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Selection of Drainage Network Using Raster GIS – A Case Study

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ABSTRACT: *Sewer design is a repetitious procedure which has traditionally been performed using nomographs and hand calculations. In the design of sewerage system there may be several possible layouts. There is no hard and fast rule to fix the layout which will result economical design. In general selection of layout is governed by designer's perception of topography and his judgment. Alignment of sewers and storm water drains should follow natural drainage pattern in order to avoid deep depth of cutting for economic designs. Alignment of drains is a complicated procedure in which many factors like topography, land use,land cover and right of way will play important role. In order to avoid cumbersome trial and error procedure, GIS can be effectively used to minimize computational time for alignment design of drains. Raster GIS is powerful tool in watershed modeling which includes visualization of DEM, delineation of watershed, extraction of channel network and derivation of slope and aspect. These parameters are extremely useful for alignment of drains and in disaster management during floods.*

KEYWORDS: *Channel network, catchment area, Digital Elevation Model, Raster GIS, Watershed delineation,*

I. INTRODUCTION

Rapid urbanization is the modern trend and this urban sprawl results in increase of population density, impervious cover, water and solid wastes. This urbanization demands modernization of existing drainage systems in economical way. The economics can be achieved only if drainage pattern follows natural streams. Drainage network efficiency in an environment is complex in nature. This requires adequate experience of the planning engineer and appropriate data. Geographical information system (GIS) is one of such tool which can be used in general way to many complex problems especially when dealing with terrain related problems.

Urban areas are characterized with dynamic change in terms of demography, land use, living standards of inhabitants, increase in per capita water demand and consequently in the waste water that is discharged from households and industries. The infrastructure has also to cope with this dynamics. Inadequacy of a sewer system may be resulted by incorrect design or due to infrastructure that has become insufficient through time. The latter can be caused either by unprecedented increase of population or because of deterioration of the sewer over years which are parameters that cannot be easily forecasted. In addition design principles have evolved over the years hence making the old infrastructure incapable to cope with existing standards. In addition, effect of climate change can also have some impact in areas where higher intensities of rain are estimated. Some reports estimate halving of return period in the future

The traditional procedure which is commonly used by many engineers is to setup a node-link model in a sewer design application and assigning the required properties such as elevation, flow, slope, diameter, length, roughness and other such pipe or manhole characteristics manually. In of enabling precise design, this procedure requires data acquisition which is not always easy or can be an expensive option because extensive survey is indispensable for accurate design

On the other hand, surface data is widely available and is relatively easily obtainable. Surface information from digital elevation models (DEM), aerial photographs, city master plan, street network, etc are relatively easily available. Some information such as DEM and aerial photographs can be downloaded from internet while others can easily be obtained from respective municipality from survey undertaken by some other organization.

Agencies may not be willing to spend large amount of money on surveying and data acquisition which are required for accurate design and analysis. Instead they might be satisfied if designs and analysis based on surface information can come up with proxy but close to conventional results. In summary, if estimation of sewer properties from surface information is found to be successful, it can serve as:

- Automatized procedure in the sewer design process
- basis for rough estimation of sewer properties
- cross-checking for missing data in specific sewer catchments
- simplified sewer network inventory

The ultimate goal of this study is to minimize cost and time required for design of sewer network. In this perspective, the research questions are

1) Is the horizontal layout of sewer network close to street network? Will this depend on location, topography, street network structure of particular catchments?
2) Can surface area, volume or typology of buildings or blocks help in estimation of sewer discharge and thereby help in the determination of sewer size?
3) Can the sewer slope be estimated from surface information such as DEMs?

It is evident that topography is the main determining factor in vertical layout of sewer network. There are some parameters in sewer design which are closely related to the ground properties above. One of the sewer properties which can be derived from surface is inclination of sewer. Slope is one of the most important parameters for sewer network design. Open channel flow characteristics are mainly dependent on the slope of the pipe. If Manning´s flow equation is considered, where flow is driven only by gravity.

Digital Elevation Models (DEM) also called digital terrain models provide a 3D representation of the real-world topography. DEM creation requires data collection and processing procedures. Data collection step depends on the areal extent and importance of the study.

DEMs play vital role in hydrological analysis especially in delineating watersheds, obtaining stream network, and related analysis.GIS´s spatial analysis capability is an important tool in the design of sewers. Sewer design requires spatial location of individual segments both in the vertical and horizontal dimension. The efforts can be simplified with the help of spatial analysis tool incorporated within GIS. This capability of GIS has found application in many design procedures. In this regard, GIS may be useful in acquiring design information which includes topography, surface features, and street network in order to delineate sub-watersheds, to locate pump stations, and to determine the path for the trunk main

Drainage network from an area is largely governed by topography of the area. For the design of an efficient and economical network of any drainage network, it is necessary to have detailed information about surface characteristics, land use in study area, topographical features [1].

Design of drainage system in gently sloping terrain involves selection of path of drain, its slope, section, materials of construction so that the cost of the project is optimum. For sloppy terrains in hilly areas the problem is much complex because the design of downstream sub water shed network layouts depend on the contributions from upstream sub water sheds.

Digital Elevation Models (DEMs) are extremely useful in areas of civil engineering like 1)terrain visualization, 2)alignment of roads,3)calculation of water spread areas for dams,4)reservoir capacity 5)Alignment of sewers and 6)location of STPs[2].

The Present paper describes an approach of terrain modeling and its use in selection of alignment of drainage for Kukatpally area in Hyderabad, India as case study. The approach uses the spatial analysis capabilities of GIS for selection of optimum layout. Digital data and a GIS software which can analyze and prepare DEM. Raster GIS supports a series of spatial functions that are ideally suited for selection of drainage path. These spatial analysis functions are used to preprocess the data for use by the drainage design programme.

In present work public domain software SAGA GIS [3] has been used and channel network obtained from analysis was compared with natural drainage network plans available from existing records. The deviation from recorded data and derived channel network is very insignificant even the elevation data is very sparse.

II. LITERATURE REVIEW

Several algorithms have been developed for optimal or near optimal design of drainage networks. Most of these network design algorithms employ mathematical programming techniques such as dynamic programming, separable programming, and geometric programming to generate an optimal network.

The development of the GIS offers the potential for significant improvement in the design efficiency of drainage systems. Some attempts have been made in using the GIS for the design and analysis of sewer networks. Przybyla and Kiesler (1991) combined the graphic capabilities of a GIS with an existing sewer system modeling packages to create the Lexington-Fayette Sewer System. The Lexington-Fayette Sewer System uses facilities mapping system and an automated cartographic system running within AutoCAD along with two sewer modeling programs, HYDRA and NEWSE, for the analysis of sewer systems. The primary focus of the work by Przybyla and Kiesler (1991) was the assessment of an existing sewer system performance. Other examples of network applications of GIS that are similar to sewer networks include gas pipeline and water distribution networks[4]

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Currently, some engineering firms are using GIS in their sewer system design process. Frequently, however, their approach is to enter the completed sewer network layout into a GIS to determine the elevation profile and excavation volume between any two manholes maintaining the Integrity of the Specifications

Many algorithms are available in literature like Deterministic 8 (D8): , Rho8, Deterministic infinity (D1), BraunschweigerDigitales Relief model, FD8 and Kinematic Routing Algorithm (KRA)[3]. Each one having its own advantages and disadvantages. In the present study multi-flow direction algorithm (FD8) is used to derive channel network grid[5].

III. METHODOLOGY

3.1 Derivation of DEM

The total Station survey data of Kukatpally Municipality was obtained from NCPE, Hyderabad in the form of xyz text file all along the road network.

Point file in x,y,z text format is used to prepare 100m resolution grid. For each cell in the output grid, an area of a fixed radius greater than 20% resolution of grid i.e. 100m in this case, and maximum of 20 points are used in order to assign elevation to the cell under consideration. One may set this radius using the Search Radius field in the creation of DEM window. Select the optimum radius that ensures that a sufficiently large number of points is found around each cell and there are no gaps in output grid. Larger radius values will cause module execution to take longer, and one should try to find a correct balance. One can introduce in the Maximum Point field, an integer number to select surrounding points. If this field is set, only the values of the closest points around a cell will be used by the interpolation algorithm. If N points are found around a cell within the selected search radius, the value assigned to that cell is calculated using the following expression[3]

$$\widehat{z} = \frac{\sum_{i=1}^{n} z_i d_i^k}{\sum_{i=1}^{n} d_i^k}$$

where z is the value of the point and d the distance from that point to the cell being interpolated.

3.2 Preprocessing of DEM

In order to obtain continuous stream channels from the DEM, it is essential to remove pits or sinks from the grid. Removal of pits is known as preprocessing of DEM. The standard algorithms are available in SAGA GIS in order to identify the sinks and fill them to obtain preprocessed DEM. The other method is deepen the

Drainage routes by excavating the areas of high elevation so that the flow is continuous. However the later method requires more execution time to process the pits. For this reason the first method is more widely used.

3.3 Derivation of Catchment Area

The preprocessed DEM can be used by flow routing algorithms. SAGA GIS is powerful raster analysis engine and its best when dealing with flows and other hydrological concepts. Flow routing algorithms constitute the key element of hydrological analysis. Many different alternatives exist, each one of them with its pros and cons.

Basically, these algorithms can be divided in two groups: First group consider the flow to move between cell centers and the second in which the flow moves “freely” around the DEM cells(known as Flow Tracing algorithms).

The former group algorithms are related with the D8 method (the oldest and the only one that you will find in other GISs) and the second group algorithms are quite more complex.Another division can be made separating those who consider auni-dimensional flow (commonly referred as Single Flow Direction algorithms) and those who consider a bi-dimensionalone (Multiple Flow Direction Algorithms).

Deterministic 8 (D8): The classical. Flow goes from the center of a cell to the center of one (and only one) of the surrounding cells. Flow directions are, therefore, restricted to multiples of 45^o, which is the main reason for most of the drawbacks of the method.

In the present case study multiple flow direction method is used to derive catchment area grid.

3.4 Defining channel networks

Catchment area grid is necessary to obtain other grids like channel network, channel direction and sub watershed grids. However, one of the most important (if not the most) task that can be accomplished using catchment area information is the extraction of channel network grid which is the final objective of case study. In order to derive channel network grid two grids are compulsory: The first one is preprocessed DEM grid that will be used to route the flow and trace the channels, and second is an initiation grid that will supply the information about where the flow has to be routed to create channels. SAGA will choose as initiation cells (cells from where the flow will be routed to trace channels) in the initiation grid that fulfill a particular condition. The catchment area grid is generally used as initiation grid[3]. The channel network grid is in raster format and it cannot be read by CAD packages like autocad. In order to import channel network into drafting softwares, the channel network grid is converted into shape files which can be imported into standard cad packages. The shape(.shp) files are supported by all vector GIS softwares.

IV. STUDY AREA

Kukatpally Municipality is a selection grade municipality surrounded by MCH, Quthubullapur and Serilingampally municipalities located at latitude of $17^0 30'$N and longitude of $78^0 20'$E. Presently it is part of GHMC.

Fig 1 : Project area location in GHMC area

The total area of Kukatpally Municipality is 4441 hectares and is divided into 46 Municipal election wards. The Population of the Municpality as per 2006 record is about 5,00,000. The municipality has the largest residential housing board colony in Asia known as KPHB colony. The prestigious JNT university is also located in this municipality. It has about 400Km length of roads. It is located in the vicinity of the ridge line between Krishna and Godavari river basins.

For the purpose of analysis Kukatpally municipality zone is selected, with road network map, water bodies and x,y,z file from total station survey. Inverse distance algorithm is used to derive DEM from A total number of 19000 points, taken along the road network

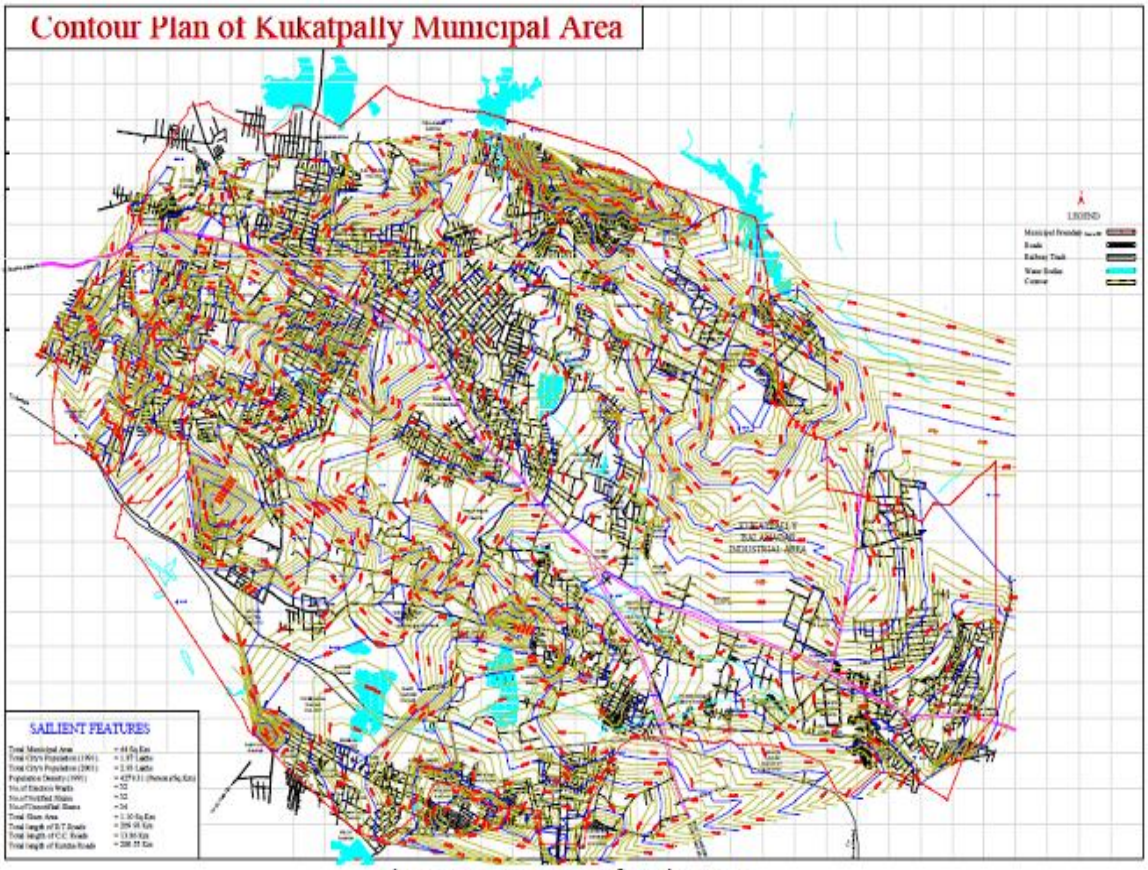

Fig 2: Contour map of Project area

V. ANALYSIS

Channel network pattern is derived from preprocessing of original DEM is shown below.

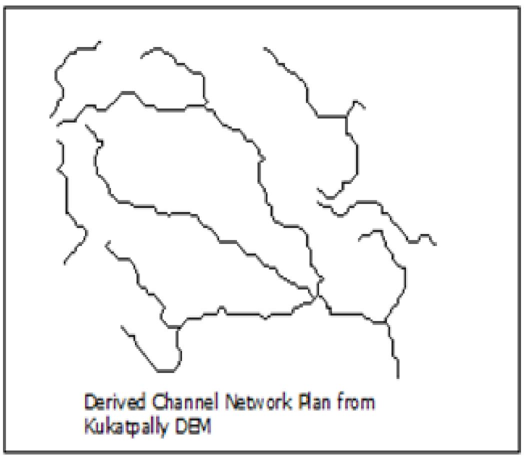

Fig 3: Derived Channel Network Plan

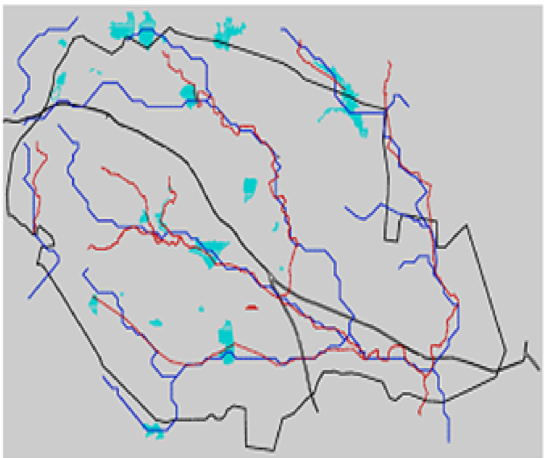

Fig 4: Superimposed Derived Channel network on existing drainage network

The shape file of channel network is exported to Auto-cad to study the existing pattern and Channel network map has been compared with existing drainage network plan of the study area; The Existing drainage network map is overlaid with original drainage map of the study area.

It has been observed that the existing natural drainage network and that derived from preprocessed Kukatpally DEM are almost coinciding except, where elevation data is missing. This can be inferred from the fig no.: 4.

VI. RESULTS AND CONCLUSIONS

1) Channel network can be derived from total station survey file and constructing digital Elevation model
2) The network map can be effectively used in alignment of drains
3) The derived network map can be helpful if natural drainage map is not available
4) The deviation is minimum even when point file data includes surface significant points.
5) Small deviation can be observed if data is sparse and due to cultural phenomenon.

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