drawbacks of the present study was Material cost of pipelines were not incorporated according to pipeline network design and it would be incorporated when doing in future studies. Water quality and quantity data of the river throughout the year are required to do a better study using GIS.

5. Conclusion

The Water Tower at Ihalagama and Source at Algama were selected as the water tower and water source locations for the community based water supply system in Attanagalla area.
Raster GIS can overlay the layers easily, has terrain modelling capability and incorporates cost functions. Therefore Raster GIS is a great facilitator for spatial modelling for the prioritisation of planning and management of water supply schemes.
Select the water source location by using this Arc GIS model.

6. Acknowledgements

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