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Using GIS and Remote Sensing Technique for Zoning of Wastewater Drainage of Allahabad City

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Abstract The present study is aimed to develop a GIS based method for "Divide (zoning) the Allahabad city into different wastewater zones to optimize the drainage length using the GIS and Remote sensing". The study was performed at three different levels of analysis viz. land use/land cover analysis, site suitability analysis and hydrological analysis using remote sensing data to develop the zones. These analyses were carried out using ARCGIS 10 and ERDAS IMAGINE softwares. Land use/land cover (LULC) analysis was performed by supervised classification method using the maximum likelihood classifier. The site suitability analysis was carried out by considering technical feasibility, environment sustainability and social acceptability. Factors such as ground slope, land use, distances from surface water, roads, railway network and dwelling place were considered for site selection analysis. Buffer analysis was performed at these layers and converted it into raster format. Raster data of these layers were overlaid in the GIS and weighted overlay method was performed. The above analysis resulted in identification of suitable site for wastewater treatment plants (WTPs). Hydrological analysis was carried out for determining the slope, flow direction, flow accumulation, drainage network using digital elevation model. The analysis resulted in identification of watershed and its natural drainage network. Finally, these results were combined together to identify the zones for wastewater drainage of the city and suitable sites for wastewater treatment plants.
Keywords *GIS; DEM; Zoning; Drainage Network; Wastewater; Watershed*

1. Introduction

Wastewater management is one of the most serious challenges faced by urban dwellers in developing countries. It is due to unplanned development of cities because of lack of a comprehensive master plan. If wastewater drainage plans are made according to the natural slope and are planned before the development of a city or towns then the water logging problems in urban areas can be easily solved and waste water treatment becomes easier. For an efficient wastewater treatment system the best way is to divide the whole area into different zones conforming to natural slopes and other features.

Zoning is the spatial division of an area with homogeneous characteristics. Different types of urban zones in city can be identified from their function and scale such as water distributed zones, commercial zones etc. Nikoo and Mahjouri (2013) have reported that traditional zoning methods do not consider the related uncertainties. In traditional zoning method of zone identification, all analysis and data preparation cannot be performed on a single platform. Further, it is also not possible to collect, manipulate and analyze the mass data, which are provided by GIS and remote sensing techniques. Saleh and Sadoun (2006) have reported that GIS provides a flexible and efficient platform for planning and analysis, especially when large amounts of ever changing spatial information are dealt with.

In this paper, an approach is presented to efficiently retrieve all the information from different data sources and different levels of analysis for wastewater zonation. This zonation can be used to design an efficient system for wastewater drainage network in urban area. The present study is aimed to identify the waste water drainage zones in Allahabad city and potential sites for commissioning wastewater treatment plants (WTPs). The data required for the analysis were collected from different sources including Ganga pollution control board (GPCB) Allahabad, Survey of India (SOI), National Remote Sensing Center (NRSC) and U.S Geological Survey (USGS). The GIS databases were prepared from data obtained from these sources.

The analysis was performed at three different levels viz. land use/land cover analysis, site suitability analysis and hydrological analysis with the help of ArcGIS10 and ERDAS IMAGINE software. In land use/land cover analysis, remote sensing data of LISS III were used. Supervised classification method using the maximum likelihood classifier was performed for land classification. The various land use classes, delineated from the LISS III image, include built-up land (settlement), agriculture land, sand, water, and forest/shrub and open/barren land. Site suitability analysis was performed by considering a number of factors to ensure technical feasibility, environment sustainability and social acceptability. The factors include slope, land use/land cover, distance from surface water, distance to existing major roads, and distance from populated areas. Hydrological analysis was performed on SRTM digital elevation data for determining the slope, flow direction, flow accumulation, drainage network and watershed area. Finally, these results obtained from different levels of analysis were combined together to identify the wastewater drainage zones in Allahabad city.

2. Study Area

Allahabad, a district of Uttar Pradesh state is situated at the confluence of two major rivers Ganga and Yamuna and a mythical invisible river Saraswati. The study area is bounded between $25^0$20'N to 25^0 33'N latitude and $81^0$42'E to $81^0$55'E longitude. Figure 1 shows the geographical location of the study area (Allahabad city). The topography of Allahabad city is flat and temperature varies between maximum 47.8^0C in summer to lowest 4.1^0C in winter. The city receives on an average annual rainfall of 930 mm.

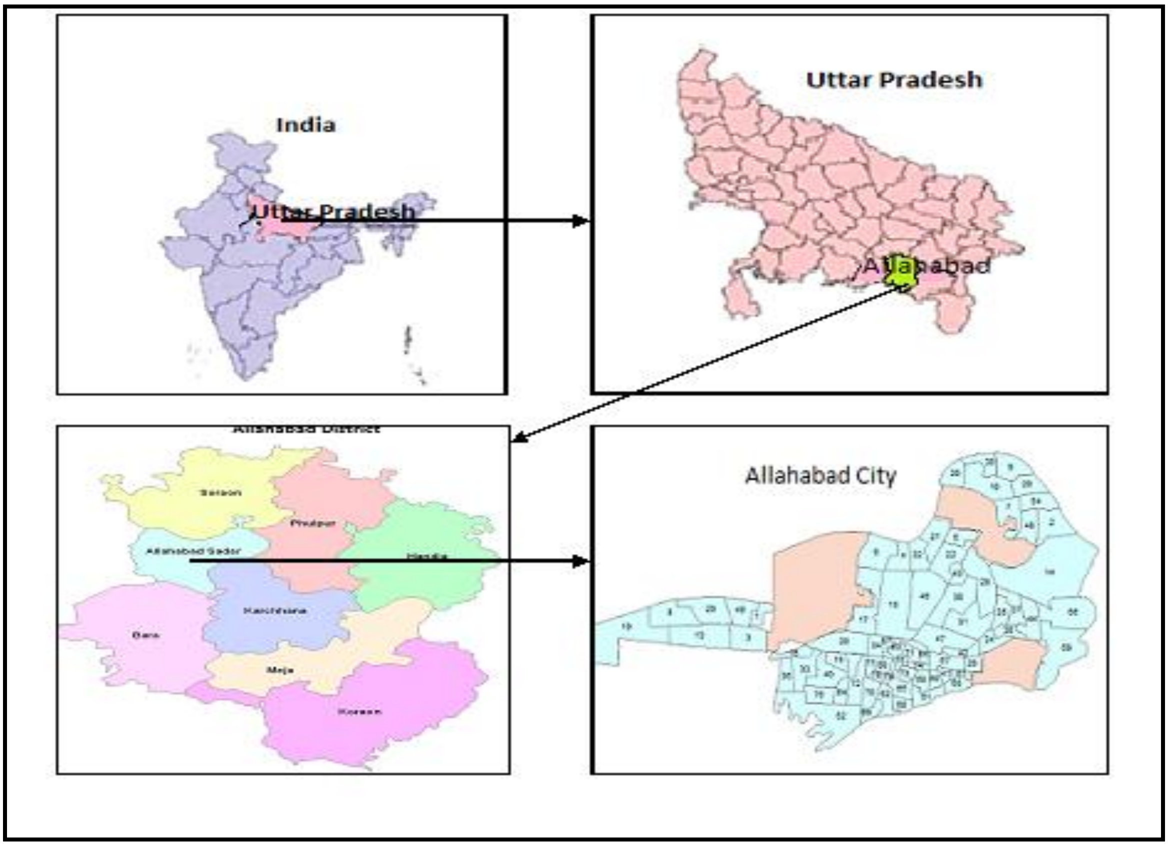

Figure 1: *Geographical Location of Study Area*

3. Methodology

The flow diagram of developed methods for delineation of zones is shown in Figure 2. It includes data collection, data preparation and data analysis. A number of digital data were collected from different sources including Survey of India (SOI) topographical map (G44P15) at a scale 1:50,000, waste water drainage map available from Ganga pollution control board (GPCB) Allahabad, LISS-III (2008) image data at 30 meter resolution from National Remote Sensing Center (NRSC) and Shuttle Radar Topographic Mission (SRTM) digital elevation data for the year 2005 with resolution 3 arc second used for the present analysis.

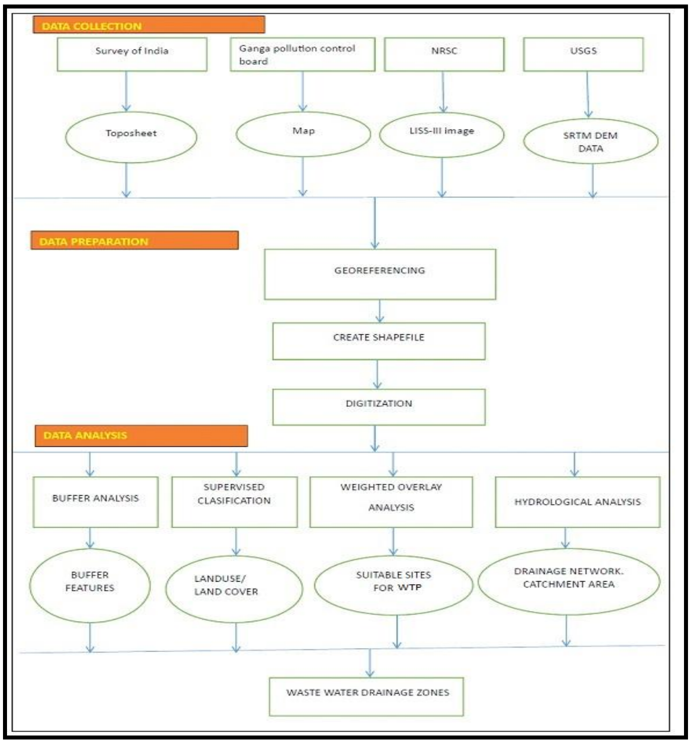

Figure 2: *Flow Chart of the Methodology Adopted*

Road network, river and railway networks were extracted from Survey of India toposheet using ArcGIS10 software. Shape file of Allahabad city boundary and the cantonment area was extracted from the map provided by Ganga Pollution Control Board (GPCB), Allahabad. LISS-III image data were used to find the land use/land cover map layer of the Allahabad city using supervised classification method. Drainage extraction and hydrological analysis was performed on SRTM raster data that obtained from USGS.

3.1. Land Use /Land Cover Analysis

Land cover relates to the type of feature present on the surface of the earth. It can be grass, asphalt, trees, bare ground, water, etc. Land cover is distinct from land use despite the two terms often being used interchangeably. Land use is a description of how people utilize the land for socio-economic activities. Urban and agricultural land uses are two most commonly known land use classes. There are two primary methods for capturing information on land cover; i.e. field survey and analysis of remotely sensed imagery (Littesand et al., 2008).

The present classification scheme is based on the land use and land cover classification system developed by Anderson et al. (1976) for interpretation of remote sensing data at various scales and resolutions. Anderson et al. (1976) defined the various levels of classification schemes based on resolution of image. Level I was originally designed for use with low to moderate resolution satellite data such as Landsat Multispectral Scanner (MSS) images and the image resolutions of 20 to 100 m were appropriate for this level of mapping. According to Level I scheme, land use/ land cover maps were derived with the six classes namely built-up land (settlement), agriculture land, sand, water, forest or shrub land and open/barren land.

In present study, Level I classification scheme is used. In order to achieve better accuracy in results, two separate land use/land cover classes added in present study i.e. water logged area and water sand. Water sand is considered as river bank sand that contains water. Two separate classes are included because evidences from the field survey show that the pixel values of these classes are mixed with the build-up land class pixel value.

The land use/ land cover maps were prepared using the supervised classification methods as shown in Figure 3. A supervised classification was performed on image using Maximum Likelihood algorithm in ERDAS IMAGINE 10. The supervised classification technique is preferred in this work because the data of the study area is available and the author has a prior knowledge of the study area. Diallo et al. (2009) have reported that Maximum Likelihood decision rule is still one of the most widely used supervised classification algorithm for accurate results.

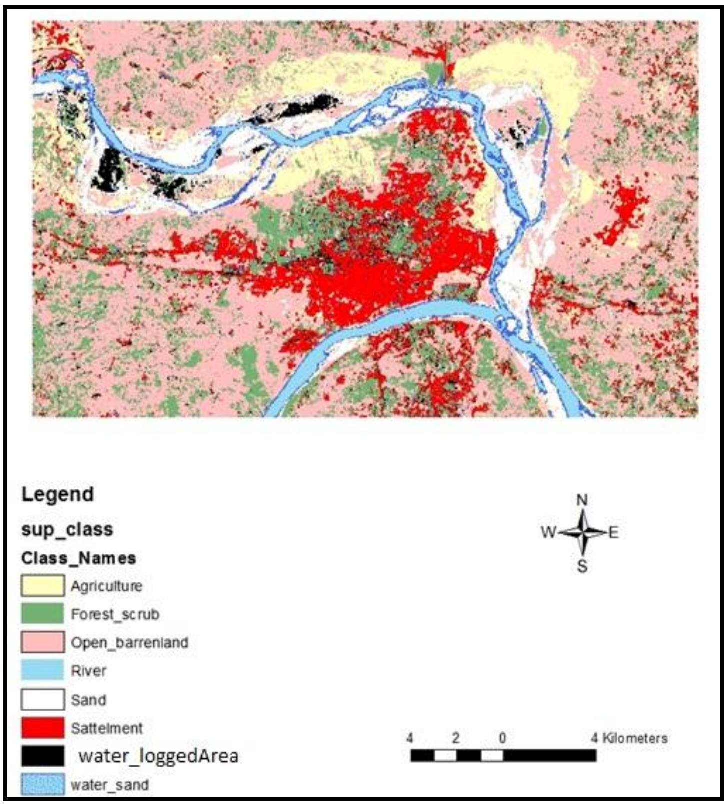

Figure 3: *Land Use/ land Cover Map of Allahabad City*

The spatial coverage of each class is shown in Figure 3. The accuracy of classification obtained through matrix is shown in Table 1. In the table, accuracy obtained is shown by comparing referenced point that is randomly generated and the classified image point. It can be observed from the table that the overall accuracy in land use classification is 89.19%.

Table 1: *Result of Accuracy Generated in Supervised Classification*

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Water_Sand	**0**	**0**	**0**	**--**	**--**
Water_Loggedarea	0	0	0	---	---
Agriculture	3	2	2	66.67%	100.00%
Forest_Scrub	7	6	5	71.43%	83.33%
Sand	3	3	3	100.00%	100.00%
Open_Barrenland	19	21	19	94.36.00%	90.48%
Settlement	3	4	3	89.46.00%	75.00%
River	1	1	1	100.00%	100.00%

Totals	36	37	33
Overall Classification Accuracy = 89.19%			

3.2. Site Suitability Analysis for Wastewater Treatment Plant

Malczewski J. (2004) has reported that GIS is most useful for land use suitability analysis in planning and management. The GIS based land use suitability has been applied in a wide variety of situation including suitability of land for agriculture activities, selecting the best site for the public and private sector facilities and regional planning etc.

Site suitability analysis (spatial modeling phase) was performed with the help of ArcGIS geoprocessing tools to create buffers around the features and overlay operations to select sites that satisfy the site selection criteria i.e. distance from water bodies, towns, roads etc. Weighted overlay process was performed on all the parameters. An overview of the site suitability analysis and the main GIS operations involved is shown in Figure 4.

Buffers were created around various features using ArcGIS tools. Buffers of 100 m around road features, 200 m for forest or shrub, 500 m for urban residential area and 500 m for the rivers were created because these areas are prohibited for wastewater treatment plant sites. To find a suitable site weighted overlay method was performed on remaining classes. In weighted overlay analysis, weights were assigned to different features according to their suitability. Grassland and barren areas were considered most suitable location for wastewater treatment plant and therefore they were assigned maximum weightage.

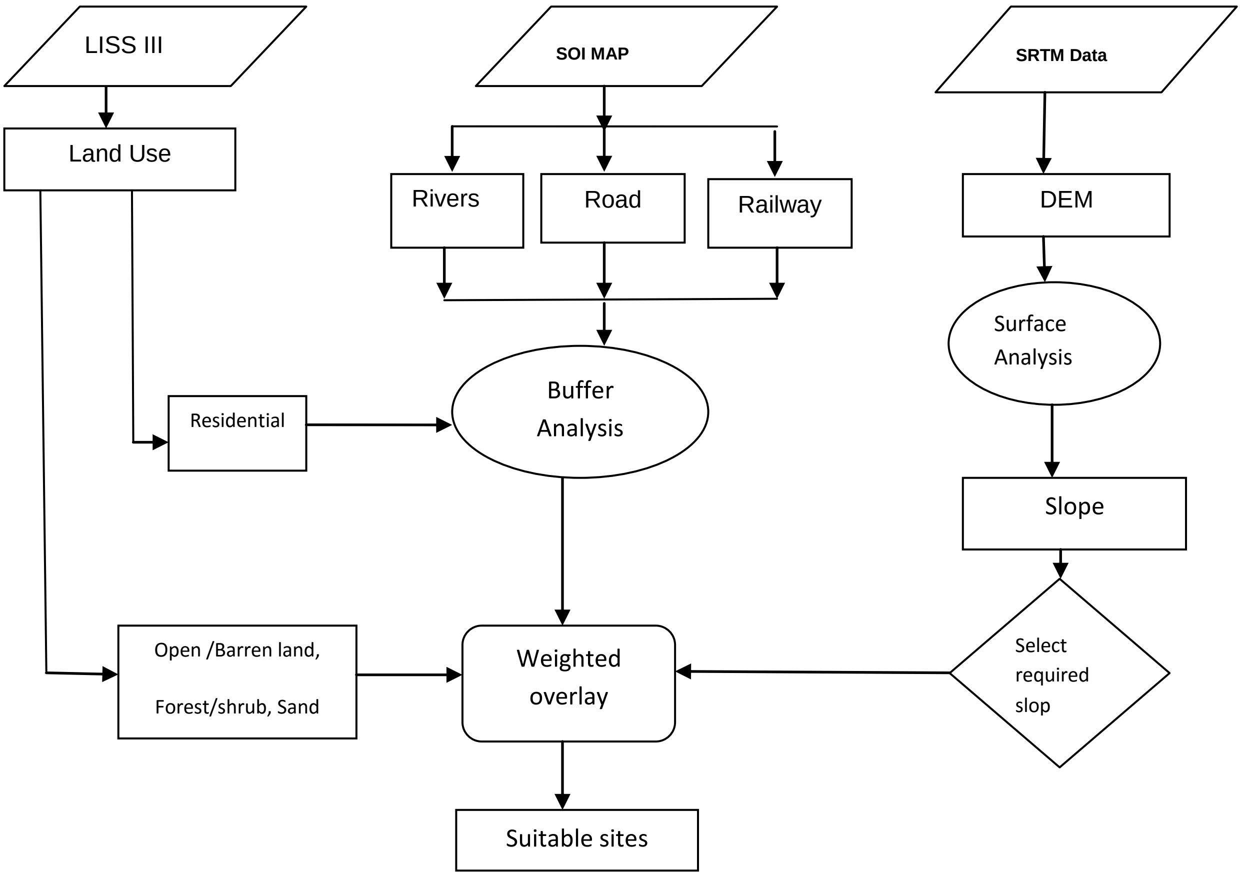

Figure 4: *Flow Chart of Site Selection for WTPs*

The weights assigned to different land use classes are user defined, and are based on how many classes are included in weighted overlay method. Maximum weight of four was assigned to most suitable class i.e. open/ barren land on a scale of four. The assigned weights to different land use/land cover classes are shown in Table 2.

Table 2: *Weights Assigned to Land Use/Land Cover Classes*

Land Use/Land Cover	Assigned Weight
Agriculture land	3
Sand	2
Forest or shrub land	1
Open / Barren land	4

Site slope is an important factor for site selection of WTPs. Treatment plants should be constructed in area having gentle slope so as to get free flow of waste water under gravity.

Slope layer was obtained from SRTM digital elevation model and categorized in five different categories ranging from (3 to 71) as shown in Figure 5.

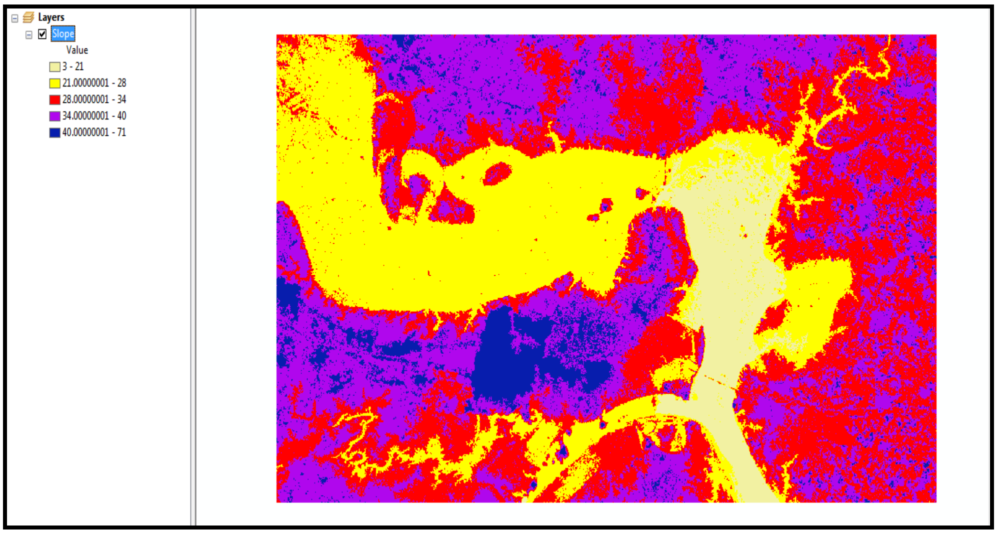

Figure 5: *Image Showing the Slope of Study Area*

In present study, the weights were assigned to different slope category. For better site suitability of WTPs, moderate to low slope is required and therefore only two slopes that fulfill the suitability are considered and assigned the weights on the scale of 2. The assigned weights to different range of slopes are shown in Table 3.

Table 3: *Weights Assigned for Slopes*

Slope(value)	Assigned Weight
3-21	2
21-28	1

The digital layer of various features and its buffer are considered as constraints for the selection of suitable site. The buffer area includes distance from rail network, road, river, distance from settlement and some restricted areas are shown in Figures 6-11.

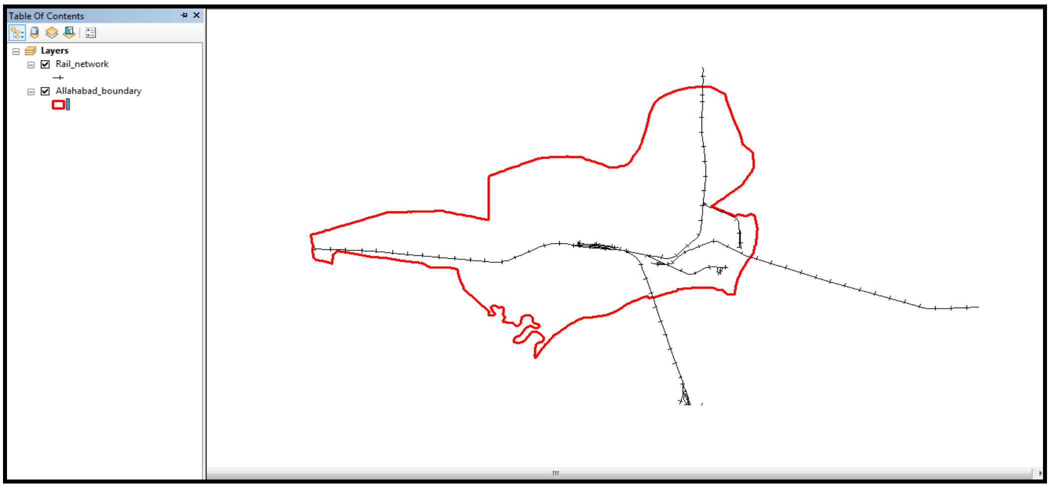

Figure 6: *Rail Network without Buffer*

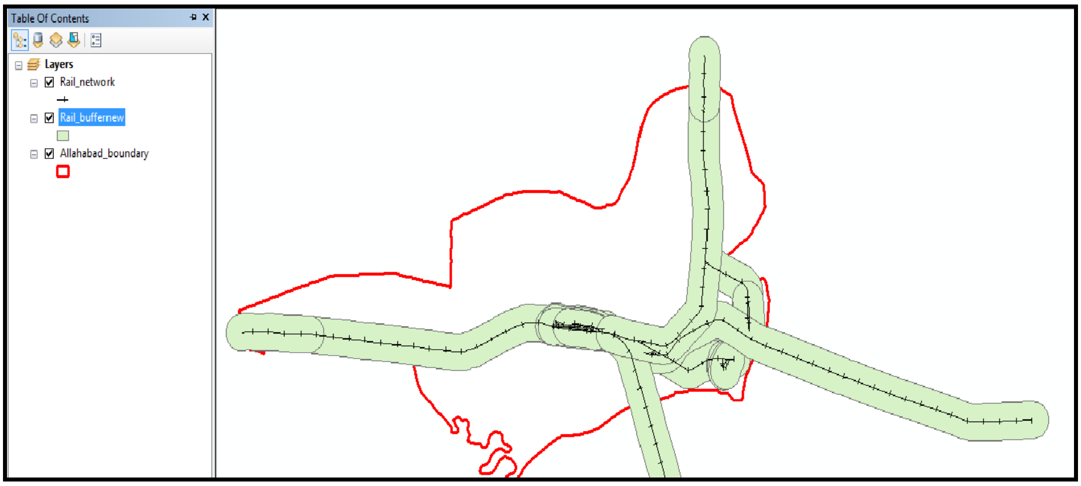

Figure 7: *Rail Network with Buffer*

Figure 8: *River without Buffer*

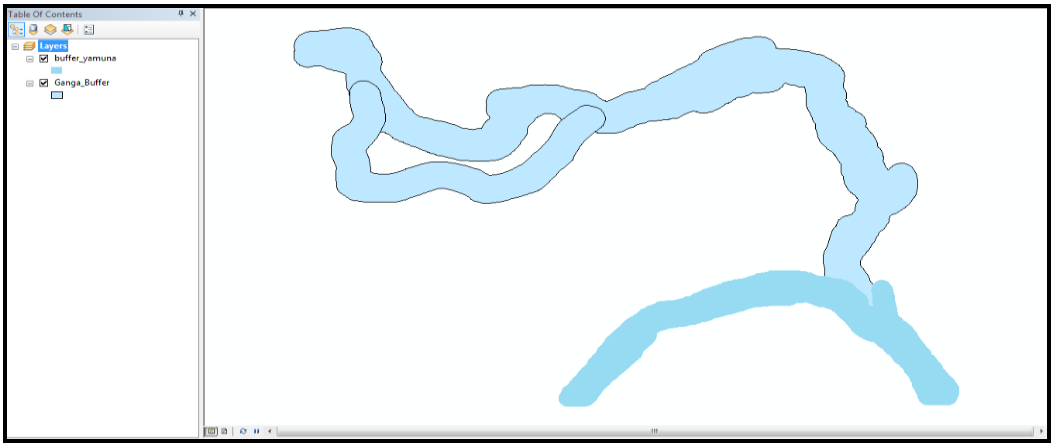

Figure 9: *River with Buffer*

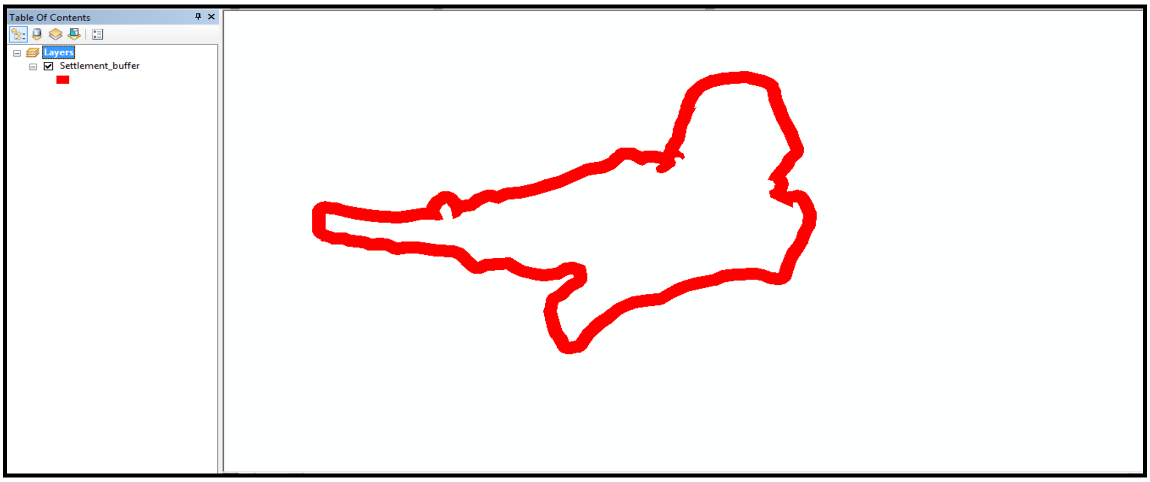

Figure 10: *Settlement Area with Buffer*

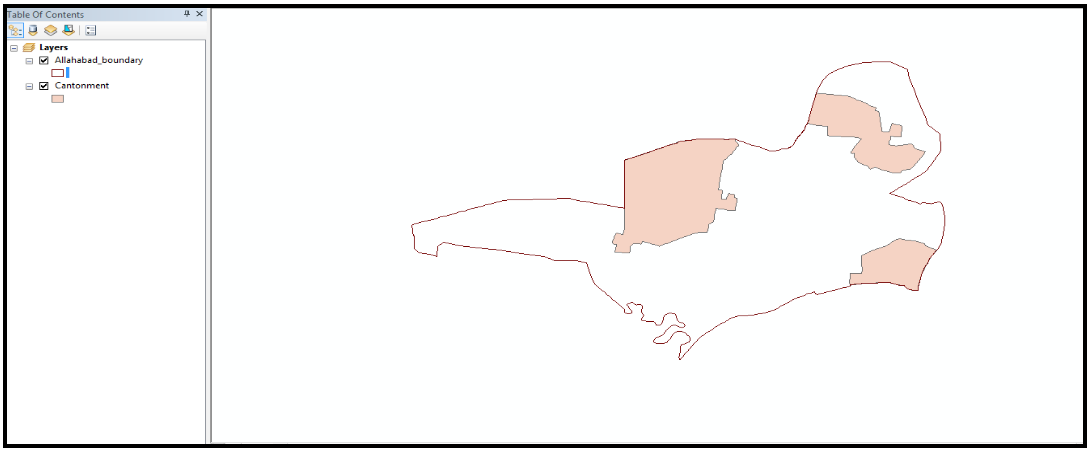

Figure 11: *Cantonment Area*

The overlay operations were performed on the layers obtained in the preceding sections. The grid function (combine) was used to overlay all factors on cell by cell basis and to create an output layer showing all suitable areas. This function was performed for only those areas, where all layers had valid data. In other words, if an area is identified as unsuitable because of any one specific factor, it has been shown as unsuitable in the output layer (Figure 12) such as cantonment area, buffer around settlement area, rivers and rail networks. Furthermore, the grid combine function has the advantage that every cell in the output layer is assigned the respective cell value of the input layers as attribute data, in the form of weights which are necessary for subsequent queries of the output layer.

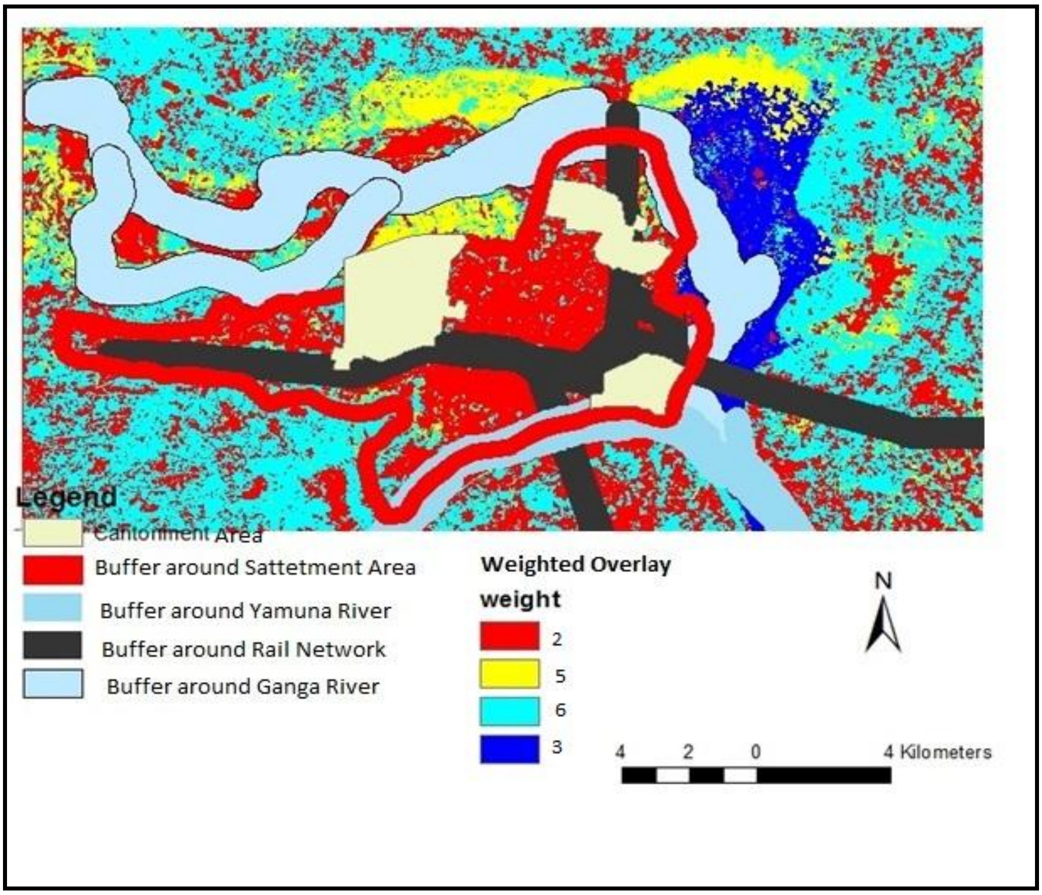

Figure 12: *Site Suitability Map for WTPs*

By weighted overlay method, the suitable sites are identified based on their weights. Highest weight indicates most suitable area. From Figure 12, it can be observed that features of weight six is most suitable site as compared to other sites having lower weights. The approach presented here is easy to understand and can be used to select waste water treatment plant sites easily. The criteria used in this study are not fixed but can be varied depending on different types of area. The level of uncertainty of results depends on the accuracy of the data, weight assigned by user to parameters or features and functions or processes used in the spatial model.

3.3. Hydrological Analysis

Using a digital elevation model as input, drainage network is extracted using ArcGIS 10 and Arc Hydro tools. It provides a method to describe the physical characteristics of a surface. Xuelian et al. (2009) reported that ArcGIS and Arc Hydro tools are mature softwares to extract drainage networks from DEM. Thus, the software can be used to extract drainage network. The steps for extraction of drainage network include: Preprocessing DEM, generating the flow directions, computing the flow accumulation and extracting the drainage network.

A DEM is a raster representation of a continuous surface, usually referring to the surface of the Earth. The accuracy of this data is determined primarily by the resolutions. Other factors affecting accuracy are data type (integer or floating point) and the actual sampling of the surface when creating the original DEM. Errors in DEMs are usually classified as either sinks or peaks. A sink is an area surrounded by higher elevation values, and is also referred to as a depression or pit. Information about DEM is available in the help menu of ArcGIS 10 software.

Lin et al. (2005) reported that a variety of methods have been developed to process raster DEM automatically for extracting drainage networks and their properties. The most commonly used procedures for extracting drainage networks from raster DEMs are based on O'Callaghan and Mark's (1984) algorithms for flow direction determination coupled with arbitrary constant value for the minimum contributing area needed to form a channel. The stream threshold choice will influence the extracted drainage network and generally, the threshold is assumed as a constant value.

The spatial analysis tool of Hydrology is performed in sequential order to find the watershed. The flowchart given in Figure 13 shows the process of extracting hydrological information, such as watershed boundaries and stream networks from DEM. The detailed discussions about the intermediate process to find the watershed and drainage network are discussed in following sections.

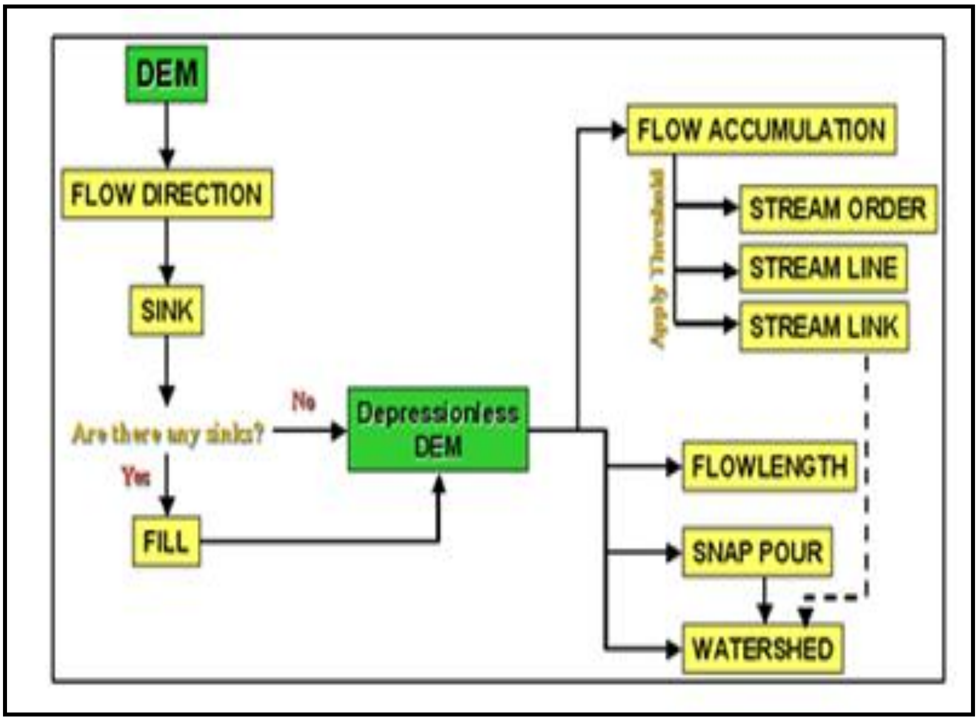

Figure 13: *Process of Extracting Hydrological Information from a DEM*
Source: Sitanggang and Ismail (2010)

3.3.1. Flow Direction

The first step to process the DEM comes as result of flow direction. Flow direction is a parameter in hydrological modeling which is determined by finding the direction of steepest descent from each cell and the distance is determined between cell centers. Identification of flow direction is the key step in extracting drainage network (Xuelian et al., 2009).

The Hydrology menu (Flow direction) in the spatial analyst toolbox of ArcGIS 10 was used to generate the flow direction in the grid. If there is any sink (the cell, that around is higher and the middle is lower) then first the depression DEM is created by performing the fill operation in the Hydrology menu in the Spatial Analyst Tools to remove sinks. After removing sinks, flow direction layer is created from depression DEM using the Flow Direction sub menu in the Hydrology menu in the Spatial Analyst tools. Flow direction thus obtained is shown in Figure 14.

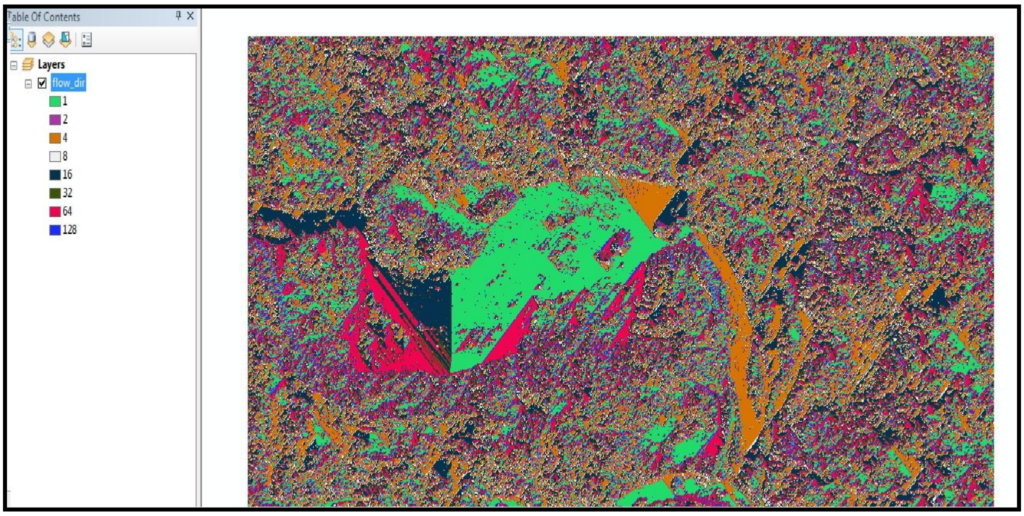

Figure 14: *The Results of Flow Direction*

Each grid is assigned some integer value ranging between 1 to 128. The value 1 shows the lowest value and value 128 shows the highest value in grid. The flow direction is from highest value to the lowest value in the grid. This flow direction grid map is used in the next step to determine the flow accumulation.

3.3.2. Flow Accumulation

The flow accumulation is a measurement of the amount of water accumulated in overland flow over a surface. The purpose of computing the flow accumulation is to build drainage network (Xuelian et al., 2009).

Flow accumulation can be delineated from a DEM using the flow direction output. The Hydrology menu (Flow Accumulation) in the Spatial Analyst tool of ArcGIS10 is used to find the accumulated flow as the accumulated weight of all cells flowing into each down slope cell in the raster. Thus the main stream of study area is obtained.

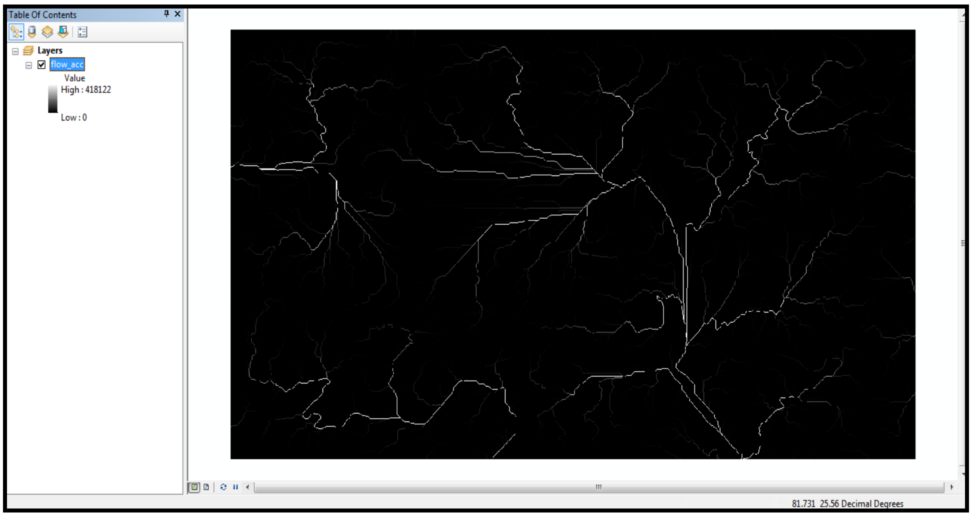

Figure 15: *Flow Accumulation Results*

As the water flows from higher to lower elevation, one can easily calculate the flowing of water at every point based on the stream direction matrix of regional topography and from this the stream accumulated matrix of regional topography can be obtained.

3.3.3. Create Outlet (Pour) Points

Watershed delineation required the placement of pour points. A pour point is the point at which water flows out of an area. A pour point should exist within lowest area of because it shows the total contributing water flow to the given point.

3.3.4. Drainage Network

Drainage networks can be delineated from a DEM using the flow accumulation as input. The Hydrology menu (Stream order) in the Spatial Analyst Tools of ArcGIS 10 calculates the drainage network when apply threshold value of 50.

Flow accumulation in its simplest form is the number of upslope cells that flow into each cell. By applying a threshold value to the results of flow accumulation using the stream network as feature dialog in the sample extension, a stream network can be delineated as shown in Figure 16.

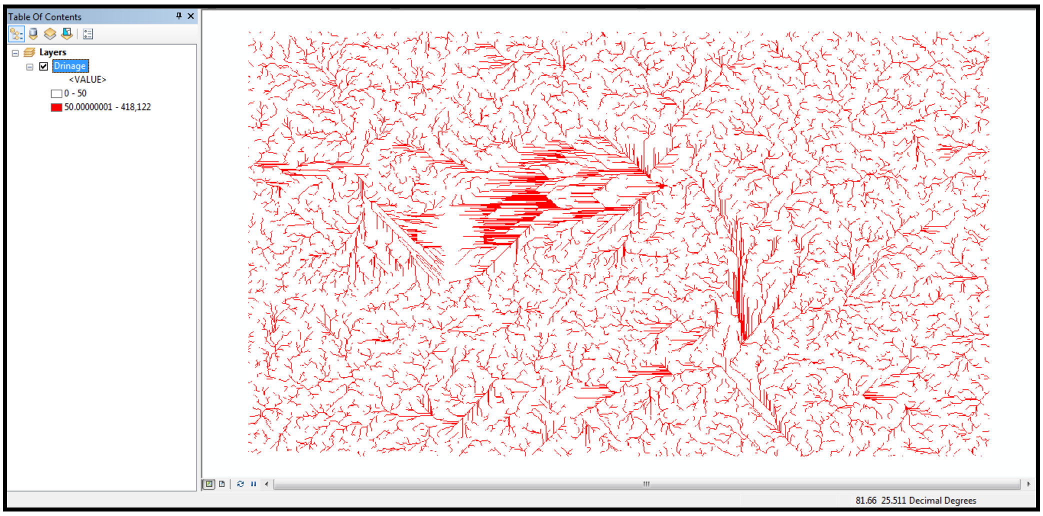

Figure 16: *Extracted Drainage Network*

3.3.5. Watershed Delineation

A watershed is the upslope area that contributes flow to a common outlet as concentrated drainage. The Watershed tool identifies the contributing watershed to a specified point, known as a pour point. Multiple watersheds can be delineated for multiple pour points. Watershed is created using the sub menu Watershed sub menu in the Hydrology menu of the Spatial Analyst tools in ArcGIS10. The inputs are a raster of flow direction and the pour point layer. The Watershed layer is converted into raster format to vector (.shp) format for the analysis.

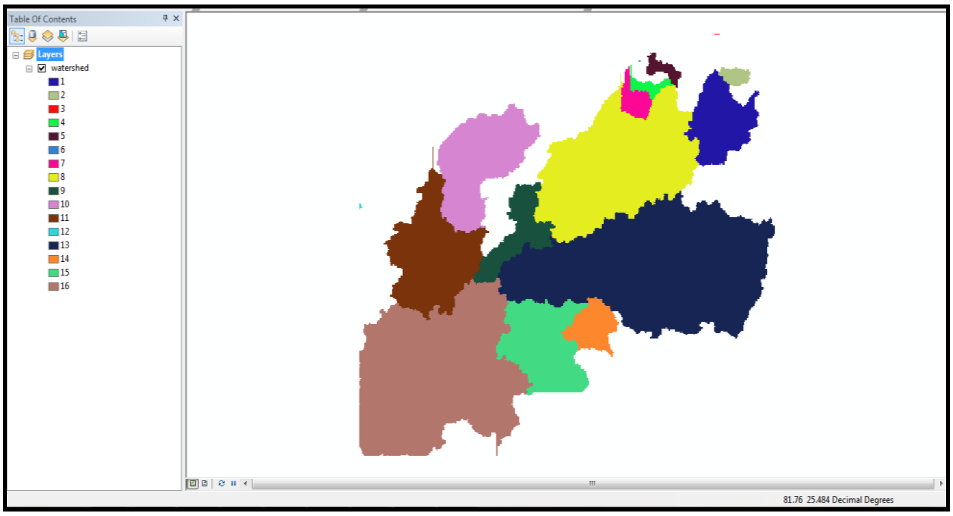

Figure 17: *Watershed Boundary*

The watershed boundary is obtained from the nodes where the steepest slope is oriented towards the drainage basin are progressively added to the catchment starting from the outlet node. In first step we create more pour point according to flow direction and main stream that resulted multiple watersheds as shown in Figure 17. In this work the pour point is a point in the lowest area. Some pour points intersect with the river are removed and watershed polygon of this pour point merged to the adjacent watershed polygon until the pour point lies in the suitable site for WTPs as given in the section 3.2.

4. Development of Wastewater Zones

The various maps generated in the preceding sections helps in decision making process of zoning of wastewater drainage of Allahabad city. Zoning analysis involves the use of ArcGIS software for extracting layer from different set of data that are resulted from previous sections. The resulted overlaid map is shown in Figure 18.

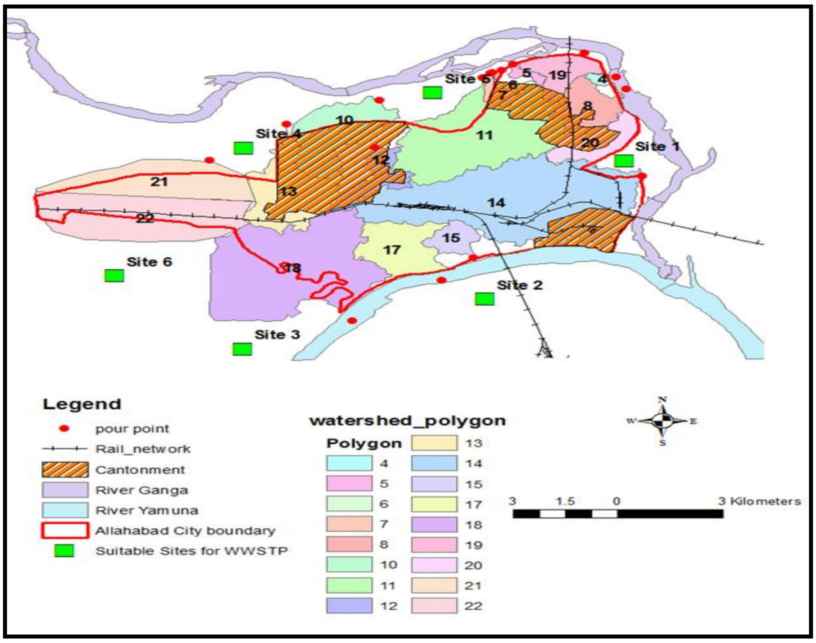

Figure 18: *Watershed Polygon and Other Features*

In present study rail network is considered as a base network. Based on distance between the watershed polygon and suitable sites, the city is divided into the different zones which are as follows-

1. Site 1 covers the watershed polygons 4, 8, 19, 20 and 14. From polygon 19 and 14 only those areas are taken which are towards the east side of the rail network. These polygon areas are combined and considered as Zone 1.

2. Site 2 covers the watershed polygons 15, 17 and 14. From polygon 14 only those areas are taken which are towards the south side of rail network. These polygon areas are combined and considered as Zone 2.

3. Site 3 covers the watershed polygon 18 and some part of polygon 13 in the south direction from rail network. These polygon areas are then combined and considered as Zone 3.

4. Site 4 covers the watershed polygons 21, 13 and 22. These polygon areas are combined and considered as zone 4.

5. Site 5 covers the watershed polygons 5, 6, 11, 12 and part of polygon 14 on the north side of the rail network. These polygon areas are combined and considered as Zone 5.

From the above analysis, the city can be divided into five different wastewater drainage zones to establish suitable sites for waste water treatment plant. The resultant map of waste water drainage zones of Allahabad city is shown in Figure 19.

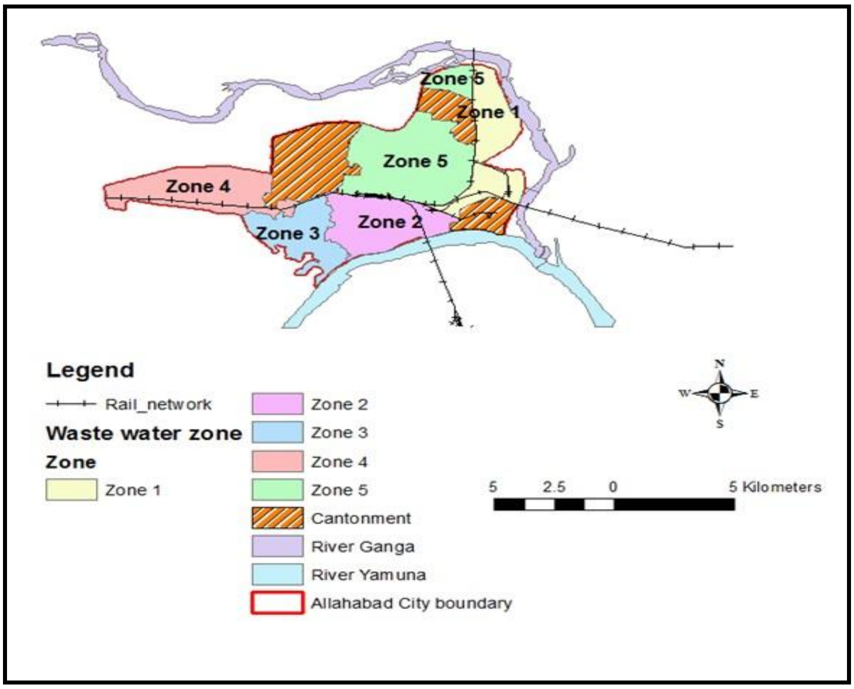

Figure 19: *Waste Water Drainage Zones of Allahabad City*

5. Conclusions

In this paper a GIS based technique is presented to develop the wastewater drainage zones for Allahabad city. The results of land use and land cover analysis reveals that existing land classes in the study area can be classified into eight different classes, namely built-up land (Settlement), agriculture land, sand, water, and forest/shrub, waterlogged area, water_sand and open/barren land. These classifications may prove useful for formulating appropriate plans and policies for sustainable development of city. The buffer analysis and weighted overlay method indicate the suitable site for wastewater treatment plant. Hydrological analysis provides the drainage network and watershed area of the city. The results of complete analysis indicate that the city can be divided into five different waste water drainage zones on the basis the suitable sites for waste water treatment plant and watershed area. The results of present work may prove useful in improvement of water logging problems in city.

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