Report

Evaluation of urban storm water network in Hyderabad city using SWMM

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2013-2016

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Abstract

Management of the quantity and quality of storm water runoff from urban areas is a complex task which has become an increasingly important environmental issue for urban communities. Together with economic and social issues, this increased awareness of the impacts of urban drainage systems has resulted in a need for system managers to obtain information regarding the drainage system response to varying climatic conditions. In an ideal situation, storm water systems would be designed and analyzed with catchment modeling systems which fully replicated the important processes involved with the generation and transmission of storm water. This ideal situation, however, requires catchment modeling systems, generally mathematical in form, to be developed that include all potential and feasibility. Effective urban storm water management is highly dependent on appropriate consideration of the spatial variability of urban watershed characteristics. This realization has prompted increasing use of physically based urban watershed models such as the Environmental Protection Agency (EPA) storm-water management model (SWMM) (Huber et al. 1983). The use of spatially distributed, physically based models enhances the ability to simulate the dynamic runoff response of urbanizing catchments.

The available historical hydrological data, which is suitable for urban hydrological studies, have been evaluated in the Hyderabad city. No flood inundation maps, short terms rainfall and water level data is available for the study area. However historical hourly rainfall within study area at Hyderabad station (maintained by IMD) has been collected and analyzed. The hourly rainfall computed for 2, 5, 10, and 25 years return periods using Extreme Value Type 1 distribution and developed the IDF formula. During the project period five tipping bucket rain gauges and one automatic water levels recorder have been installed in the study area. The storm water drainage network details were collected and GIS database has been prepared. Using thematic layers of DEM delineated the 15 sub-catchments and drainage network. Using these thematic layers, the study area has been schematized using 15 nodes and 13 links in the EP-SWMM model. Based on measured rainfall and water level data in the study area, the EP-SWMM model performance has been evaluated in terms of stage computation in the study area. The average runoff coefficient found in the study area is 0.863. After successful testing of the model, the design storm for 2, 5 10 and 25 years return periods have been considered as input into the model and found that the present storm water drainage network is not sufficient to drain two-year return period storm. The data monitored in the basin may act as benchmark dataset for further research and to explore other flood mitigation measures in the study area.

Chapter 1

INTRODUCTION

Storm water drainage systems in the past were designed for rainfall intensity of 12 – 20 mm. These capacities have been getting very easily overwhelmed whenever rainfall of higher intensity has been experienced. Further, the systems very often do not work to the designed capacities because of very poor maintenance. Encroachments are also a major problem in many cities and towns. Natural streams and watercourses have formed over thousands of years due to the forces of flowing water in the respective watersheds. Habitations started growing into towns and cities alongside rivers and watercourses. As a result of this, the flow of water has increased in proportion to the urbanization of the watersheds. Ideally, the natural drains should have been widened (similar to road widening for increased traffic) to accommodate the higher flows of stormwater. But on the contrary, there have been large scale encroachments on the natural drains and the river flood plains. Consequently the capacity of the natural drains has decreased, resulting in flooding.

In most of the cities, damage to vital infrastructure has a bearing not only locally but could even have global implications. They are also densely populated and people living in vulnerable areas, both rich and poor, suffer due to flooding. It has sometimes resulted in loss of life, damage to property and disruptions in transport and power, bringing life to a grinding halt, causing untold misery and hardships. Even the secondary effects of possible epidemics and exposure to infection takes further toll in terms of loss of livelihood, human suffering, and, in extreme cases, loss of life. Therefore, management of urban flooding has to be accorded top priority. Increasing trend of urban flooding is a universal phenomenon and poses a great challenge to urban planners the world over. Problems associated with urban floods range from relatively localised incidents to major incidents, resulting in cities being inundated from a few hours to several days. Therefore, the impact can also be widespread, including temporary relocation of people, damage to civic amenities, deterioration of water quality and risk of epidemics. Improper disposal of solid waste, including domestic, commercial and industrial waste and dumping of construction debris into the drains also contributes significantly to reducing their capacities. It is imperative to take better operations and maintenance actions.

Before developing the computer software for the design of storm water drain, knowledge and computer programming and the thorough understanding of design principle of storm water drains are necessary. The developed software has to be user-friendly and well interactive. The design principle starts from the analysis of historical rainfall data to simple hydraulic equations. The quantity of surface runoff resulting from rainstorm has dramatically increased due to in imperviousness and decreases in infiltration and evaporation associated with urbanization. These increases require construction of drainage systems with sufficient capacity to carry the large amount of surface water and/or mitigation measures to reduce peak flow rates to pre-urbanization levels. Therefore, estimation of surface runoff due to rainfall events is a key factor in drainage system net working design, which is employed in the present study. Hydrologic models and hydraulic models are tools commonly used in determining runoff hydrographs from rainfall excess.

The Rational method which is widely used for the design of storm drainage system is simple to use, but it allows only the determination of the discharge hydrograph peak. Limitations include the inadequacy to account in large catchment for pipe routing or variations in rainfall intensity, contributing area and rate of contribution. The further drawback in the method is the lumping of all physical factors into two parameters (runoff coefficient and time of concentration) which makes parameter estimation subjective and is generally found to be simplistic to permit actual discharge to be adequately predicted from observed rainfall. In the recent past much research has gone into the development of digital simulation models which can aid in the design, evaluation and management of the urban drainage system. At present, there are several urban catchment simulation models available and in this study application of such model is presented the Storm Water Management Model (SWMM).

Present study uses information contained within GIS data base in the ERDAS & Arc View environmental together with a catchment modeling system such as the Storm Water Management Modeling (SWMM).The main objects of the present study are to develop the outfall hydrograph, water profiles along the storm channels, evaluate the runoff volume for the designing storm of various return periods and feasibility to integrate the existing drainage network with interflow to mitigate urban storm water flooding in the study area of GHMC Zone XII.

Chapter 2

LITRATURE SURVEY

The introduction of new design principles on drainage net working is a sensitive issue in the recent times. It is very important for those making recommendation to remember that the current design principle may have been successful for many years and that unnecessary changes may serve only to confuse and complicate matter while generating to positive benefit. In addition, the rehabilitation of drains is considered and it will be necessary to have an understanding of the original design methods and assumption made in those methods. To analyze a complex drainage net work, computer modeling has become a necessity. Computer modeling has become an integral part of storm drainage planning and design in the mind-1970s. The proliferation of micro-computers in the 1980s has made it possible for virtually every engineer to use state of the art of analytical tool for the analysis of comprehensive storm water management for an entire city. Methods available for Computer models, storm water runoff models and their comparisons are dealt in the following sections.

Large numbers of investigations have been carried out by many authors. Starting from Tholin Hydrograph method (Tholin et al. 1959), the urban runoff models have been developed through British Road Research Laboratory Model, RRLM (Watkius 1962), University of Cincinnati Urban Runoff Model, UCURM (Papadakis et al. 1972), HEC-1 (Hydrological Engineering Centre 1985), HEC-2 (Hydrological Engineering Centre 1982) and SWMM (Metcalf and Eddy 1971) and its later version EPA-SWMM (Rossman 2005).

2.1 Urban Runoff Models

National Institute of Hydrology (1986-87) in its report has presented the details of the various available overland flow models and their methodology of functional analysis has been explained. In most of the models reviewed, the required input data are the topography of the area, rainfall, soil type and land use pattern of the area. Thirteen models are discussed and compared including, SHE (System Hydrologic European) model, USDA model, SWMM model, UCURM model, RRLM model, HEC-1 and HEC-2. These are physical models, which simulate catchments transformation process based on physical processes involved with some degree of reality.

General procedure in modeling overland flow is explained. The steps involved in the modeling of overland flow are (i) to decide the method of spatial representation of the catchment, (ii) to decode upon the various key parameters to be used and finally (iii) to select an appropriate numerical method for solving the equations (NIH 1986-87).

In the rational method of modeling the greatest drawback is that it provides only one point (peak flow) on the runoff hydrograph, whereas in case of complex storm analysis and catchment characteristic analysis, the entire flood hydrograph is required (NIH 88-99). The Curve number and Manning roughness coefficient value for different types of landuse are used as input data to many models for overland flows (Sheafter et al. 1982). The analysis is made keeping the entire basin as a single catchment and compared the results of the same model to the basin considering it as different sub-catchments. It is found that, the semi-distributed model gives a better goodness of fit than the lumped basin approach (Kite et al. 1992). In large catchment, when the area of the catchment is not equal to the area of the storm, then it will have a large coefficient of storm runoff (Eagleson 1985). A conceptual rainfall runoff model for urban catchment, which incorporates the semi distributed modeling concepts, has been developed by Aronica and Cannarozzo (2000). In the model proposed, the catchment was divided into external sub-catchments connected to the drainage network. Each external sub-catchment was modeled as two separate conceptual linear elements, as a reservoir and a channel; one for the pervious part and other for the impervious part of the drainage area. The drainage network is schematized as a cascade of non-linear cells and the flood routing is simplified in the form of kinematic wave and represented as a flux transfer between adjacent cells. The field experimented data are used for comparison of the results of simulation, which have pointed out how both the variation in the spatial representation of the rainfall and the variation in the spatial descertization of the catchment has a definite influence on the outlet hydrographs, especially for high intensity storm events.

The development and application of the two-dimensional model based on the explicit finite difference scheme (Mac Cormack) coupling the overland flow and infiltration processes for natural hill slope which is represented by topographic elevation and soil hydraulics parameters (Esteves et al.2000). This model allows modeling of hortonian overland flow and infiltration during complex rainfall events. Green and Ampt equation (Esteves et al. 2000) has been used for reproducing of overland flow and transfer between different levels of catchments in the region. The accuracy of the results is tested by comparison with experimental field data on the basis of calibrated soil and surface friction parameters. The results indicated the effect of micro-topography on their distribution of the flow depths, the magnitude and direction of flow velocities and infiltration depths using 1D-Kinematic wave equation for variable width and curvilinear flow paths. This equation is derived from the 2D-kinamtic wave equation expressed in the orthogonal-curvilinear co-ordinate by aligning the coordinate system with runoff surface topography. The 1D -equation is solved by four points implicit finite difference scheme in a sheet flow model using multiple flow paths, which is described and tested on an impervious surface (Tisdale et al., 1999).

2.2 Methods available for storm water runoff calculation

Methods available for estimating the quantities of storm water draw urban areas and small watersheds may be classified as the rule of thumb approach, the macroscopic approach and the continuous simulation.

The first method for the calculation of storm water runoff was involved in 1857 with a rule of thumb approach. The 20th June 1857, on the Savoy street sewer is London 25.4mm rainfall occurred in 75 minutes and it produced a peak flow of 2.728×10^{-4}cu.m/sec/area. Thus was the basis of the rate of thumb approach. Based upon the information thus available; Bidder, Hawksley and Bazalgette obtained some empirical relationship between rainfall and runoff to design the sewer system. At that period, a general English rate of thumb was “about half of the rainfall would appear as runoff from urban areas". Even though these ideas are not scientifically based, they were the stepping stone to the development of modern hydrologic models.

Following the concept of early rate of thumb "empirical formulae" became the principle tool for quantifying the runoff. Most of this second generation approach was macroscopic. They considere3d the entire drainage area as a single unit, assured the rainfall as uniformly distributed over the area and they calculated the runoff only at the downstream point. The foremost example of this approach is the rational method (Kuichling, 1889) introduced in United States. It was based on four years of rainfall data using non- recording rain gauges and one year of runoff data from pairs of white washed sticks. Five open ditches ware used fro flow determination. Rational method has been used foe over a half a century with changes in its original form. Even today also practicing professionals working in urban hydrology area are using this method due to its simplicity. A second example of the macroscopic approach is the unit hydrograph method developed by Sherman (1932). Unit hydrograph is the hydrograph of a centimeter of runoff from a drainage basin produced by a uniform rainfall of unit duration's. Originally, the unit hydrograph concept was applied mainly to river basins, but now a day it is used for urban watershed also, after the introduction of concept of instantaneous unit hydrograph. Nash model (1957) uses the concept on instantaneous unit hydrograph.

The third generation approach is "microscopic approach" characterized by an attempt to quantity all pertinent physical phenomena form input (rainfall) to the output (runoff) involving the following steps: 1) determination of the design storm, 2) calculation of the rainfall across rate, 3) determination of the flow to gutter from overland flow, 4) routing of the gutter flow to the main channel, 5) system and 6) determination of the out flow hydrograph. the accuracy of the results is affected by accuracy of calculating the hydraulic phenomenon and the validity of assumptions employed. Tholins hydrograph method (Tholin and Keifer,1959) is an example of the microscopic approach. In the past, most of the microscopic approaches dealt with individual storm events. But with the advent of microcomputers, continuous simulation of hydrologic process is possible now (Carmford and Linsely, 1996) and this trend is on increase.

The forth generation approach is "Simulator Models" for the urban watershed analysis. Physical models, analogue model or digital models may simulate hydrologic systems. Storm water management model (SWMM) and Stanford watershed model are widely useful for urban watershed and small watershed studies.

2.3 Comparison of Urban Runoff Model

Heeps and Mein (1974) compared the performance of three urban runoff models namely the Road Research Laboratory Model (RRLM), Storm Water Management Model (SWMM) and University of Cincinnati Urban Runoff Model (ULURM). This comparison is done for the hydrograph peak point as well as for the entire hydrograph. The results of study indicated that when applying the three selected non-calibrated model on small urban catchments, the SWMM model performed marginally better than the RRLM model and both these models are more accurate than the UCURM.

The following are the conclusion arrived from their studies:

a) Uncelebrated deterministic models for urban runoff, such as RRL, SWMM and UCURM yielded a fairly good agreement between the simulated and measured runoff events on typical urban catchment of small size.

b) On an average about 60% of the simulated peak flow are within 20% of simulated time to peak and runoff Volumes. The agreement between the measured and simulated values could be further improved by model calibration.

c) Out of the three model studies, the SWMM simulated results are marginally better than those by RRL and both these models are accurate than UCURM, with all model in a calibrated version. The main advantage of the RRL is its simplicity since it can be applied without a computer. The SWMM is on the other hand, much more general, versatile and is being continuously refined and improved.

d) The SWMM model has the most advantage routing scheme among the considered method in the different models as available and so the accurate of flow routing becomes particularly important when studying large watersheds.

Several qualitative compassion of the RRL, SWMM, UCURM, ILLIDAS, and STORM models have been reported in the literature. A qualitative comparison of several was prepared by Larger and Smith(1974) in the table 1.

2.3.1 Storm Water Management Model

The SWMM (Huber and Dickinson 1992) is a comprehensive mathematical model for simulation of urban quantity and quality in storm and combined sewer system. The SWMM is one of the most widely used model for analysis of urban runoff quantity and quality. Manning's equation and a nonlinear runoff flow routing procedure are the basis of the transformation of rainfall excess to runoff hydrograph.

The Environmental Protection Agency (EPA) SWMM is one of several advanced computer assisted models designed to simulate urban storm water runoff. The SWMM is capable of predicting and routing the quantity and quality constituents of urban storm water runoff. The model consists of four functional program blocks, plus a coordinating executive block. The blocks can be overlaid and run sequentially or can be run sequentially or can be run separately with interfacing data file. The choice of mode depends on user needs. The first of the functional blocks, the Runoff block, simulates continuous runoff hydrographs and pollutographs for each subcatchment in the drainage basin. Runoff hydrographs are predicted based on an input hyetograph and the physical characteristics of the subcatchment ; including area, average slope, degree of imperviousness, overland flow resistance factor, surface storage and overland flow distance.

Pollutographs are generated based on the volume of storm runoff and the antecedent conditions including rainfall history, street sweeping data, land use and related data. Runoff flows within each subcatchment may be routed via gutters or pipes; however, all flow from a particular subcatchment must enter one designated manhole for transfer to the second functional block, the transport block.

The conceptual representation of the drainage system is based on the “link-node” concept which does not constrain the drainage system to a dendritic form. Links transmit flow from node to node. Properties associated with the links are roughness, length, cross-sectional area, hydraulic radius, and top surface width. The primary dependent variable in the links is the discharge (Q). Nodes are the storage elements of the system and correspond to manholes or pipe junctions in the physical system. The variables associated with a node are volume, head, and surface area. The primary dependent variable is head (H), which is assumed to be changing in time but constant throughout any one node.

The Storage/Treatment block permits inclusion of external storage elements and treatment facilities in the modeling scheme. Treatment modes programmed includes bar racks, dissolved air flotation systems, fine screens, sedimentation tanks, micro-strainers high rate filters, effluent screens and chlorine contact tanks. Treatment facilities are sized based on influent flow rates. Estimated costs can be generated for storage and treatment facilities chosen.

The latest PCSWMM version is PCSWMM 98 (April 1995). PCSWMM98 is a decision support system for the EPA Storm Water Management Model SWMM, providing a large array of file management; data file creation, output interpretation, and reference tools for the storm-water modeler. Rewritten for the Win ‘95/NT operating systems, PCSWMM98 has taken a new approach to provide a unprecedented level of flexibility and power. Users can develop their own in-house modeling environments using the extensive selection of plug-in tools and PCSWMM’s seamless integration of any external processes (programs, batch files, macros, etc.). PCSWMM98 is distributed with the latest BETA version of SWMM 4.4 from Oregon State University, as well as the SWMM 4.31 release and works in conjunction with the Rain, Temperature, Runoff, Transport, Extran, Storage /Treatment, Combine and Statistics modules.

2.3.2 Need for modeling

Drainage systems have changed from principle ditches to complex networks of curbs, gutter and conduits. Simple thumb rules and empirical formulae are generally inadequate. It is after essential to account for all key hydrologic processes and combine thus in composite models that yield outputs at points of interest in time and space. Since the little hydrological data are available on small watersheds. It is accepted that mathematical modeling is the only available means of making reliable predictions of the effects of land use change on stream flow quantity analysis.

2.4 Urban Hydrology integrated with GIS

GIS has a long history of use in the water resources field; this is due in large part to the early availability of remotely sensed spatial data suited for this purpose. Work in natural area tends to focus on grid, or raster based, hydrology, whereas work in urban areas because of their complex hydraulic and hydrologic remains tends to use more complex models that are vector based. Raster based approaches use rectangular as their fundamental unit within which hydrology characteristics are uniform. Vector based models use coordinate geometry to define unique boundaries of hydrologic characteristics. A good overview of the concept of GIS and database technology and their application within the field of natural system hydrology is found in Singh and Fiorentino (1996).

Hellweger and Madidment (1999) developed an integrated application for delineating drainage basins and determining surface runoff in natural watershed using the HEC-HMS (Hydrology Engineering Center – Hydrologic Modeling System). Application of GIS in urban storm water system has been more limited because of the need for large, expensive, and detailed spatial and temporal databases (Heaney et al. 1999a)

Finberg and Uhrick (1997) discuss integrating an infrastructure database in Broward County, Florida, with a GIS and water distribution and wastewater models. The HydroWorks model is use to simulate the wastewater collection system with close integration with database of infrastructure characteristics and the GIS.

Refsgaard et al. (1995) describe the evolution of the Danish Hydraulic Institute's (DHI) land process hydrologic model SHE (System Hydrology Europeen) and its extensive use of GIS.Hellweger (1996) developed an ArcView (GIS) application using the Avenue scripting language to perform the calculation of an SCS-based model, TR-55.

Shamsi (1998) distinguishes three forms of information exchanges between ArcView GIS and the EPA storm water management model (SWMM): interchange, interface, and integration, listed in order of complexity. Integration, as defined by Shamsi(1998), combines a SWMM graphical user interface (GUI) with a GIS to provide a complete data environment. Shamis (1997) points out the advantages of a GUI and provides a summary of software features and needs for SWMM interfaces.

Bellal et al. (1996) studied partly urbanized basins using a linked GIS and hydrological model. The hydrological model was based on a nonurban water budget, with modifications to account for urbanization. The GIS was based on a digital elevation model (DEM) and raster based land use data

Effective Urban storm water management is highly dependent on appropriate consideration of the spatial variability of urban watershed characteristics. This realization has prompted increasing use of physical based urban watershed models such as the Environmental Protection Agency Storm Water Management model (EPA-SWMM) (Huber et al.1992). The use of spatially distributed, physically based model enhances the ability to simulate the dynamic response of urbanizing. Since continuously measured runoff discharge data are generally lacking in urban area for model calibration purposes, physically based models provide a means of predicting runoff based on other field measured data and map information. In addition, physically based models provide a stronger basis for evaluating the impacts of system wide structural and non structural urban storm water management strategies. With this enhanced technical capability, however, also comes an increased burden on urban water managers to satisfy the spatial data base requirements associated with more realistic, physically based modeling.

Current geographical information system (GIS) technology provides power capability for supporting the spatial data base requirements of urban storm water management. GIS technology has been heavily utilized for several years in natural resources management for digital mapping, carto-graphic modeling, and analysis referenced data, but has only recently gained recognition as a viable engineering tool in urban storm water management.

Catchment information was constructed in an ARC/INFO data base and transformation developed using this information to generate the input information necessary for operation of a SWMM-based catchment modeling system to simulate surface runoff (Choi et al.2002). The application of the GIS to storm water management of urban development can be accommodated in a low cost, PC-based computing environment and GIS is in addressing issues such as data precision, accuracy, resolution, and degree of aggregation to provides an improved assessment of the reliability of estimated parameters, compared to traditional methods (Meyer et al.1993)

Davies et al (2008a, b) presented case studies on impacts of climatic change and urbanization on drainage in the Helsingborg, Sweden (Suburban storm water and also in combined sewer system). These two studies revealed that, urbanization was successfully simulated to reflect current trends in demographic and water management. It was also found that city growth and projected increases in precipitation, both together and alone, may worsen the current drainage problems. Conversely, installation of sustainable urban drainage systems (SUDS) has a positive effect on the urban environment.

Ram Mohan Rao et al (2013) 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.

ble 1. Comparison of Urban Runoff models and methods (Viessman. W. Jr. et al 1989)

Sl	Model	Surface routing	Sewer routing	Quality routing	Degree of sophistication of surface floe routing	Degree of sophistication of sewer floe routing	Accrete modeling surcharging	Flexibility of modeling of sewer components	Explicit modeling of in system storage	Treatment modeling	Receiving model available	Degree of calibration/verification required	Simulation period	Availability	Documentation	Data requirement
1	Rational Method	Peak flow only	Peak flow only	No	Low	Low	No	Low	No	NA	No	Usually not verified	Individual storms	Nonproprietary	Good	Low
2	Chicago	Yes	No	No	Moderate	NA	NA	NA	NA	NA	No	Moderate	Individual storms	Nonproprietary	Fair	Moderate
3	Unit Hydrograph	Yes	In combination with surface	No	Low	Low	No	Low	No	NA	No	High	Individual storms	Nonproprietary	Fair	Moderate
4	STORM	Yes	In combination with surface	Yes	Low	Low	No	Low	No	Yes	No	Low	Long term	Nonproprietary	Good	Moderate
5	RRL	Yes	Yes	No	Moderate	Low-moderate	No	Low	No	NA	No	Moderate	Individual storms	Nonproprietary	Good	Moderate
6	MIT	Yes	No	No	High	NA	NA	NA	NA	NA	No	Moderate	Individual storms	Nonproprietary	Good	Moderate
7	EPA-SWMM	Yes	Yes	Yes	High	Moderate	Yes	High	Yes	Yes	Yes	Moderate	Individual storms	Nonproprietary	Good	Extensive
8	Cincinnati (UCUR)	Yes	Yes	Yes	High	Low	No	Low	No	No	No	Moderate	Individual storms	Nonproprietary	Good	Extensive
9	HSPF	Yes	Yes	Yes	Moderate	Moderate	No	Low	No	No	Yes	High	Individual storms	Nonproprietary	Good	Extensive
10	ILLUDAS	Yes	Yes	No	Moderate	High	No	Low	No	NA	No	Moderate	Individual storms	Nonproprietary	Good	Extensive

Chapter 3

STUDY AREA AND DRAINAGE PROBLEM

Hyderabad became the capital of the state of Andhra Pradesh in 2014 The city of Hyderabad was founded by Mohammed Quli Qutub Shah on the southern bank of Musi River in 1591. Hyderabad is situated in the Deccan plateau, at an elevation of 536 meters above sea level. The city lies between 17.24° N latitude and 78.30° E longitude as shown in figure1. After creation of Greater Hyderabad Municipal Corporation (GHMC) and divided into 16 Zones , Hyderabad became the second largest in India, in terms of its' geographical area, with a spread of 7,000 sq. Km and within outer ring road spread of 1460 sq. Km. It has been seen from the records of rainfall from the Indian Metrological Department (IMD), the months of July, August and September are generally heavy rain months. The total rain in these months works out to 551 mm for normal rain fall. Hyderabad city gets annual average rainfall nearly 847 mms. City gets nearly 664 mms of rain fall in June to September period.

Hyderabad is unique topography of many undulations, rain water flows to the low-lying areas rapidly resulting in inundation of many low lying areas very quickly. Due to the above reasons several parts of the city experiences local floods mainly confined to the low lying areas in the built up areas and the fore shore areas of the tanks. This type of situation was not experienced in the past, possibly due to much less population as compared to the present level and also the fact that infrastructure and constructions were limited. Due to this situation the city experienced floods as a result of heavy rains in recent years.

The population shift resulted in enormous pressure for shelter and services fray the infrastructure. Not only in Hyderabad but in all Indian cities and towns, large habitations are coming up in low-lying areas, often encroaching over drainage channels. In some cases, houses are constructed even on top of nallahs and drains. Encroachment in the immediate upper catchments of hilly urban area has also caused serious flooding in the flood plains of cities surrounded by hills. Urbanisation in Hyderabad leads to increase in impervious areas which, in turn, significantly increased the rate of runoff, resulting in overwhelming of designed capacity of the storm water drainage system.

3.1 Drainage Problem

City of Hyderabad experienced unprecedented flooding in August 2000 leading to massive property damages and some human loss. City of Hyderabad with a population of around 3.82 million (2001 Census) and spread over an area of 55sq.km had severe floods in September 1908; August 2000 and August 2008. Property losses and human lives lost along with extent of people affected in these floods is presented in table 2 below. The current water drainage capacity of Hyderabad is to handle 12 mm/hour rainfall. Clogged up drains, unauthorized encroachments of moosi river beds and development along river banks that block natural drains further reduce storm water drainage capacity of the urban areas.

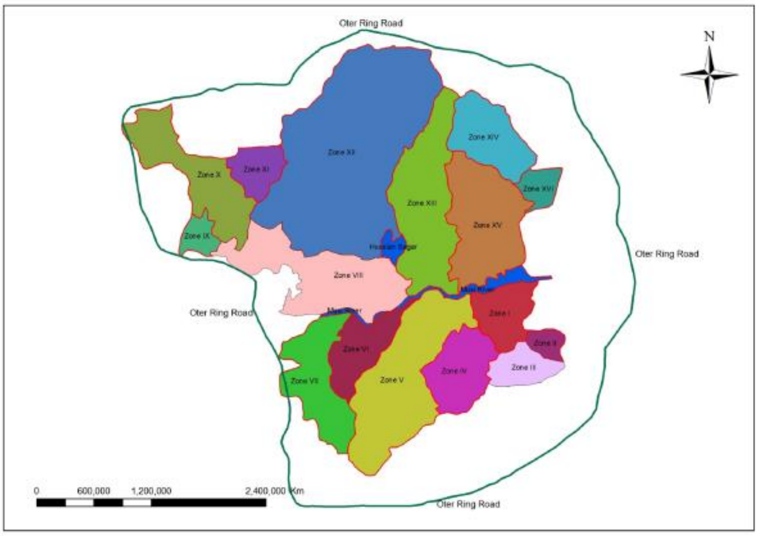


Figure1. Hyderabad City with GHMC Zones within the Outer ring road

Hyderabad became the capital of the state of Andhra Pradesh in 1956 and experienced a large scale of migration from coastal areas, Rayalseema and other parts of Telangana region. Poverty was the main factor for this rural-urban migration because of the employment opportunities created by the rapid development that took place especially in the Ninety's. As per 2001 census, Hyderabad city is one of the fastest growing metropolitan cities with a decadal growth rate of 32%.After creation of Greater Hyderabad Municipal Corporation (GHMC), Hyderabad became the second largest in India, in terms of its' geographical area, with a spread of 7,000 sq. Km and within outer ring road spread of 1460 sq. Km.

The population shift resulted in enormous pressure for shelter and services fraying the infrastructure. Urban development plans could not cope with the population settlements which came up quickly wherever land was available. This haphazard growth had its consequential effect on the communities, whenever there is a heavy rain fall which caused inundation of the low lying areas due to the peculiar topography of the city and surrounding areas. The drainage system did not have the capacity to drain the runoff of the rains quick enough to prevent inundation. The common experience has been that the surplus rain water created major traffic jams inundated several areas of the built up area, and floods in some parts of the city resulting in damages to public and private property.

Not only in Hyderabad but in all Indian cities and towns, large habitations are coming up in low-lying areas, often encroaching over drainage channels. In some cases, houses are constructed even on top of nallahs and drains. Encroachment in the immediate upper catchments of hilly urban area has also caused serious flooding in the flood plains of cities surrounded by hills. Urbanisation in Hyderabad leads to increase in impervious areas which, in turn, significantly increased the rate of runoff, resulting in overwhelming of designed capacity of the stormwater drainage system. As a result of all these happenings, even small amounts of rainfall are generating urban flooding.

Flooding is largely caused by Meteorological factors (like cyclonic storms, monsoon rains), Hydrological factors (like Groundwater and soil moisture level prior to storm Natural surface infiltration rate, Presence of impervious cover, Channel cross-sectional shape and roughness) and Human factors like Land use changes (e.g. surface sealing due to urbanization, deforestation) increase runoff and sedimentation, Occupation of the flood plain and thereby obstructing flows, Inefficiency or non maintenance of infrastructure, Urban micro-climate may enforce precipitation events, Indiscriminate disposal of solid waste. In the case of Hyderabad frequent flooding is largely caused by human factors rather than meteorological and Hydrological factors. Present study basin as GHMC Zone XII selected by GHMC officials as shown in figure 2

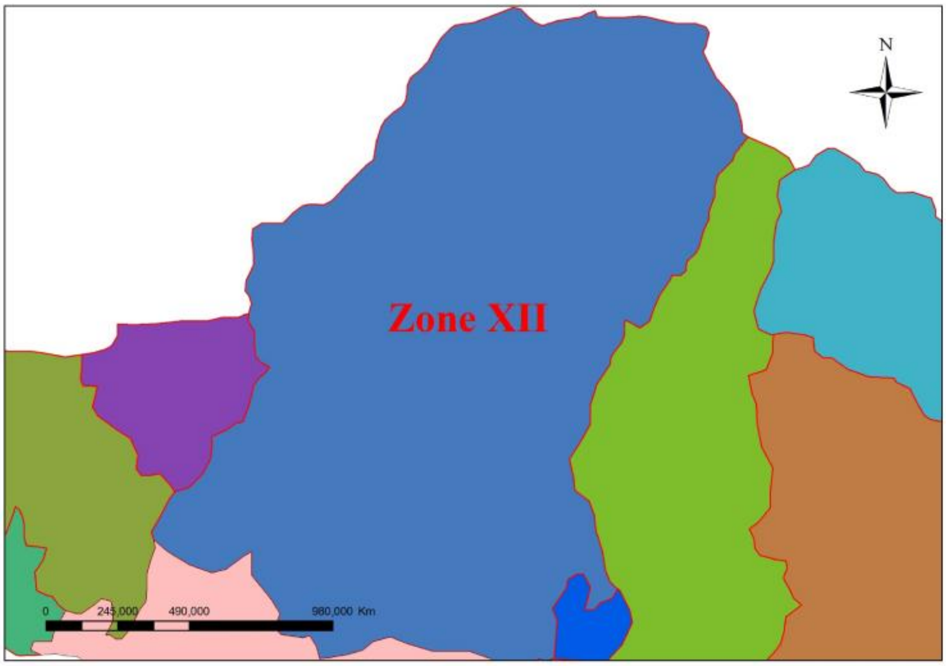


Figure2. Study basin GHMC Zone XII

Chapter 4

METHODOLOGY

Urban areas concentrate population and production and provide some obvious advantages over rural settlements. Urban community is served with the facilities of all kinds mostly at door step at a cheaper price compared to rural community. In particular, the service providers have larger and concentrated customer population in urban areas to enable them to maintain lower specific cost for the provision of potable water supplies, sewers and drains, garbage collection, telecommunication, transportation, health, educational and emergency services.

Urbanization accompanies the introduction of vast impervious areas, efficient hydraulic conveyance systems and supply of large volumes of pipe water resulting changes to an urban setting to dramatically alter the surface and subsurface hydrology. Urbanization is also responsible for increase of discharging pollutants to natural water bodies. The concentration of domestic, commercial and industrial wastes causes major environmental and health problems for the inhabitants.

Modeling of hydrologic processes for estimating runoff generated from the catchment for the purpose of stormwater drainage design is discussed here. Storm water runoff generated by a rainfall event depends on the catchment characteristics and rainfall characteristics. Design requirements for urban stormwater drainage are usually specified in terms of a rainfall of certain return period.

4.1 Catchment and sub catchment delineation

The catchment area to be drained is required to be defined based on the topography of the area. In some cases, there may be discharges into the catchment other than through gravity flow from areas outside the normal catchment. For example, there may be pumping of urban drainage flow from an adjacent catchment. The effective catchment area contributing to the catchment drainage flow includes all such contributory catchments.

Drainage network in a catchment whether pre-urban or urban catchment, consists of distribution of drainage paths (drains, streams) that converge to form the main drain/stream at the outlet of the catchment concerned. Urban catchments are usually modeled not as a single catchment but as collection of subcatchments. This practice has several advantages. Distributed properties in a heterogeneous urban catchment can be taken into consideration. In relation to the design of components of urban storm water drainage system, the design flows are required not only at the outlet of the catchment but also at the outlets of all drainage paths converging to the main stream. Also, the effect of attenuation of peak flow within the drainage network of the catchment by routing the flows discharged into the main stream (and sub-mains) at different points with time lags provides realistic distributed discharges in the network. Overland flow routing may be not necessary if a subcatchment is very small.

4.2 Rainfall Analysis

Rainfall characteristics important for planning and design of storm water drainage in a catchment are rainfall intensity, temporal variation including rainfall duration and rainfall depth, spatial variation and recurrence interval of rainfall. Intensity is a measure of the quantity of rain falling in a given time (e.g. mm/hr). Duration is the period of time during which rain falls. Recurrence interval or return period of a rainfall of certain magnitude is the average length of time expected to elapse between the rainfall events of equal or greater magnitude.

4.2.1 Intensity-Duration-Frequency Analysis

Intensity-duration-frequency (IDF) curves at a location are one way of presenting rainfall data available at location by statistical analysis. Frequency refers to the probability that a storm of given magnitude will be equaled or exceeded in a given year and is equal to the reciprocal of the return period in years. IDF curves provide average rainfall intensities corresponding to a particular return period for different durations.

4.3 Surface flow analysis

After filling the depression storages on the surface, surface water generated by precipitation flows downstream first as overland flow. Overland flow concentrates into rill flow, and then rill flow concentrates into gully flow and into stream flow. Surface water flow is driven by gravity as a free surface flow against ground undulations, vegetations, soil surface roughness, pebbles, debris, etc. Accurate hydraulic analysis of surface flow by the application of conservation laws is not practical owing to the complexities of different scales involved in the surface flow process. Therefore, surface flow analysis is carried out under varying assumptions in catchment modeling. At one end of the range of analysis, outflow from the catchment is directly related to excess rainfall by statistical/empirical means with no attention given to hydraulics of flow. At the other end, physically based approaches by the application of fundamental laws of conservation of mass and momentum are applied to route flow through the catchment. Physically based approaches in surface water flow modeling have become increasing used with the advancement of computational hydraulics. However, various assumptions, such as overland flow as sheet flow, flow as uniform flow, etc. are common to simplify the hydraulic analysis. In most cases the direct analysis of adequate stream flow data is better than the use of rainfall based techniques for the estimation of various stream flow characteristics. However, because rainfall data are generally more widely available than stream flow data, the concept of using rainfall data to estimate stream flow characteristics is well established. A simple catchment model relates the discharge hydrograph to the mean catchment rainfall hyetograph also as a function of time.

4.4 Catchment modeling concepts

Catchment models are simplified representations of hydrological processes in the catchment part of the hydrologic cycle to simulate catchment response to precipitation. Catchment models provide changes in catchment water storages, outflows due to a given precipitation.

There are different types of catchment models developed at various complexities. They can be event based or continuous precipitation-runoff type models. Event based models are applied for discrete storm events where as the continuous precipitation-runoff models are applied to time series data of precipitation of long period.

For urban drainage design problems, the engineer is most interested in finding the peak discharges resulted from a given rainfall event for sizing the drainage facilities. The event based models are best suited for this purpose. In some cases, the urban drainage water management in a urban drainage systems with canal networks and water retaining and detaining structures, infiltration structures is of interest. Water stored are released, flows are regulated for various purposes such as for the use in irrigation, power generation or to maintain environmental flows. In these cases, the understanding of catchment responses together with the existing systems are of interest and the application of continuous precipitation-run off type models over a longer period is necessary. This type of models are also important in the estimation of flood inundation under repeated rainfall events in wet weather periods and water table variations in dry weather periods.

4.5 Stochastic and deterministic models

Stochastic models are based on data. Statistical concepts are used to link input (for instance rainfall) to the model output (for instance runoff). Commonly used techniques are regression, neural networks , etc.

Whereas, deterministic models do not consider randomness. The model determines an output for a given input based on certain formulation. Deterministic models are commonly used for runoff modeling that is useful for storm water drainage and hence only types of deterministic models are discussed below.

4.6 Lumped vs. Distributed Models

Lumped models do not explicitly take into account the spatial variability of inputs, outputs, or parameters. They are usually structured to utilize average values of the catchment characteristics to determine runoff at the outlet of the catchment. Lumped models ignore the internal spatial variations flow and provide the stream flow only at the outlet of the catchment.

Distributed models, can account for spatial variations in input parameters and state variables within the catchment. In these models, catchment is divided into elements (by a grid) and precipitation, infiltration, evaporation and other catchment processes are modeled and overland flow, soil moisture is computed at element level.

4.7 Conceptual vs. physically based models

In conceptual models, the catchment is conceptualized as having homogenous soil properties, receiving uniform rainfall, under one type of management, etc. Conceptual lumped models use an integrated description of parameters representing an average value over the entire catchment. They remain non-physically based, however, as they use synthetic methods of transforming rainfall to runoff. Examples of lumped conceptual models are the Rational Method, and the NRCS (SCS) curve number model. A large catchment can be divided into a number of subcatchments to apply different hydrologic parameters to different sub-catchment. Then conceptual model can be considered as conceptual distributed models.

Physically based models, incorporate physical formulations of the different hydrologic processes and often include numerical solutions to partial differential equations. They attempt to represent the physical processes observed in the real world. Physically based models are usually distributed models and have the advantage of simulating complex hydrologic systems and utilizing distributed field hydrologic data. These models require more distributed data on rainfall and catchment properties. Flow is routed over the land and along streams by the application of conservation laws with some approximations. Detail spatial and temporal distribution of responses is available. Example of physically based catchment models of this type include: MIKE SHE (Refsgaard and Storm, 1995), Stanford Watershed Model (SWM), Storm Water Management Model (SWMM)), Hydrological Simulation Program – FORTRAN (HSPF)

4.8 SCS-Curve Number Method

The SCS-CN method is used in runoff volume calcula-tion using the values related to landuse and soil data so that integration of these data determine CN values for the watershed to consider amount of infiltration rates of soils. The CN values for all the types of land uses and hydro-logic soil groups in GHMC Zone XII are adopted from Technical Release 55. In this regard, Soils are cate-gorized into hydrologic soil groups (HSGs). The HSGs consist of four categories A, B, C and D, which A and D is the highest and the lowest infiltration rate respectively. To create the CN map, the hydrologic soil group and land use maps of the Klang watershed are combined by cross function in ARCGIS to get a new map integrated of both the land use and soil data.

4.9 GIS Analysis

The following aspects of methodology used for delineation of the GHMC Zone XII of Hyderabad City map in GIS environments are discussed as follows.

Estimating catchment modeling system parameters have been developed to improve the traditional calibration process, which requires a time insensitive and tedious search for accurate valve of large number of model parameters. Catchment information was constructed in an ERDAS image process/Arc View data base and transformations developed using this information to generate the input information necessary for operation of EPA-SWMM based catchment modeling system to simulate surface runoff processes in Patna Town area .Base map coverage’s are depicted schematically in figure 2a &2b. The following coverage’s were developed

1) Catchment delineation
2) Subcatchment delineation
3) Elevation
4) Land use map
5) Drainage network map
6) Drain exit points for all subcatchments

The above coverages in turn define the model parameters like area of sub-catchment, length and slopes of channel/drains and Manning's roughness coefficient. The model further routes the runoff collected from sub-catchments through the drainage network using St. Venant's equation (fully dynamic wave equation).

Hence step-wise methodology would consist of:

- The study area is to be delineated from the base map and its different features indicating the drainage networks, location of different pumping houses and outfalls.
- Land use classification of the study area showing the pervious and impervious areas and roughness characteristics of the surface to determine the storm runoff.
- Digitization of contour map of study area and development of DEM. The slope map will be generated from DEM to identify the runoff (flow) direction
- Rainfall analysis and estimation of design storms for various return periods
- The existing cross sections of the drains will be analyzed to assess whether the sections are adequate to carry the storm runoff? If not, what should be the designed cross section?
- By using mathematical model the water surface profile along the channels and outfall hydrographs will be developed for design storm of different return periods. Appropriate measures would be formulated to overcome the impacts of anticipated short period rainfall events due to climate change.

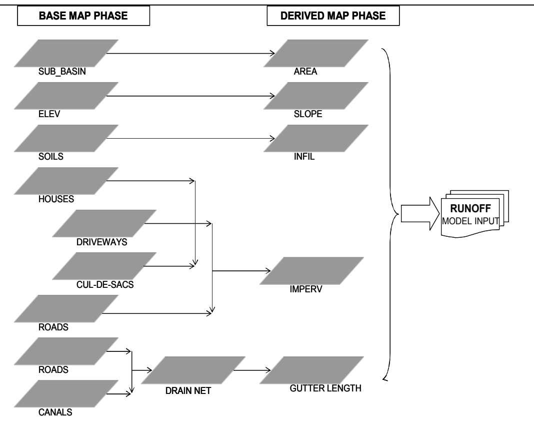


Figure 3a. Procedure for GIS to SWMM-1

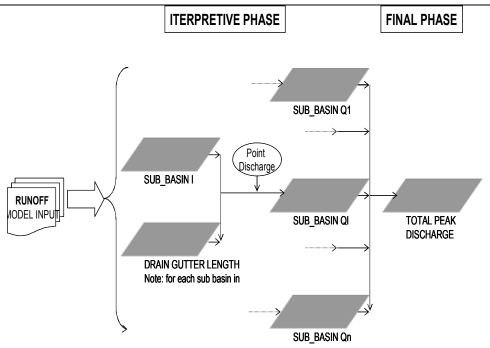


Figure 3b. Procedure for GIS to SWMM-2

4.10 Storm Water Management Model (SWMM)

EPA-SWMM solves the conservation of mass momentum equation that governing the unsteady flow through drainage network of the channels and pipes. In the analysis we chose to use kinematic wave method of routing flows through our drainage system. This is an efficient but simplified approach that cannot deal with such phenomenon as back water effects, pressurized flow, flow reversal, and non-dendritic layouts. EPA-SWMM also includes a Dynamic wave routing combinedly solving the continuity and momentum equations known as Saint Vaenant equation which is presented as:

$$\frac{\partial Q}{\partial t} + \frac{\partial Q}{\partial x} = 0 \qquad \text{Continuity} \qquad (1)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial (Q^2 / A)}{\partial x} + gA\frac{\partial H}{\partial x} + gAS_f + gAh_L = 0 \qquad \text{Momentum} \qquad (2)$$

Where the x is the distance along the conduit, t is the time, A is the cross-sectional area, Q is the flow rate, H is the hydraulic head of water in the conduit (elevation head any possible pressure head), S_f is the friction slope (head loss per unit length), h_L is the local energy loss per unit length of conduit and g is the acceleration due to gravity.

Chapter 5

RESULTS AND DISCUSSIONS

As per the schematic diagram (Fig. 3a & 3b) the base map coverage was used to derive the coverage maps of elevation, land use, drainage and sub drainage area delineation, drainage network and outfall maps. The brief descriptions of the generated maps are as under:

5.1 Elevation map

Digital Elevation Model (DEM) for the study area downloaded from SRTM 30m Grid and elevation varies from 445m to 558m as shown in the figure 4. By using DEM data, the percentage slope map was prepared and color coded according to the steepness of the terrain. The study area was classified into eight classes (Fig. 5).

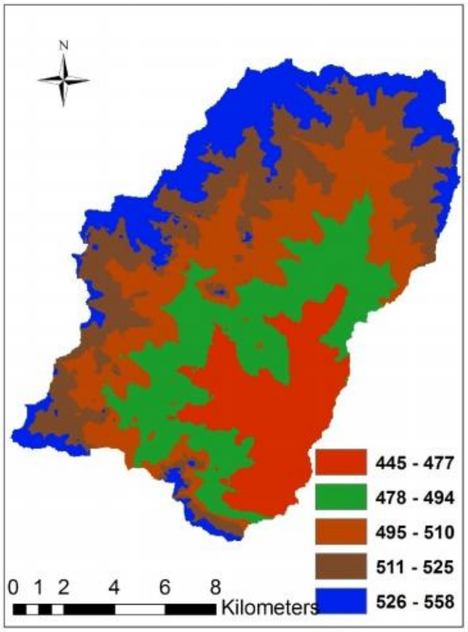


Figure 4. SRTM Digital elevation model of the study basin.

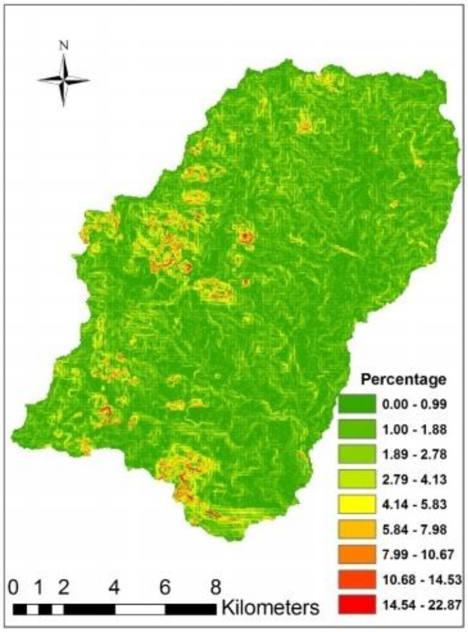


Figure 5. Percentage slope map of the study basin.

5.2 Land cover and soil map

Identification of various land cover of the study area was based on the digital image downloaded from earth explorer. Classification is done selecting training sites generating signature and convoluting the training statistics over the entire map. The class so identified is also verified by ground truth data. This technique is known as supervised classification. For land use classification L8 OLI/TIRS, Dt 21st May 2015 data has been used and performed supervised classifications (Fig. 6) and different class area shown (Table 2). Soil map destination (Fig.7) using NBSS maps to calculate the hydraulic conductivity by weighted average method in each sub watershed for estimating infiltration by using the SCS curve method.

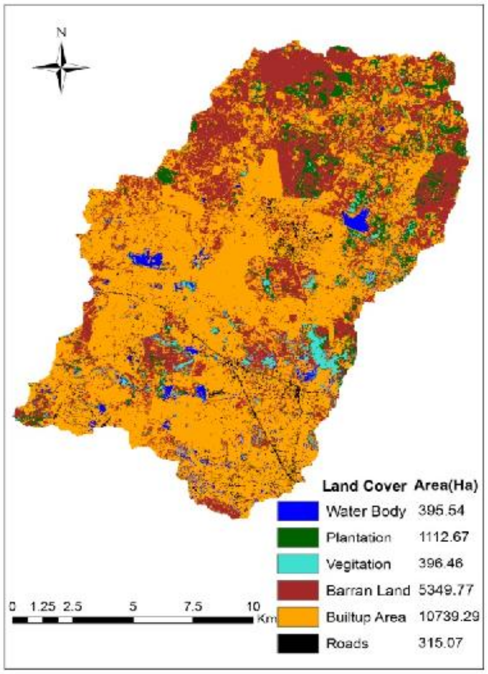


Figure 6. Land use classification of the study basin.

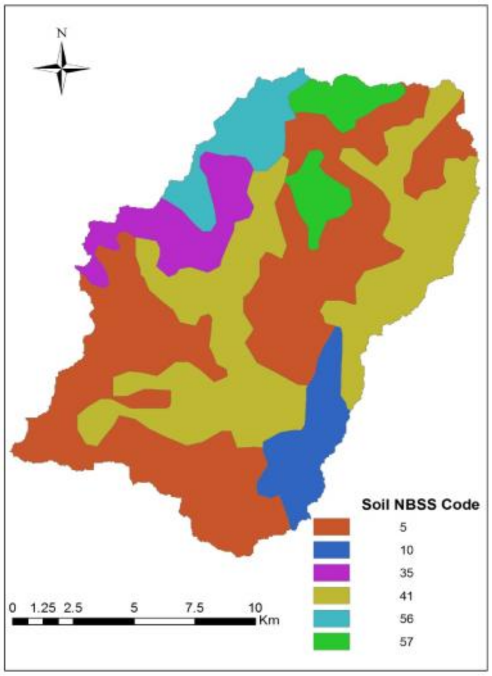


Figure 7. NBSS Soil map of the study basin.

Table 2: Land use classification of the study area.

Sl	Name of the classification	Area(ha)
1	Water bodies	395.54
2	Plantation	1112.67
3	Vegetation	306.46
4	Barren land	5349.77
5	Built-up area	10739.29
6	Roads	315.07

5.3 Sub area watershed delineations

In the first step the study area was divided into sub catchment. The delineations were based upon the topography of the study area, utilizing DEM (Fig. 4), The storm water drainage network details of GHMC Zone XII were collected and GIS database was prepared in ArcGIS hydrology tool for delineating drainage network and sub watersheds. Using thematic layers of DEM 15 micro watersheds were delineated in the Zone XII-basin shown in the figure 8 and verify GHMC Network in the basin.

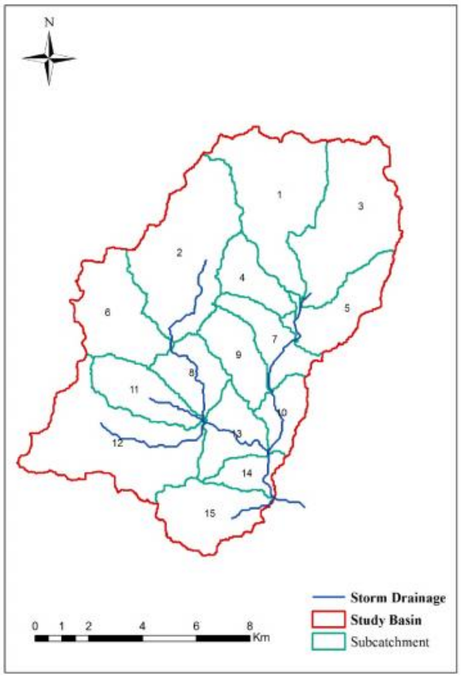


Figure 8. Watershed , sub-watershed and drainage ent work delineation using DEM of the study basin.

5.5 Design Storm Analysis

The hourly rainfall data for the past 5 years (2010-2014) was obtained from IMD, Hyderabad for Hyderabad gauge station in the Baghumpeta Air port and analyzed. Gumble Extreme Value (EVI) distribution has been used to find out the design rainfall for different return periods.

Due to non-availability of raingauge in the study area, five tipping bucket rain gauges and One automatic water level recorders have been installed in the study area to collect short interval rainfall and water levels as shown in Figure 9. The collected data has been processed and analyzed. The average sub basin rainfall has been calculated using Thiessen polygon method and the influence area of each raingauge station is shown in Figure 10.

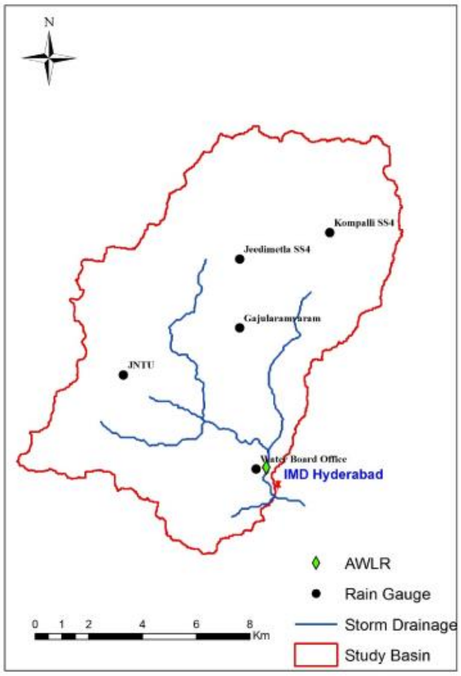


Figure 9. Location of the rain gauge and automated water level recorder in the study area.

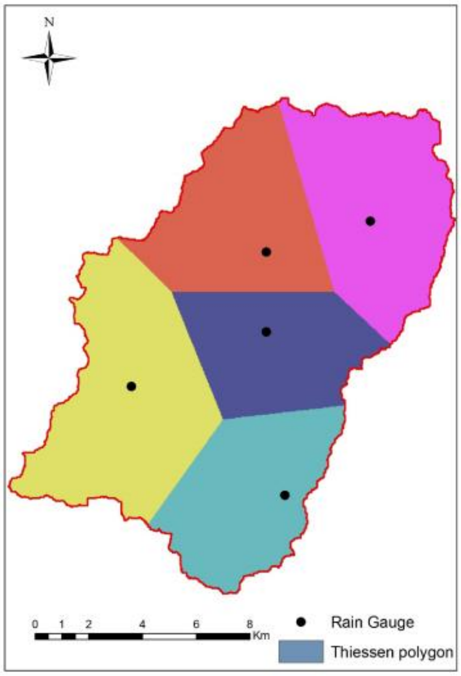


Figure 10. Thiessen polygon map of the basin.

The responses of the average rainfall to observed water levels in within the study area are shown in Figures 11.

The relation between Intensity Duration and Frequency (IDF) is given by:

$$I = \frac{CT^m}{t^n} = \frac{a}{t^n} \tag{3}$$

Where *I* is intensity mm/hr, *T* is frequency of the year (return period) and *t* is duration of storm in hr.

Determination of Constants ‘a’ and ‘n’

In order to determine the constants ‘a’ and ‘n’ of Equation (9), a log-log graph is plotted as shown in figure-12. The data for the graph is taken from table. From the Graph, n = 0.85 and values of a = 46.506, 63.349, 74.490, 88.561, 98.997 and 109.30 for 2-year, 5-year, 10-year, 25-year , 50-year , and 100-year recurrence intervals. To obtain the values of C and m, derived values of 'a' are plotted on log-log scale against corresponding recurrence intervals.

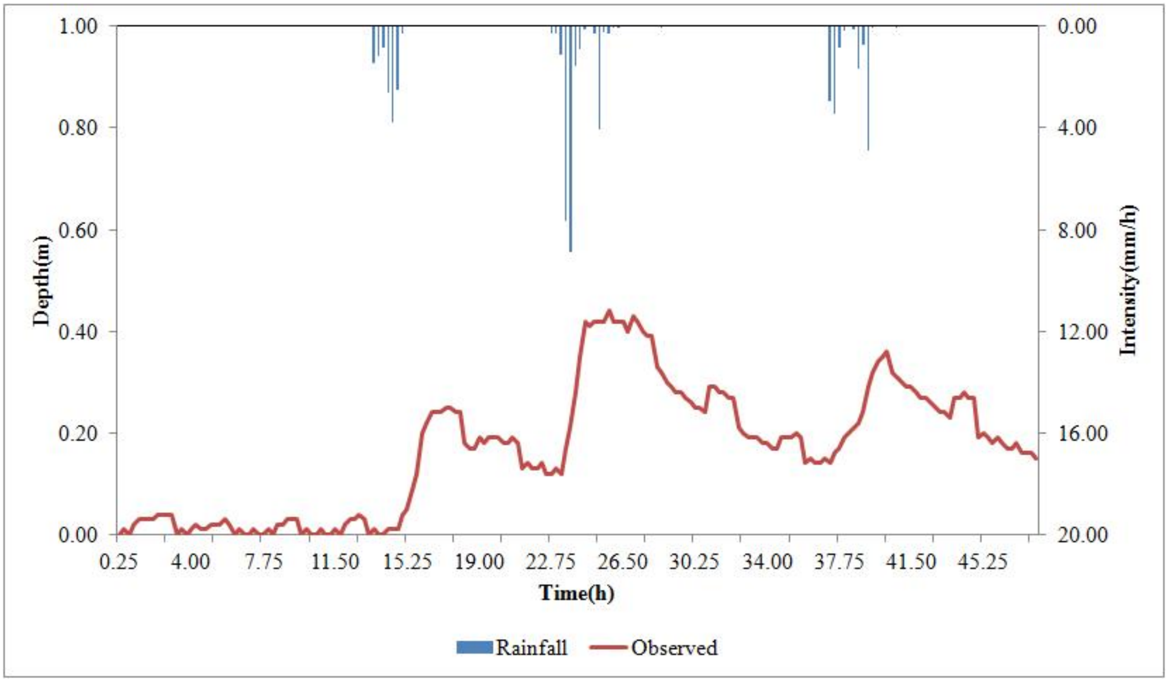


Figure 11. Observed water level and precipitation event from 3-4 Oct 2016 (48hr)

The constants ‘c’ and ‘m’ of Equation (9) are determined by plotting the data of Return Period Vs. ‘a’. The resulting graph is shown in Figure 13. Values obtained are a = 43.223 and n = 0.212.The final IDF curve equation is obtained as:

$$I = \frac{43.223T^{0.212}}{t^{0.85}} \tag{4}$$

Using above equation develop the Intensity Duration Frequency curves 2, 5, 10, 25, 50 and 100 year return period of design storm as shown in figure 14. By using alternative block method to develop the hyetographs from design storm of IDF curves as shown inj the figure 15.

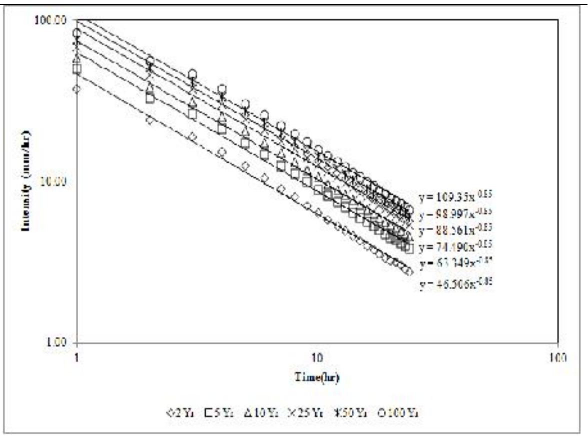


Figure 12. Log-log graph for different return period.

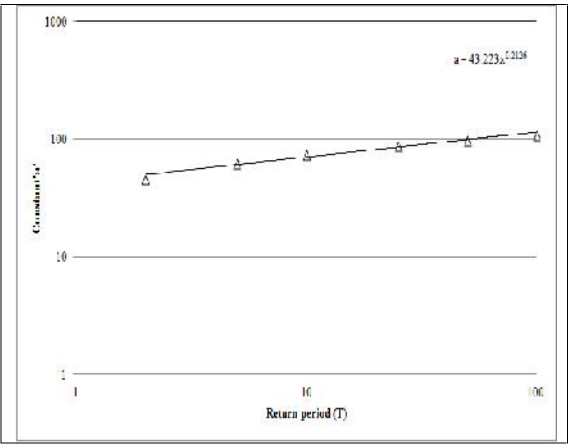


Figure 13. Graph beteen retun period T and constant *a*

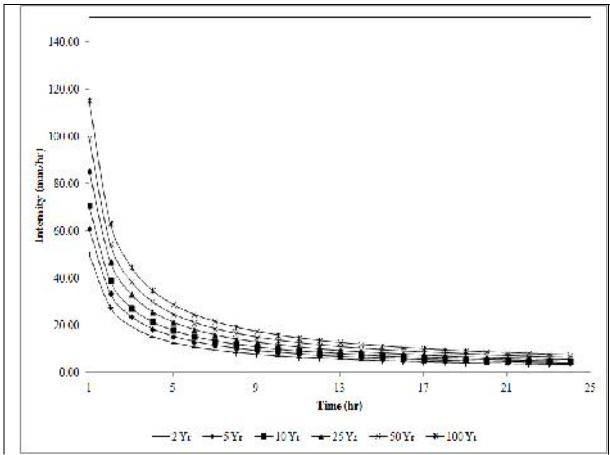
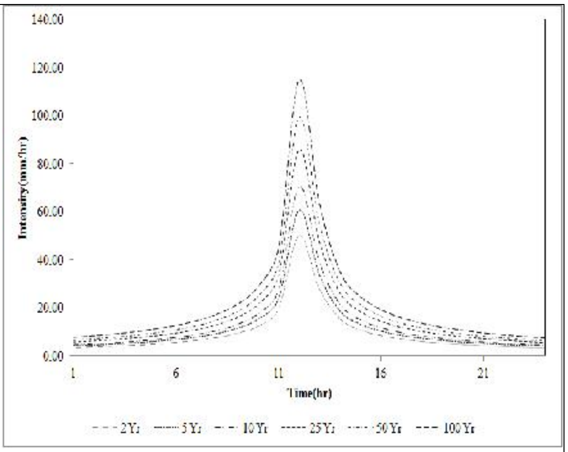
	

Figure 14. IDF curves for different return period.	Figure 15. Hyetographs for different return period.

5.6 Model Simulation and Calibration

SWMM model is designed to simulate the runoff of a drainage basin for any pre-described rainfall pattern. Total watershed is broken into a finite number of smaller units as shown in the figure 16 or sub-catchments that can be readily described by their hydraulic or geometrical properties.

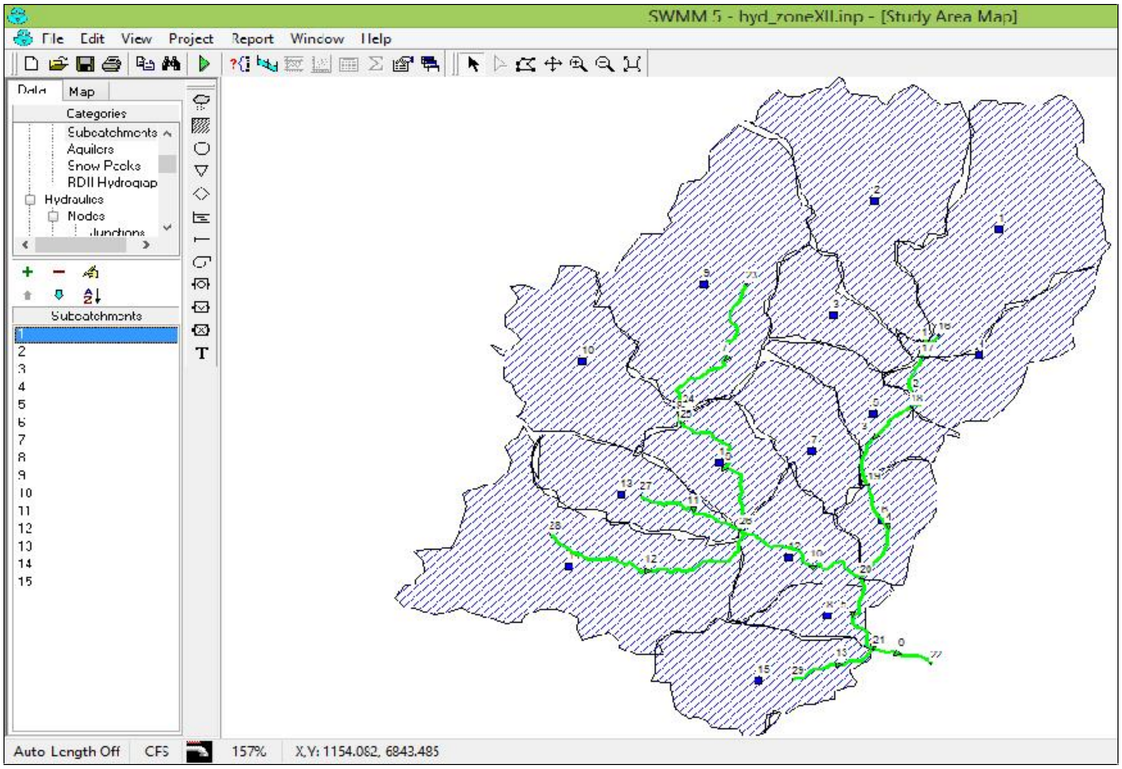


Figure 16. SWMM model setup of the study basin

In the first step the study area was divided into sub-catchments. The delineations were based upon the topography of the study area, utilizing Digital Elevation Model (DEM). Runoff was calculated by using SCS curve number method. Percentage of slope and land use map was prepared. Percentage of imperviousness and percentage of slope of each sub catchment parameters were calculated by weighted average classification of the percentage slope map and land use map. Manning's roughness co-efficient for the impervious and pervious area was taken as 0.012 and 0.24 respectively form the SWMM user manual. For model simulation dynamic wave equation was applied and runoff routed through the existing drainage system.

Calibration is the process of running a model using a set of input data and comparing the model results to actual measurements of the system. The calibration procedure takes into consideration the peak rate of the event as well as the shape of the hydrograph. After the model is calibrated to a specific storm, it is validated with observed water level data

Initial calibration efforts showed that the model over-predicted due to conservative estimates of imperviousness and/or contributing area of the drainage basins. Thus, a detailed GIS analysis and field investigation was undertaken to determine the effective impervious area. The field investigation produced accurate delineation of drainage boundaries.

In order to test SWMM with field input parameters, one continuous events from 3rd -4th Oct 2016 (48hr) of observed hourly rainfall and water level data have been considered for model performance at junction of Kukatpalli nalla and chemical nalla in the basin. Analysis indicated that the model predicted water levels for continuous events is in good agreement with observed water levels as shown in the figure 17. It was observed that the peaks of observed stages are always less than the modeled stages. This is probably due to blocking of drains with garbage, floating material and improper interconnectivities between storm water drains. Improper maintenance of storm water drains causes the reduction of flow in the drains and the same process is reflected in the comparison of simulated and observed stages in the study area.

5.7 Routing through the designed network with design storm

In the first hand analysis we applied the Kinematic Wave equation for flow routing to have an idea about the behavior of the existing drainage system. As this is a simplified approach that cannot deal with phenomena such as backwater effect, pressurized flow,

flow reversal, and non-dendritic layouts, we adopted a Dynamic Wave routing procedure. The existing drainage system mostly consists of brick lining. The Roughness coefficient of the drainage system has been considered as 0.012 (SWMM user manual). Runoff generated from each sub drainage area is passed through a single out let which is connected to drainage node or junction; again it connects to the main drain and finally conveys the whole discharge to the outfall. Model simulation results of hydrographs of 2 year return period at outfall are shown in the Fig. 18.

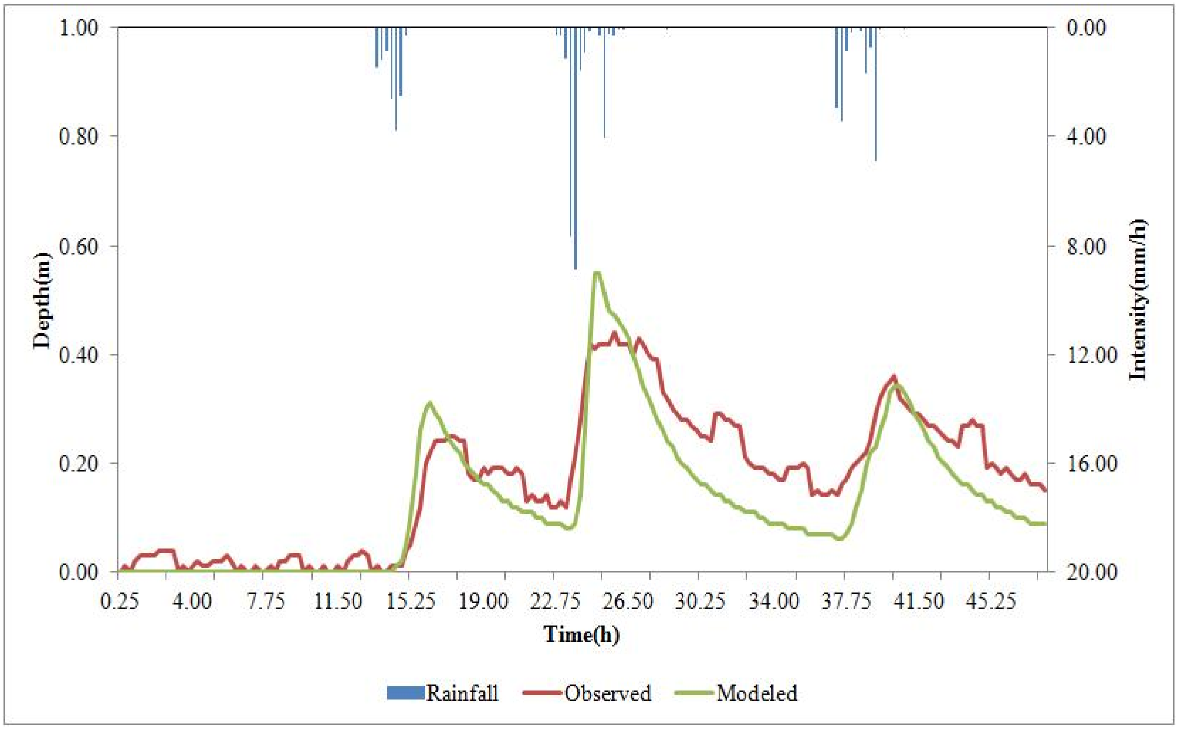


Figure 17. Model validation observed WL with model WL 03rd Oct 2015 to 04th Oct (48hr)

In SWMM, flooding will occur whenever the water surface at a node exceeds the maximum defined depth of the drains. Normally such water will be lost from the system. The water elevation profile of drain, reveal that the drains are inadequate to carry flow to the outfalls. This flow spills out along the drains and accumulates in the low lying areas, causing flood inundation at different nodes or junctions as shown in the figure 19. From the analysis we found that the existing drainage system is inadequate even to drain off runoff generated from 2 year return period rainfall. The inundation area with return period was identified.

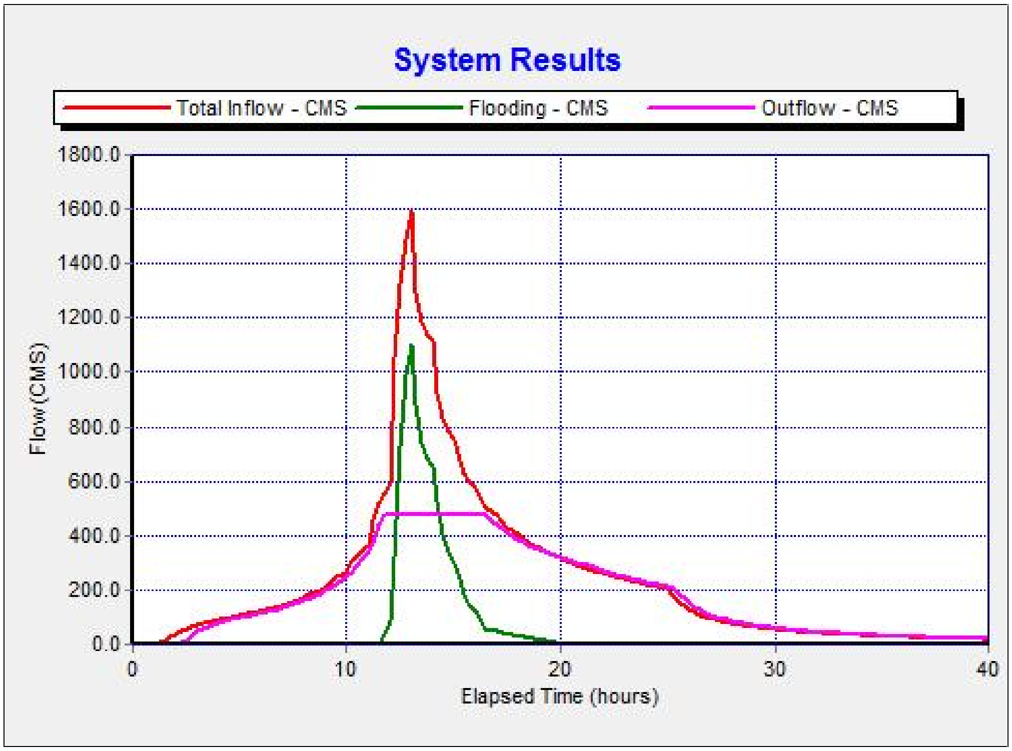


Figure 18. 2 Year design storm of hydrograph at outlet.

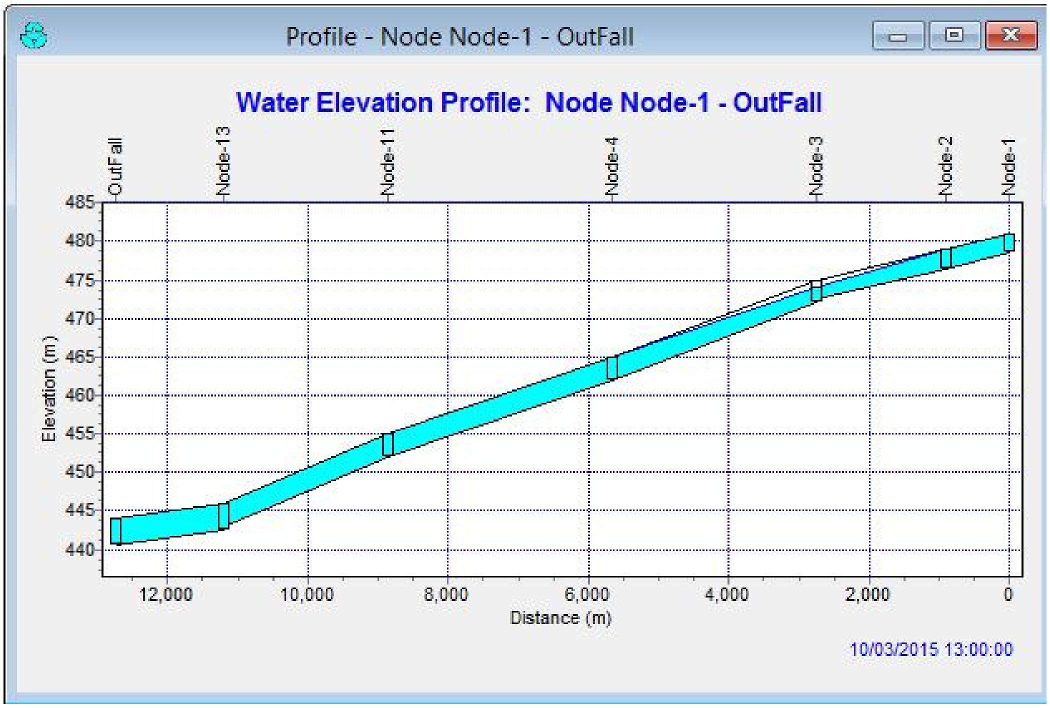


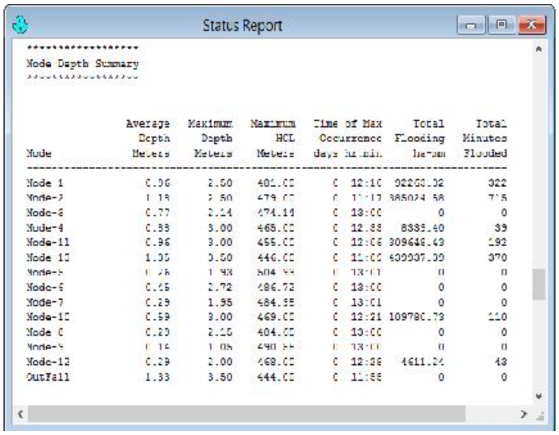
Figure 19. Water surface profile along the drain for 2 year design storm

5.7.1 Design of Channel Capacity

The flows in drains are assumed free surface flow through prismatic channel having constant cross sections at different reaches. Manning's formula was used for design of channel assuming uniform flow (friction slope parallel to the bed slope) to accommodate peak flow. The existing drainage system was made several decades back. After subsequent developments in the study area there is no scope at present for widening the channel in most of the locations. The only way out to accommodate peak flow is by changing the geometrical properties of the drainage system without changing bed slope and roughness coefficient of the channel.

For design of the drainage system for 5 years return period hyetograph, spreaded uniformly over the entire area has been considered. Modified geometrical properties and proposed drain of the drainage corresponding with existing drainage system is given in the Table 3.

Table 3. Geometrical properties of existing and modified storm drainage network of the basin



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******************
Node Depth Summary
******************

                     Average  Maximum  Maximum  Time of Max    Total    Total
                       Depth    Depth      HGL   Occurrence  Flooding  Minutes
Node                  Meters   Meters   Meters  days hr:min    ha-mm  Flooded
------------------------------------------------------------------------------
Node 1                  0.06     2.50   401.00     0  12:10  92263.02      322
Node-2                  1.18     2.50   479.00     0  11:17 385024.58      715
Node-3                  0.77     2.14   474.14     0  13:00         0        0
Node-4                  0.88     3.00   465.00     0  12:33   8335.40       39
Node-11                 0.96     3.00   455.00     0  12:06 309648.43      192
Node 10                 1.05     3.50   446.00     0  11:00 409037.09      370
Node-5                  0.26     1.93   504.93     0  13:01         0        0
Node-6                  0.45     2.72   486.72     0  13:00         0        0
Node-7                  0.29     1.95   484.95     0  13:01         0        0
Node-10                 0.59     3.00   469.00     0  12:21 109780.73      110
Node 8                  0.20     2.15   404.00     0  13:00         0        0
Node-9                  0.14     1.05   490.55     0  13:00         0        0
Node-12                 0.29     2.00   468.00     0  12:38   4611.24       43
OutFall                 1.33     3.50   444.00     0  11:55         0        0
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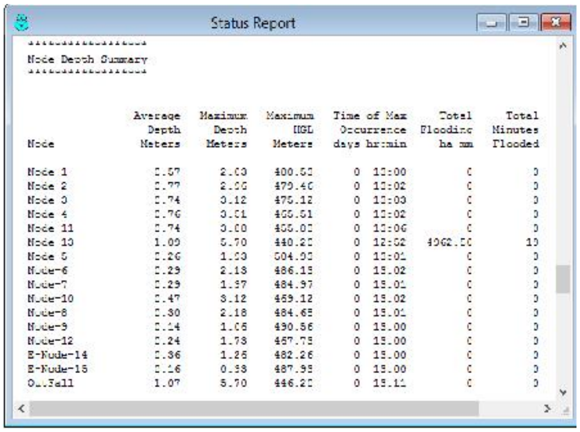

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******************
Node Depth Summary
******************

                     Average  Maximum  Maximum  Time of Max    Total    Total
                       Depth    Depth      HGL   Occurrence  Flooding  Minutes
Node                  Meters   Meters   Meters  days hr:min    ha mm  Flooded

Node 1                  0.57     2.03   400.53     0  13:00         0        0
Node 2                  0.77     2.00   479.40     0  13:02         0        0
Node 3                  0.74     3.12   475.12     0  13:03         0        0
Node 4                  0.76     3.01   455.51     0  13:02         0        0
Node 11                 0.74     3.00   455.00     0  13:06         0        0
Node 10                 1.09     5.70   440.20     0  12:52   4062.50       10
Node 5                  0.26     1.93   504.93     0  13:01         0        0
Node-6                  0.29     2.13   486.13     0  13:02         0        0
Node-7                  0.29     1.97   484.97     0  13:01         0        0
Node-10                 0.47     3.12   469.12     0  13:02         0        0
Node-8                  0.30     2.18   484.65     0  13:01         0        0
Node-9                  0.14     1.05   490.56     0  13:00         0        0
Node-12                 0.24     1.73   467.73     0  13:00         0        0
E-Node-14               0.36     1.26   482.26     0  13:00         0        0
E-Node-15               0.16     0.93   487.93     0  13:00         0        0
OutFall                 1.07     5.70   446.20     0  13:11         0        0
```

From the analysis it reveals that modified design as proposed is adequate to convey the storm runoff to the outfalls without any spilling and flooding. The shape, volume and peak rate of system inflow and outflow are well matching at outfall as shown in figure 20. Further, water elevation profile along the drains shows the zero flooding and without spilling at nodes of the drainage system of design storm of 5 year returns period as shown in figure 21

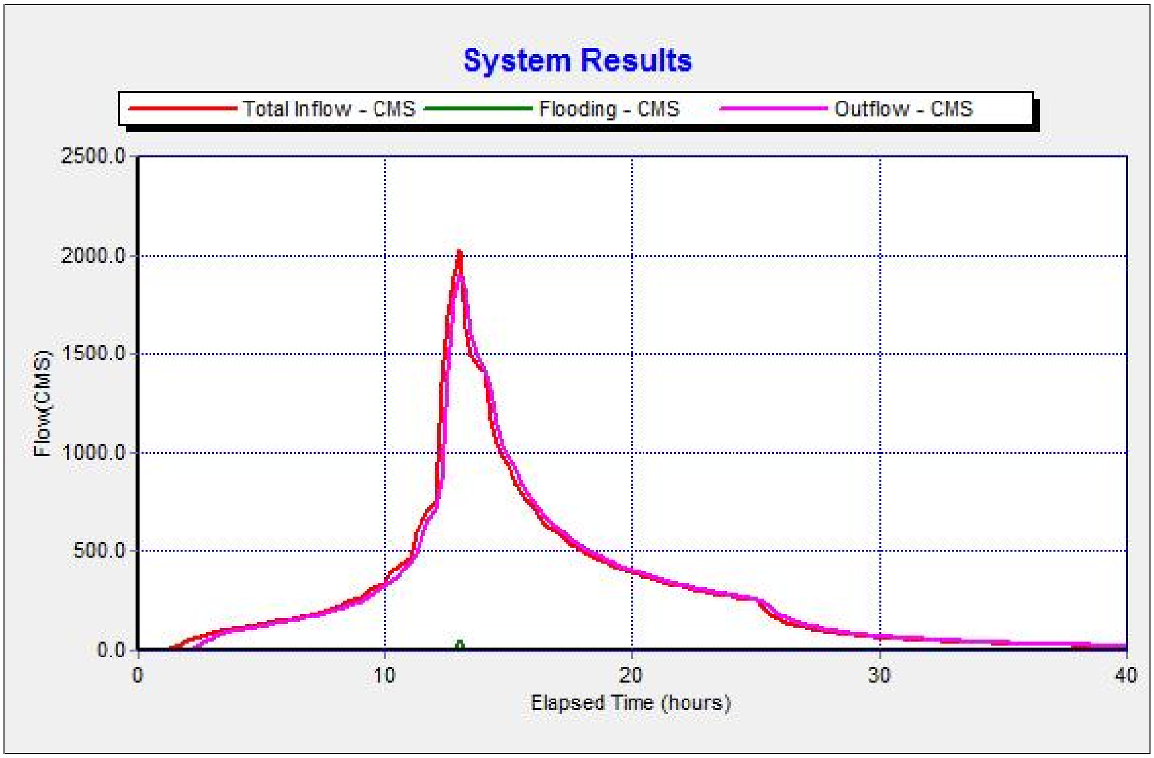

Figure 20. System inflow and outflow hydrographs of 5 year design storm at outlet of the basin.

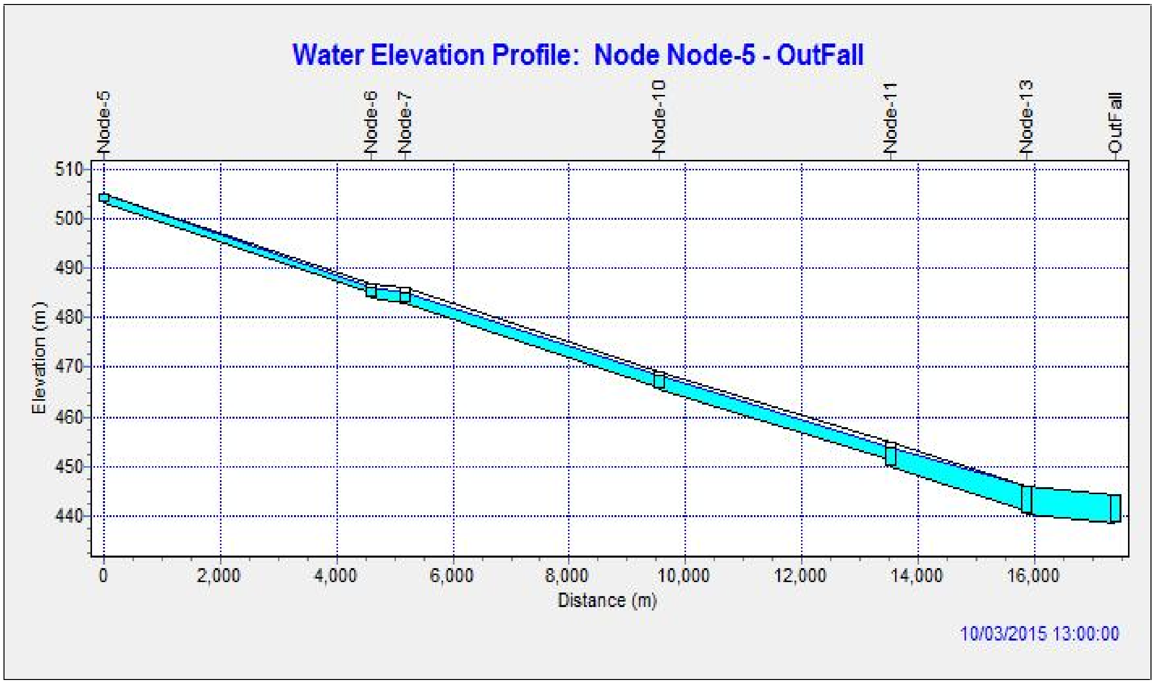

Figure 21. Water surface profile along the drain of chemical nalla of 5 year design storm.

Chapter 6

CONCLUSION

The storm drainage system of Patna Town has been analyzed in the present study. EPA SWMM has been used in GIS environment to simulate the storm runoff and the same has been routed through the storm drains. Five years of hourly rainfall data have been used to estimate design storms and analyzed the simulated runoff results.

The SWMM model was run to dispose of the present runoff generated considering the originally designed by GHMC drainage networks without any blockage and we found it is inadequate to dispose of the runoff. The condition of the existing drainage networks of GHMC Zone XII is not even able to dispose off the rainfall depth of 2 year return period. As a result GHMC Zone XII is facing flooding and water logging every year. The maintenance of the conveyance system is very poor and people are less concern about the health of the system. The drains are chocked due to throwing of garbage, polythene bags, wastages of vegetable and fish markets etc. directly into it. Thus people need to be awakened and attention should be given for renovation of the existing drains. Micro level drainage system is very poor and many areas are not connected to the main drainage system. Thus development of micro level drainage should be strengthened and connected to the main drainage system.

Simulation studies were performed on the originally designed drains to carry the existing runoff with 2 and 5 year design storms. It is found that the discharge spills out of the original drains and the system is not adequate to carry the storm runoff to the outfalls even 2 year design storm.

In this study the geometrical properties of the drain (design) has been modified and extended the length drains. The simulated runoff with design storm of 5 year return period has been routed through the modified drainage system. Water surface profile along the drains has been developed and we found that this storm runoff is well accommodated in the drains. Thus flooding has been reduced considerably for the modified drains. It is recommended that the drains need periodic cleaning and proper maintenance following the modified design criteria, the surface flooding may be reduced to a great extent. The hydrographs at different outfalls have been developed for various design storms of GHMC Zone XII. This is very useful information and recommended for Best Management Practice (BMP) for design of sumps or ponds and also to decide pump capacity.

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