ASSESSMENT OF URBAN RUNOFF USING REMOTE SENSING AND GIS

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Abstract

Land-use and land-cover changes may have four major impacts on the hydrological cycle and water quality: they can cause floods, droughts and changes in river and groundwater regimes and they can affect water quality. In addition to these direct impacts there are also indirect impacts on climate and the subsequent impact of the altered climate on the waters. Urbanization the conservation of land to uses associated with the growth of population and economy is a significant land-use and land-cover changes especially in recent human history. One of the emerging problems in the urban area is the hanging land surface from pervious to impervious and obstruction in the drainage area. Reduction and decrease in the infiltration rate travel time which significantly increases peak discharge and runoff and collection of hydro-meteorological parameters are time consuming and expensive.. GIS is used to analysis spatially referenced data as it is efficient for storage, retrieval, and manipulation. The Objective of the study is to estimate the excess surface runoff of the watershed. To derive a storm hydrograph to the watershed for future runoff predictions and to validate the model using field observation.

Keywords: Urban runoff, GIS, Curve Number, Quick bird Satellite image.

I. INTRODUCTION

Land-use and land-cover changes may have four major impacts on the hydrological cycle and water quality: they can cause floods, droughts and changes in river and groundwater regimes and they can affect water quality. In addition to these direct impacts there are also indirect impacts on climate and the subsequent impact of the altered climate on the waters. Urbanization the conservation of land to uses associated with the growth of population and economy is a significant land-use and land-cover changes especially in recent human history. The process of urbanization has considerable hydrological impacts in terms of influencing the nature of runoff and other hydrological characteristics, delivering pollutants to rivers and controlling rates of erosion. At different stages of urban growth, various impacts can be observed.

In the early stage of urbanization, removal of trees and vegetation may decrease evapotranspiration and interception and increase stream sedimentation. Later, when construction of houses, streets and culverts begins the impact may include decrease infiltration, lowered groundwater table, increased storm flows and decreased base flow during dry periods. After the development of residential and commercial buildings has been completed, increased imperviousness will reduce the time of runoff concentration so that peak discharges are higher and occur sooner after rainfall starts in the basins. The volume of runoff and flood damage potential will greatly increase. As a result, the rainfall-runoff process in an urban area tends to be quite different from that in natural conditions depicted in classical hydrological cycles. This effect of urbanization, however, varies according to the size of the flood. As the size of the flood becomes larger and its recurrence interval increases the effect of urbanization decreases.

The integration of remote sensing (RS) and geographical information systems (GIS) has been widely applied and has been recognized as a powerful and effective tool in detecting urban growth. Remote sensing collects multispectral, multi resolution and multi temporal data and turns them into information valuable for understanding and monitoring urban land processes and for building urban land-cover data sets. GIS technology provides a flexible environment for entering, analyzing and displaying digital data from various sources necessary for urban feature identification, change detection and database development. In hydrological and watershed modeling, remotely sensed data are found to be valuable for providing cost-effective data input and for estimating model parameters. The introduction of GIS to the field makes it possible for computer systems to handle the spatial nature of hydrological parameters. The hydrological communities now increasingly adopt GIS based distributed modeling approaches.

II. NEED FOR THE STUDY

- One of the emerging problems in the urban area is the changing land surface from pervious to impervious and obstruction in the drainage area.

- Reduces infiltration rate and decrease travel time which significantly increases peak discharge and runoff.
- Collection of hydro-meteorological parameters are time consuming and expensive.
- GIS is increasingly used as sophisticated database management system for efficient storage, retrieval, manipulation and analysis of spatially referenced data.

Objective:

- To estimate the excess surface runoff of the watershed
- To derive a storm hydrograph to the watershed for future runoff predictions
- To validate the model using field observation

Study Area:

- The Meenambakkam watershed approximately comprises about 70 sq.km.
- The average temperature in summer is 37ºC and in winter it is 24ºC
- Average annual rainfall received by this area is 1300mm
- The location of the area is12º59.4' N and 80º9.7' E
- The soil types of this area cover both deep, imperfectly drained, clayey soil and moderately deep, well drained, clayey soil.
- As for the precipitation data, daily rainfall data for a period of 10 years (1997-2007) was obtained from Statistical department and Meenambakkam rain gauge station.

In this study, the observed flow rate from the watershed outlet at Nandambakkam weir was considered for validation of this model.

The following fig. 1. shows the quick bird image of study area.

Fig. 1. Quick Bird Image of Study Area

III. METHODOLOGY

Excess Rainfall Estimation Using the SCS CN Method:

Excess rainfall generated in a watershed is known to vary spatially. The variation in excess rainfall follows that of landuse, land cover, and soil type. Typically, the way to account for this variation is to divide the watershed into smaller areas of "uniform"landuse, land cover, and soil type combinations (Ajward, 1996). An average curve number (CN) for the whole watershed determined using the area weighting method is then given by:

$$CN= \Sigma(CNi \times A)/ A \quad (1)$$

where:

CN is the curve number of the sub-area I (Ai).

This procedure is the standard procedure used in the SCS rainfall-runoff relationship. It gives an average excess rainfall depth for the entire watershed, Pe, that corresponds to an average rainfall depth, P.

The rainfall-runoff relationship in this method is derived from the water balance equation and a proportionality relationship between retention and runoff. The SCS rainfall-runoff relationship is given by (Novotny et al., 1994):

$$Pe=(P-Ia)/(P-Ia+S) \quad (2)$$

where:

P is the rainfall depth (mm).
Pe is the depth of excess rainfall (mm).
Ia is the initial abstractions (mm).
S is the volume of total storage (mm).

Storage includes both the initial abstractions and total Fig. 3. shows the comparison between the growth of capital money invested on land in Tambaram and that invested in bank over the past ten years. It is observed that the price index on land is more than twice the price index on bank. infiltration.

The initial abstraction is a function of landuse, treatment and condition, interception, infiltration, detention storage, and antecedent soil moisture (Novotny et al., 1994). The initial abstraction and the total storage are related in an empirical statistical equation which is given as:

$$Ia = 0.2S \quad (3)$$

Substituting equation 3.3 into equation 3.2 yields:

$$Pe = (P-0.2S) / (P+0.8S) \quad (4)$$

The storage S (in millimeters) is obtained using the formula:

$$S = (25400/CN) - 254 \quad (5)$$

where CN is the curve number that can be obtained from standard tables for different combinations of landuse and land cover, soil hydrologic group, treatment, and condition.

The hydrologic soil group reflects a soil's permeability and surface runoff potential. Following is a description of the four different hydrologic soil groups (Novotny et al., 1994):

- Group A are soils with low total surface runoff potential due to their high infiltration rates. They consist mainly of excessively drained sands and gravels.
- Group B are soils with low to moderate surface runoff potential. They have moderate infiltration rates and moderately fine to moderately coarse texture.
- Group C are soils with moderate to high surface runoff potential. They have slow infiltration rates and moderately fine to fine textures.
- Group D are soils with high surface runoff potential. They have very slow infiltration rates and consist chiefly of clay soils.

IV. WORK FLOW

Generation of Landuse Map:

GOOGLE earth software was downloaded from the net. The study area was isolated from the quick bird image. Using ez map digitizer the study area was digitized and latitude, longitude position points was noted and made run in arc info software where the shape file was generated. Landuse classification for the study area was carried out in the same manner. Classification in Sq.Km is given in the Table 1. Total study area approximately comprises of 70 sq.km.

Table 1: Landuse area in Sq.Km

Land use	Area in Sq.Km
Residential area	21.32
Commercial area	2.35
Meadows	18.19
Open land	5.15
Transitional area	16.4
Impervious area	4.36
Water bodies	0.95
River	2.11

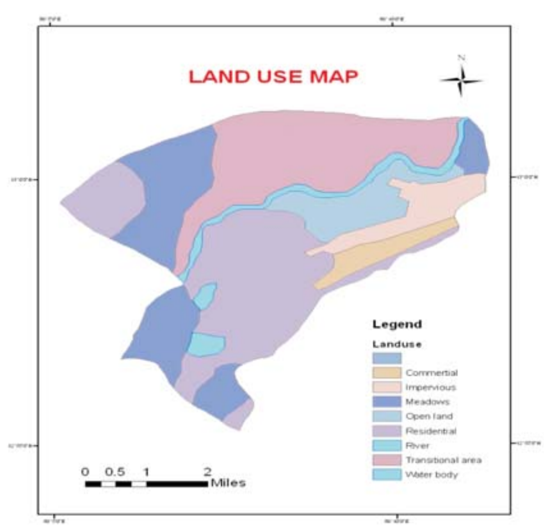

Fig. 2. Land use map

The study revels about 31% of total area is residential area which has high imperviousness leads to high runoff. The imperviousness values for the classified landuse are given in Table 2. as the imperviousness increases the runoff increases and vice versa.

Table 2. Imperviousness value

Land use	Impervious value
Residential area	65
Commercial area	85
Meadows	5
Open land	5
Transitional area	5
Impervious area	95
Water bodies	100
River	100

Generation of Soil Map:

The soil map was prepared from National bureau f Soil survey and Land use planning, Dept of Agriculture, TN, 1996. The soil types of this area cover both deep, imperfectly drained, clayey soil and moderately deep, well drained, clayey soil. The soil map is shown in Fig. 3.

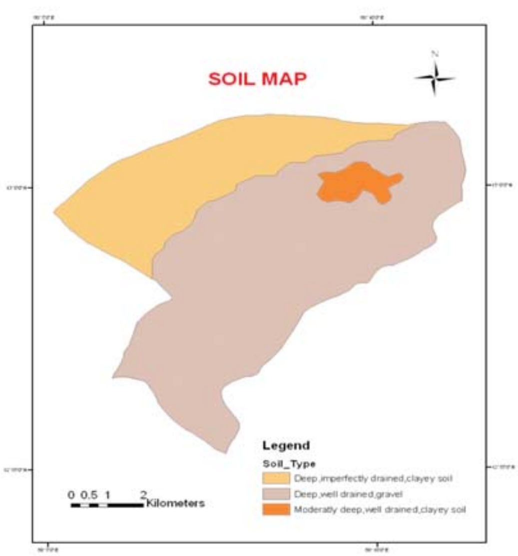

Fig. 3. Soil Map

Based on the Soil type, different land use categories have been assigned the appropriate CN value. It was developed by US department of Agriculture(USDA) comes in the very handy for computing direct runoff .

Generation of CN Map

Landuse map and soil map was overlayed to produce the CN map. Different land use has various CN value. Based on this, weighted CN The appropriate CN values and weighted CN are given in Table 3. and Table 4..

Table 3. Appropriate CN values

Land use	CN numbers		
	A	B	D
Residential area	77	85	90
Commercial area	89	92	95
Meadows	30	58	78
Open land	39	61	80
Transitional area	76	85	91
Impervious area	98	98	98
Water bodies	100	100	100
River	100	100	100

Table 4. Values of weighted CN

Land use	CN
Residential area	80
Commercial area	89
Meadows	46
Open land	47
Transitional area	82
Impervious area	98
Water bodies	100
River	100

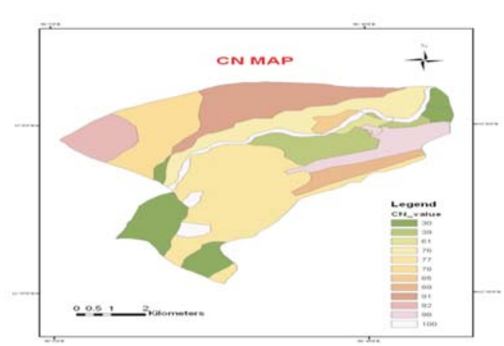

Fig. 4. CN Map

From this the maximum soil retention (S) in mm was calculated shown below in Table 5.(a) and initial abstraction (Ia) shown in Table 5. (b). Based on these parameters the accumulated runoff (Q) is calculated and shown in Table 6.. The average rainfall depth was taken as 49mm and the runoff was estimated to different land use classes. As the CN value increases the runoff is triggered to produce high runoff.

Table 5. (a) Max soil retention value (b) Initial abstraction value

Land use	S
Residential area	64
Commercial area	31
Meadows	298
Open land	286
Transitional area	56
Impervious area	5
Water bodies	0
River	0

(a)

Land use	Ia
Residential area	12.7
Commercial area	6.27
Meadows	60
Open land	57
Transitional area	11.15
Impervious area	1
Water bodies	0
River	0

(b)

Land use which has low imperviousness posses the maximum retention value.

Table 6. Accumulated runoff

Land use	Q
Residential area	14
Commercial area	25
Meadows	1
Open land	1
Transitional area	16
Impervious area	43
Water bodies	49
River	49

The average rainfall depth was taken as 49mm and the runoff was estimated to different land use classes. As the CN value increases the runoff is triggered to produce high runoff.

The basis of the time-area method is the time-area diagram that represents the relationship between runoff travel time and the portion of the watershed area that contributes to runoff during that time period (McCuen, 1989). In this method, the watershed is divided into sub-areas separated by isochrones. The travel time required for a rain drop falling on any location in a sub-area is the same as that for any other drop falling on the same sub-area. An isochrone is a contour line connecting all points that share the same travel time. Isochrones can not cross one another, can not close, and can only originate and terminate at the watershed boundaries (Dooge, 1959). Fig. 5. shows the watershed isochrone map drawn by classifying a grid of time of flow to the watershed outlet.

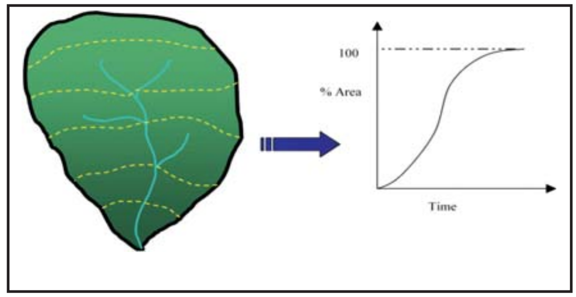

Fig 5. Isochrone map of the watershed

V. RESULT AND DISCUSSIONS

From 2 meter contour interval data DEM and slope has been generated for the study area. It is shown below in Fig. 6 -12.

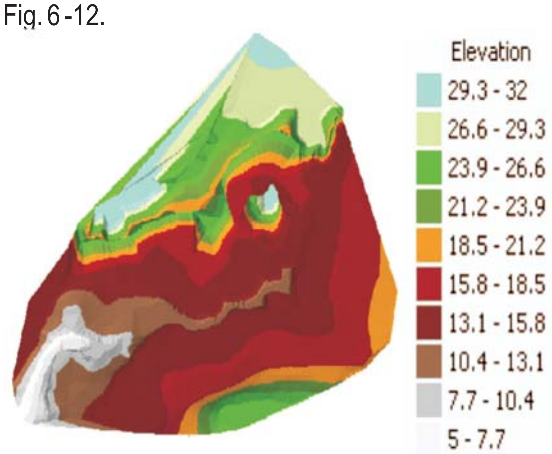

Fig. 6. TIN

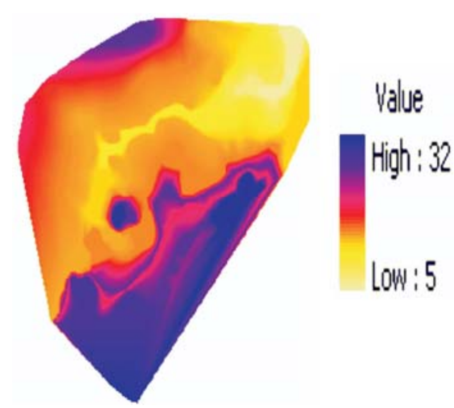

Fig. 7. DEM

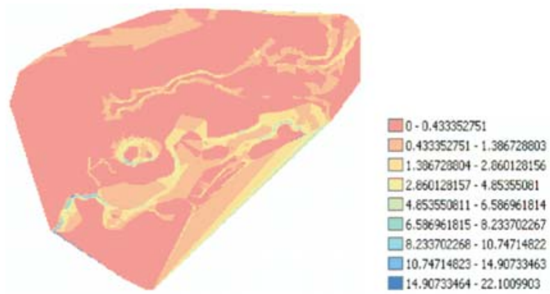

Fig. 8. Slope Map

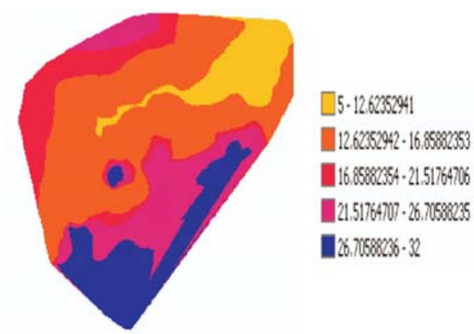

Fig. 9. Fill Map

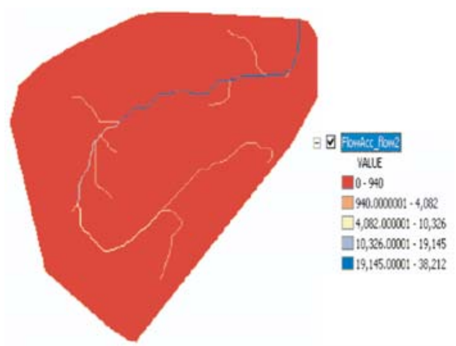

Fig. 10. Flow Accumulation

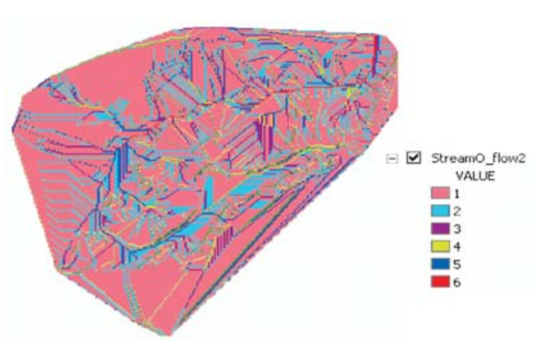

Fig. 11. Stream Order

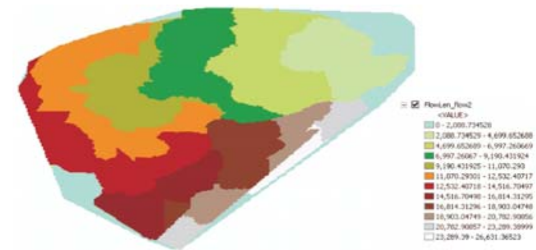

Fig. 12. Flow Length

By estimating the flow velocity through each cell, the flow time through each cell can be obtained by dividing the flow distance by the flow velocity. The grid of the cumulative travel time to the watershed outlet can then be obtained by tracing the time grid from the watershed outlet to each upstream cell and storing the resulting value in each cell. From the cumulative travel time map the isochrones of the flow time for intervals of width can be obtained. The time-area diagram is then determined by finding the incremental areas of cells between isochrones. Fig.13 and Fig.14 depicts rainfall distribution graph and Observed and simulated hydrographs Storm starting on October 1, 1993 -2006 onwards.

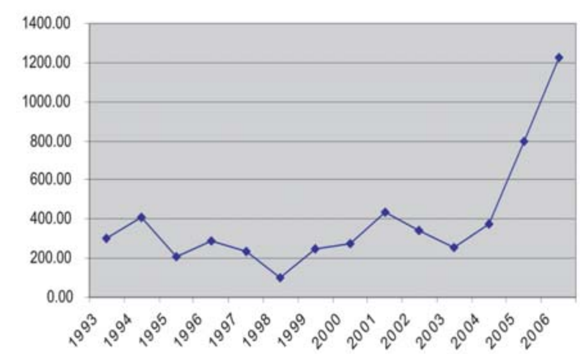

Fig.13. Depicts rainfall distribution graph

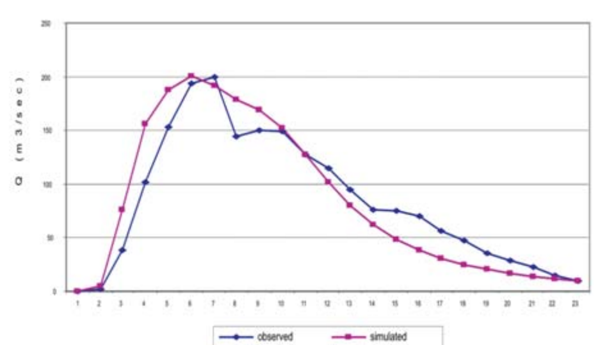

Fig.14. Observed and simulated hydrographs Storm starting on October 1, 1993 -2006

VI. CONCLUSION

The study mainly concentrated on the use of remote sensing and GIS in hydrological modeling. Satellite images of high resolutions were used for extracting information of the watershed.

By SCS method, the runoff for the watershed was estimated. This method focuses on the land use, soil type and CN values as key factors for runoff estimation. Normally land covers such as residential and commercial areas have high impervious value which tends to increase the runoff. In the study the above mentioned land covers were prominent. Soil type og group A and D was prominent. Satellite images of high resolution were used to extract these information.

Watershed properties such as slope, flow direction, flow accumulation etc were extracted from DEM generated from 2m contour interval. DEM of this elevation was quite sufficient for extracting these properties. ArcGIS software was effective in generating the outputs.

The discharge from the storm hydrograph of the study area was found to be close to the discharge value of observed value.

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