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Discharge Estimation by Rational Method using Global Mapper GIS for Sustainable Stormwater Management: A Case Study from Pune City

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***Abstract*— The sharp rise in urban development has led to an increase in impervious areas and a decrease in vegetated surfaces. The thrust toward this development has caused drought and overflow problems to occur. In the 1960s, management of stormwater quantity for flood prevention was the only imperative in the developed countries, but in subsequent decades, objectives for stormwater management have diversified to include quality, ecosystem health, reuse, integration with urban design etc along with quantity and has inspired the development of novel stormwater management approaches designed to minimize impervious cover and maximize infiltration of rainfall known as Low Impact Development (LID) in USA and Water Sensitive Urban Design (WSUD) in Australia. The massive urbanization in India has resulted in generation of huge quantities of stormwater which are unutilized and polluted. Managing urban stormwater in India poses huge challenges and the consequences of its neglect are severe. India too needs to adopt sustainable practices in overall water management. Stormwater is being managed in a traditional way in most of the urbanized cities of India. At many places, natural drains simply carry the runoff and engineered infrastructure is absent. This has led to the problem of localized flooding and consequent deterioration of roads. In order to study the present stormwater situation, a case study of Pune city in Maharashtra state is selected. In this work, an attempt is made to determine the stormwater quantity in a sub basin of Pune city by rational method using Global Mapper GIS software. It also presents the analysis of stormwater quality in the same sub basin. The constraints in adopting sustainable techniques are discussed with respect to the case study. This data will be further used to identify suitable sites for stormwater recharge subsequently.**

***Index Terms*— Stormwater Management, Low Impact development, Water Sensitive Urban Design, Rational Method, Global Mapper GIS Software.**

I. INTRODUCTION

The sharp rise in urban development has led to an increase in impervious areas and a decrease in vegetated surfaces. Traditionally, surface runoff was considered as an undesired water in developed areas which needed to be diverted as complete and as fast as possible from urban areas. In contrary to earlier concepts which considered surface runoff as clean water, the rainwater from impervious areas may be polluted. According to the report by USEPA, 2000 [1], the conventional stormwater management system decreases

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groundwater recharge, increases runoff volume and changes the timing, frequency and rate of discharge. These changes can cause flooding, water quality degradation, stream erosion and the need to construct end of pipe BMPs.
In the 1960s, management of stormwater quantity for flood prevention was the only imperative in the developed countries, but in subsequent decades objectives for stormwater management have diversified to include quality, ecosystem health, reuse, integration with urban design etc along with quantity (Refer Fig 1) and has inspired the development of novel stormwater management approaches designed to minimize impervious cover and maximize infiltration of rainfall known as Low Impact Development (LID) in USA and Water Sensitive Urban Design (WSUD) in Australia. These techniques, if implemented at a watershed scale may offer a more sustainable solution to stormwater management.

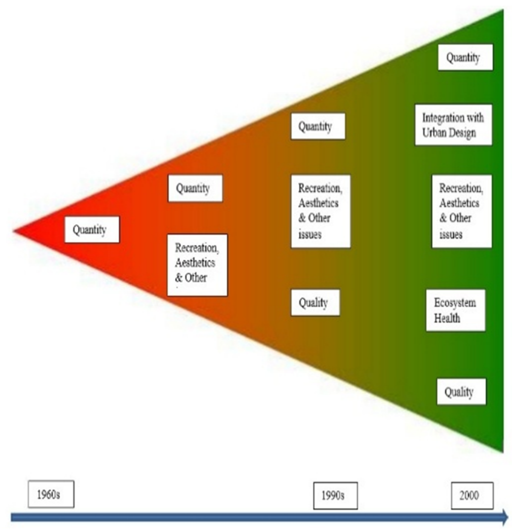

Fig. 1: Diversification of the Objectives for Stormwater Management [2]

LID is a comprehensive technology-based approach to managing urban stormwater. The LID approach combines a hydrologically functional site design with pollution prevention measures to compensate for land development impacts on hydrology and water quality. Use of these techniques helps to reduce off-site runoff and ensure adequate groundwater recharge [1].

A. Stormwater Management in Indian Context

Managing urban stormwater in developing countries poses huge challenges and the consequences of its neglect are severe. Inadequate drainage causes needless death, disease and loss of homes, property and livelihoods. Poor stormwater management also pollutes the environment and squanders limited freshwater resources.
India is currently in the early stages of a profound demographic, social and economic transition. The proportion of the population which is urban has doubled over the last thirty years and is now about 30% (India Year Book, 2006). According to Ref. [3], the runoff increases with increase in percentage of impervious surfaces which result due to urbanization. Also, this high runoff volume has a high erosive capacity. This report [3] also points out that sediment yields in areas undergoing suburban development can be as much as 5 to 500 times greater than in rural areas. Reference [4] states that the impervious surface area within a watershed is a very important parameter which decides as to how much will be the quantum of change in runoff. When there are no detention basins to arrest this additional flow and the downpour is excessive the flooding and inundation of low lying urban areas can be catastrophic.
Urban areas are characterized by extensive impervious surfaces, damaged soils, and little room for green space or for stormwater management facilities. Urbanization disrupts natural soil profiles, increases impervious surfaces and decreases vegetative cover. These changes increase stormwater runoff at the expense of groundwater recharge, degrading water quality and impairing aquatic habitats. Developing countries suffer due to the growth of the so-called irregular city. The lack of the basic infrastructure necessary to accomplish urban growth in these cities is generally critical. One of the major concerns for these regions is the problem

of urban floods. Traditional engineering solutions alone cannot solve this problem and channel enlargement measures tend to transfer the problem to downstream reaches.

High population densities in urbanized Indian cities are responsible for the water crisis being faced by these cities today. The haphazard and unplanned growth in such cities has led to a critical situation for water.

The massive urbanization in India has resulted in generation of huge quantities of stormwater which are unutilized and polluted. Although in the past urban runoff was largely viewed as a nuisance, within the new paradigm of sustainability, this water is recognized as a potential resource that should be managed accordingly.

In India, management of stormwater is either neglected or done using conventional method of providing an engineered drainage system. Stormwater management is not receiving enough attention since India has seasonal monsoon and stormwater becomes important only after a significant failure has taken place. Thus, decision making to determine the preferred ways of sustainable stormwater management in Indian context is becoming more complex.

The objective of present work is to study the quantity and quality aspects of stormwater in urbanized cities of India using case study of Pune city. An attempt is made to determine the stormwater quantity in a sub basin of Pune city by rational method using Global Mapper GIS software.

It also presents the analysis of stormwater quality in the same sub basin. This data will be subsequently used to identify sustainable practices for management of stormwater in urban centers of India.

B. Pune City: A Case Study

Pune city has been selected as a case study for this work. The city has grown tremendously in the last few decades. The current population of the city is 3.6 million and is projected to be 7.7 million in year 2041. As urban centers grow, natural land formations are altered for building and transportation. This results in a multifold increase in 'Paved' area giving rise to up to 3 times increased flow causing nearly 95% runoff [5]. There has been a two fold increase in built up area in less than a decade since 1999 (Refer Table I) [6].

TABLE I: CHANGES IN LAND USE PATTERN IN PUNE [6]

SN	Year	Barren Land	Built -up	Fallow Land	Vegetation	Water bodies	Total
1	1999	34.8	**23.8**	8.33	32.2	0.83	100
2	2008	5.73	**49.1**	20.82	23.5	0.78	100

If coupled with blocked natural drainage, this increased flow causes flooding. The rainfall pattern in the city has changed over the last few years (higher intensity, lower duration) [5]. The city has been facing the problem of flooding for the last few years. Pune’s groundwater is disappearing fast due to increased use through wells and bore wells. The Environment Status Report (ESR) has warned that such excessive use may severely affect the availability of groundwater and its quality. The report has called for increased water conservation measures to augment the city’s needs. Increased urbanization in the city has resulted in a rising demand for water in the city. The fluctuating amount of rainfall in the past two years in Pune has put additional pressure on the water supply system [5].

Excess built up area has left no open areas for natural percolation, leading to floods each week during monsoon, causing traffic jam & reduced work hours, besides air pollution.

II. MATERIALS & METHODS

A. Stormwater Quality in Kothrud Basin

According to Ref. [7], streams are the highest polluted surface water sources as they receive raw sewage. The trends presented in the report indicate that the surface water quality is deteriorating in Pune city.

As quality of stormwater is one of the major issues with respect to sustainable stormwater management systems, the water quality in the streams flowing through pune city is required to be analysed. For this, the drainage basin map of pune city (fig. II) was studied. According to this map, the city is divided into 23 drainage basins from ‘A’ to ‘W’. Out of these 23 basins, the basin ‘B’ (kothrud) was selected for water quality analysis. Figure III shows the drainage map of kothrud basin.

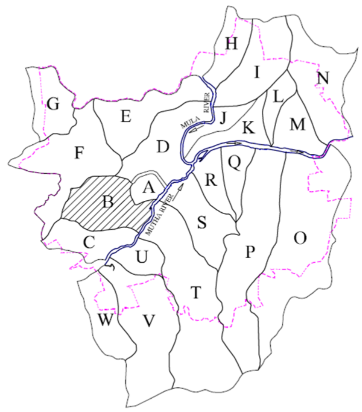

Fig 2: Drainage Basin Map of Pune City [8]

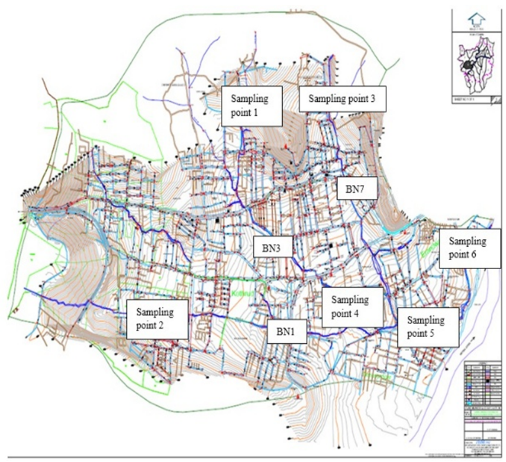

Fig 3: Drainage Map of Kothrud (B) Basin [8]

As can be seen from figure 3, there are 3 major streams flowing through this basin (BN1, BN3 and BN7). Three sampling points were selected at the beginning of each of these streams. Two sampling points were selected on downstream side of stream BN1 and at the confluence of streams BN3 and BN7 near Alankar Police Station. One sampling point was selected near Mhatre bridge where all these streams come together and discharge into the Mutha river. Grab samples were collected at all these 6 sampling locations and were immediately analyzed for Biochemical Oxygen Demand BOD_5 (20^oC), Chemical Oxygen Demand (COD), Total Solids (TS) and Total Suspended Solids (TSS). The results of analysis are presented in Table II below.

TABLE II: STORMWATER QUALITY IN KOTHRUD BASIN [9]

Sampling Location No.	COD (mg/l)	BOD_5 (mg/l)	Total Solids (mg/l)	Total Suspended Solids (mg/l)
1	321	122	540	247
2	293	94	490	345
3	196	87	477	269
4	242	109	504	208
5	365	89	594	280
6	263	113	540	239

It can be concluded from the table above that water quality in all the streams in the kothrud basin is very poor and is comparable to that of dilute to medium strength sewage. Hence, it is extremely essential to take appropriate steps to reduce the pollution level.

B. Determination of Stormwater Quantity in Kothrud Basin

In order to determine the suitable LID technique, it is required to determine the quantity of stormwater in kothrud basin. The stormwater quantity was calculated using Rational method. In this method, the runoff is calculated by using the following equation.

$Q = 10\ C\ i\ A$, where

Q is stormwater runoff in m^3/hr, C is coefficient of runoff, i is intensity of rainfall in mm/hr and A is the area of drainage district in hectares.

The frequency of storm for which the stormwater systems are to be designed depends on the importance of the area to be drained. The suggested frequency of flooding in the different areas is as follows [10]:

a) Residential areas

- i) Peripheral areas: twice a year
- ii) Central and comparatively high priced areas: once a year

b) Commercial and high priced areas: once in 2 years.

From the Intensity-Duration-Frequency (IDF) relationship for pune, the design intensity of rainfall is 74mm/hr [5].

Table III shows the runoff coefficient C for different types of areas.

TABLE III: RUNOFF COEFFICIENT [10]

Description	Runoff Coefficient C
Roads & Pathways	1.0
Residential / Industrial / Commercial, fully paved, high density	0.95
Residential / Industrial / Commercial, largely paved, medium density	0.85
Residential / Industrial / Commercial, moderately paved, low density	0.75
Open ground with bushes, steep slopes	0.5
Open ground / gardens / lawns, low to moderate slopes	0.3

For drainage area determination, Global Mapper GIS software was used. The sub-watershed area was calculated using the following steps.

1) Georeferencing of the map: The kothrud basin map was first georeferenced using the toposheet of Pune area obtained from Survey of India.
2) Digitization of contours: The contours were then digitized on the georeferenced kothrud basin map at 5m contour interval. Refer fig. 4. The contours at 1m interval were then generated using the software.
3) Triangulated Elevation Grid: The triangulated elevation grid was then generated using the elevation data for delineating the watersheds. (fig. 5).
4) Digital Elevation Model (DEM): From the triangulated elevation grid, DEM was generated using the software. Refer fig. 6.
5) Watershed Delineation: The watershed delineation was carried out by the software using the DEM as base data. (fig. 7).
6) These watersheds were generated based on the elevation data. But, while determining runoff by rational formula, the drainage areas have been modified based on elevation data as well as nature of landuse (i.e. percent imperviousness). Hence the sub-watersheds were revised considering the landuse pattern in each. Refer fig. 8.
7) Determination of flowrate: The runoff at various points was then determined using the Rational formula.

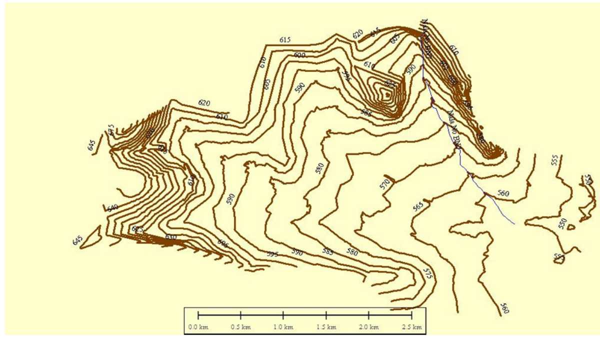

Fig. 4: Contour Digitization

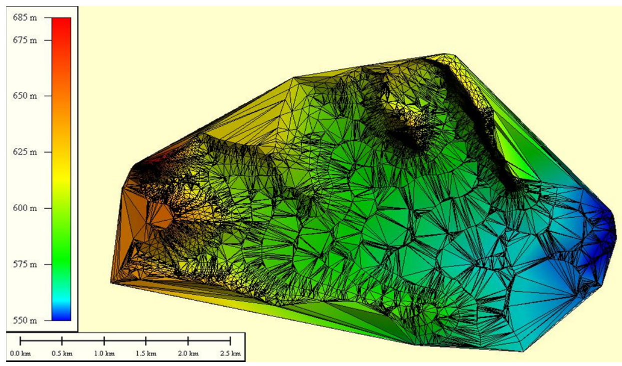

Fig. 5: Triangulated Elevation Grid

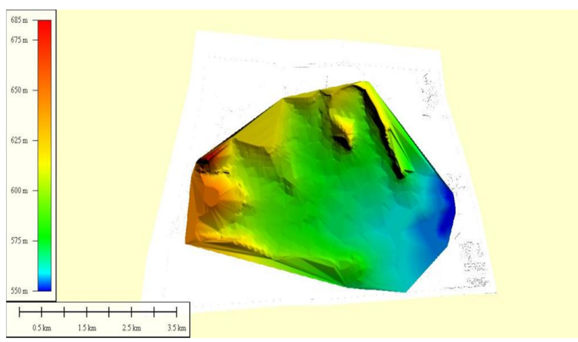

Fig. 6: Digital Elevation Model (DEM)

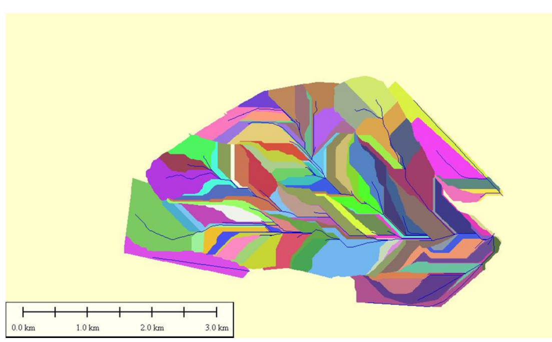

Fig. 7: Watershed Delineation

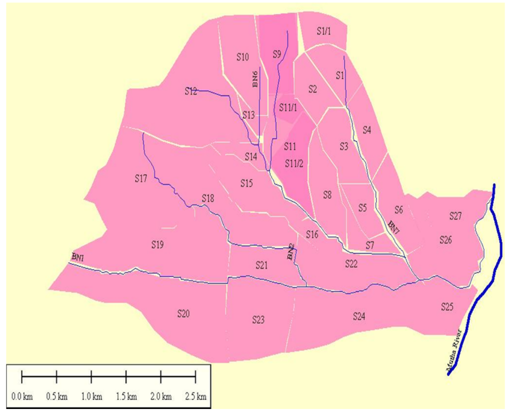

Fig. 8: Revised watersheds

For each sub-watershed, area was determined using the software and imperviousness coefficient was determined from the landuse map. Using the rational formula, the discharge at various locations was estimated. From this data, the discharge at sampling locations was determined (Refer Table IV).

TABLE IV: DISCHARGE AT SAMPLING LOCATIONS

Sampling Location No	Stream	Q in cu.m/sec
1	BN3	8.01
2	BN1	0.7
3	BN7	10.1
4	BN7	89.3
5	BN1	92.4
6	BN1	199.5

The quality and quantity data thus obtained will be helpful to select the appropriate option for sustainable stormwater management.

III. DISCUSSION

A. LID techniques

LID techniques have been successfully used in many developed countries, though most of the developing countries including India are still much behind. The primary goal of Low Impact Development methods is to mimic the predevelopment site hydrology by using site design techniques that store, infiltrate, evaporate, and detain runoff. Use of these techniques helps to reduce off-site runoff and ensure adequate groundwater recharge. Major LID techniques which have been tried as demonstration projects, lab models or have been implemented for study purpose, particularly in America and Australia are Bioretention, Permeable Pavements, Swales, Green Roofs / Vegetated Roof tops, etc [11, 12, 13, 14, 15].

B. Constraints in adopting sustainable stormwater management techniques in India

The massive urbanization in India has given rise to lot of changes in urban areas. The drivers of change can be:

A. Direct (visible physical stresses): land use changes, overuse and pollution.

B. Indirect (underlying societal causes): Political (law- policy), Economic, Social, and Technological.

The major direct driver is Land use Change. Farmlands, public (government owned) wastelands, hills, riverbanks, ponds etc. in and around cities have been converted into habitation or infrastructure (roads, bridges, office premises etc.). This has led to reduced open spaces and interrupted air circulation causing 2-3°C higher temperature than outside the city. Weekly floods during the monsoon, traffic jam, reduced work hours have become a common feature leading to economic loss from 15% to 25%. The main cause is reduced soil surface due to higher built up areas affecting water soaking ability of the city.

This enormous increase in impervious area has resulted in generation of huge quantities of stormwater which are unutilized and polluted. Although engineered infrastructure is a necessary component for drainage of urban runoff, nonstructural approaches are important complementary measures, focusing on actions to prevent and mitigate problems related to flooding, as well as those related to pollution and deterioration in environmental health conditions. It is now well established that the traditional practice of urban stormwater management contributes to the degradation of receiving waterways, and it's value as an alternative water source is being recently recognized. Consequently, this traditional practice is increasingly considered out of touch with the environmental values of society and impedes the broader pursuit of advancing more sustainable urban environments [16, 17, 18].

Selection of an appropriate technique for sustainable stormwater management depends on factors like existing landuse, percent imperviousness, availability of stormwater runoff, slopes, hydrogeology of the area. In Pune, stormwater is being managed in the traditional way by providing stormwater drains. There are 362 km length natural streams in the city which drain the runoff in Mutha river. Out of the 362km length, 51 km of stream lengths are partially obstructed and 15 km fully blocked [5]. It was observed that the existing capacity of these drains is inadequate at many places to accommodate the increasing volume of stormwater. Many roads have no road side drains and during rains, the water overflows on the roads and affects the traffic. In fact, the roads act as free passages for the flow of runoff. This results into localized flooding causing traffic jams and resulting in deterioration of the roads.

For adoption of most of the sustainable stormwater techniques, open or pervious area is required. Low availability of open area is a major constraint in adoption of sustainable techniques like retention or detention of runoff. Apart from limited availability of space, the maintenance of these may create further problems in Indian conditions. Thus, detention or retention techniques have a limited scope, particularly in highly urbanized cities. The most suitable option to manage stormwater in such condition is stormwater recharge. Hence, it is proposed to analyze Kothrud drainage basin to determine suitable recharge locations using landuse / land cover, slope, hydrogeological, pre and post-monsoon well water level data and runoff quantity data. Based on potential recharge sites, appropriate LID measures will be suggested taking into account available space, economy and other site specific constraints.

IV. CONCLUSION

It can be observed that GIS technique can be effectively used to determine the runoff from the selected catchment. In this work, Global Mapper GIS was used to delineate the sub-watersheds in the selected catchment, to determine the slope and other characteristics of the selected catchment and to determine the area of the sub-watersheds. Further, Rational method was used to calculate the runoff quantity at various points and then finally at the sampling locations. Thus, use of GIS software has reduced the time and effort required for runoff determination. This runoff quantity data will be subsequently used in identifying suitable sustainable techniques for managing stormwater in Indian conditions.

Also, from the stormwater quality analysis, it can be concluded that the stormwater is highly polluted. Hence, the stormwater needs to be managed in a sustainable way. As is evident from the literature, LID and/or WSUD techniques have been successfully used for sustainable stormwater management in developed countries. In developing countries like India, stormwater is being managed in the traditional way by providing stormwater drains. Managing the stormwater sustainably is an effective way of maintaining the health of water resources and aquatic ecosystems as well as meeting the human needs of water by minimizing the impacts of urban development. Thus, there is a need to consider sustainable options for managing the stormwater in India. Limited availability of open space and the inherent maintenance problems inhibit the adoption of retention or detention techniques in India. Such problems in the adoption of sustainable stormwater systems in developing countries can be alleviated to some extent by providing techniques promoting artificial recharge of groundwater. It is proposed to identify suitable sites for stormwater recharge in the selected basin.

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