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Sustainable Smart Blue Roof Network System with application of Geographic Information System (GIS)

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***Abstract:*— This paper emphasis on the precipitation initiated flooding which is produced by excessive depth rainfall within the city area that is overwhelmed due to improper management of drainage system. Globally water logging is a concern in all developed countries and is playing a vital role in the infrastructure management. It has become part and parcel of mostly all around the world and the good team of researchers and engineers are working to solve this issue but the recurrence of this issue is increasing. This paper speaks about the blue roof network system which has the potential to reduce the peak runoff of storm water and this study examines its potential for controlling drainage overflows through a GIS analysis in H-East ward of Mumbai, India which has been encountering water logging problem from last few decades. The Mumbai's drainage system works on the gravity based system and the end outfall is placed below as well as above the mean sea level based on various criteria such as tidal levels etc. During heavy rains, the high tides create a problem in the drainage system in such a way that the rainwater remains in the sewer and can't be drained out in the streams and this create water logging issues in the nearby vicinity. Flood management measures and study is needed at this point of time and because always space is a constraint in a city like Mumbai, the proposed measures have to be progressive to obtain the desired protection degree with minimal disturbance to the existing conditions. This study finds a solution to this problem by capturing of as much precipitation as possible every time it rains. Through a comprehensive design of control flow device over the conventional drain on the roof terrace of buildings also the study demonstrate herein with a concept of blue roofs network system on every building in the study area would decrease the number of sewer overflow events.**

Index Terms **:-- blue roof network system, drainage system, Geographic Information Sysytem, water logging.**

I. INTRODUCTION

Globally urbanization is taking place at a great pace and all the future population growth is predicted to happen in towns and cities. The annual average urban growth rate in Asia is happening at a much higher rate (1.31%) than the world average (0.83%). A. Patankar et al. (2010). Urbanization has brought about the covering of porous land, which can assimilate water, with impermeable surfaces, which can't. Conventional drainage systems have tried to transport excess rainwater away from city areas as quickly as possible. However, as city areas increase in size and population, old sewer systems are becoming less able to perform this job successfully. As a result, many sewer systems in the city like Mumbai become overloaded during large storm events, failing to undertake and transport urban runoff at the same rate at which it is created.

Several urbanized areas have burned billion dollars for isolating stormwater drainage from sewer drain by setting up new, expensive drainage systems. Likewise, large underground storage tunnels and vaults have been introduced by numerous urban areas at the expenses of billions of dollars per establishment. These tunnels and vaults are intended to gather, hold and gradually discharge the stormwater into the treatment network. Expanding stormwater pipe sizes and making tunnels and vaults is very expensive. Steve Roy (2014).

A solution to this problem is the execution of blue roof network technology, which has also constituted the demand of new evolutions to handle the consequences of drainage through the implementation of Sustainable Urban Drainage Systems (SUDS). Blue rooftops use a control flow weir over a conventional roof drain that allows short time storage and a gradual discharge of rainwater from the roof. Water can also be detained using rooftop check dams or a trays system on the roof surface area for a short duration. But in all the cases, an orifice is used to control the outflow before releasing the stored water to the building's storm drains. (Guidelines for the Design and Construction of Stormwater Management Systems, NYC - 2012)

II. LITERATURE REVIEW

The related papers were referred to study the Geographic Information System (GIS) technique and application of blue roof system on different projects and summary of papers has been written as follows.

Anna Cruijsen (2015) made an attempt to establish a sustainable urban water management design for Hoboken city. Five design approaches storages beneath parking, permeable pavement along roads, rainwater harvest cistern, green roofs and a combination of all were developed. All approaches showed a contribution to flood volume reduction, but not all approaches were as effective as combinations of all the proposed measures into an urban blue-green metabolism.

A. Licata et al. (2013) have illustrated that green infrastructure can be efficiently utilized as a stormwater management approach for handling the combined sewer overflows within the populous city in the United States. More than 20 stormwater source control pilots had been developed within rights-of-way, roadway medians, parks, public housing facilities, and rooftops. While detention and retention properties have differed with each pilot type and location.

Andrew Lo (2012) efforts to plan drainage systems using the available limited land space, along with rainwater catchment practices, in order to obtain the expected flood prevention goal. A simulation experiment was designed to assess the flood-peak reduction and flow concentration time lag for varying storm sizes. The result adequately demonstrates the suitability of utilizing rooftop catchment systems to mitigate flood problems at She-Zih.

Nitin Katiyar et al. (2012) carried out the roof- scale calibration of a pilot blue roof to measure the performance of various blue roofs at varying spatial scales in an urban drainage model. Benefits attained in this study vary for small to medium range storms and large storms, as the changes in depression storage significantly affected the generated runoff volumes.

The study demonstrates how blue roof network system can be used as a cost-effective alternative to temporarily store and gradually drain rainwater off a building's rooftop. As cities adopt sustainability goals, they are increasingly turning to building roof top solutions. Blue roofs are an attractive technology because of the multiplicity of public and private benefits. The study shows highly urbanized areas pose specific challenges due to space limitations and, therefore, require exploration of every opportunity to slow down the peak runoff near where it is generated with minimal retrofitting efforts needed.

III. PROBLEM FORMULATION

Water logging in an urban area is a common problem due to the conversion of the permeable surface to a paved area from which the rainwater flows quickly and gets impounded into the low-lying area in the absence of proper drainage system. While most of the urban drainage system is based on gravity and their outfalls are located below the high-tide level they become incapable of diverting the excess rain water away from low-lying urban areas when high-tide coincides with heavy rainfall. So having proper drainage system in the low-lying area is not enough to deal with heavy rain during high tide.

Now a day's many countries are increasing the size of the drainage system or using SUDS technique such as detention basin, retention ponds, swales, wetlands, green roofs and rainwater harvesting to overcome the problem of flash flood during heavy rain and are also proved to be effective. But using such technique in the highly populated city is not possible due to land constraint whereas for developing cities it may be costly and also occupy the surface level space.

The cost-effective method compared to SUDS technique is a blue roof network system which is the lesser known cousin of a green roof. Blue roof tackles the effectiveness of stormwater using control device instead of vegetation for the attenuation of rainwater runoff on the rooftop. This blue roof is a new technique to reduce the runoff during rain without occupying the surface level space and best suitable where the land is tight such as city center. So using blue roof technique with the integration of proper drainage system is good enough to deal with heavy rain during high tides.

IV. METHODOLOGY

Blue roof network systems represent an innovative technology that city can practically pursue today considering the amount of literature available and the possible advantages related with them. This study looks at the potential for rooftop runoff detention in Mumbai city through a GIS analysis. The Mumbai is geographically data-rich, with a high-resolution GIS base map. GIS tools are used to analyze existing building data, to quantify the available space for blue roofs on flat-roofed buildings. The Fig. 1 elaborates the research design to carry out the study.

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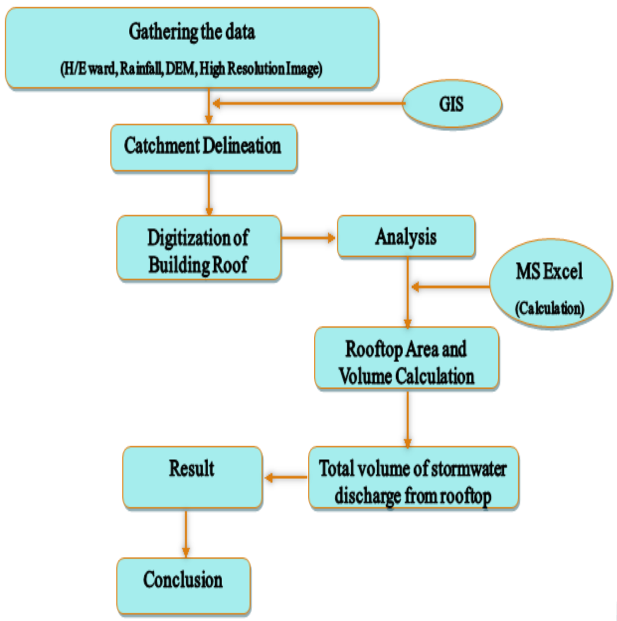

Fig. 1: Flow chart showing the methodology used

To assess the effectiveness of blue roof in delaying the runoff, a software model developed using QGIS on the buildings having different roof size class within catchment selected for installing blue roof system located in H/East ward of Mumbai city. The roof area of these buildings is classified based on average roof area present within the catchment. Many combinations of blue roof designs can be simulated, with different rainfall conditions. The results from this analysis are compared with a traditional roofing scenario.

Tests have to perform for the rainfall of 67.31 mm/hr (Maximum hourly), 50mm/hr (Brimstowad recommendation) and 25mm/hr (Existing stormwater drain capacity) to evaluate the volume of rainwater discharges from the rooftop and contribute to the stormwater drainage system. This test help to assess the peak discharge from the rooftop during rainfall and the rate at which the flow enters the drain.

V. STUDY AREA

Study area H/E ward of Mumbai city, India is selected keeping in mind the intensity of floods in previous years along the Mithi river course and Vakola nalla. The total number of available open spaces in this ward is lowest than any other wards and also had a good composition of building and slum settlement which makes it best suitable for this project work. The study area is enclosed between latitudes 19°03"02'N to 19°05"25'N and longitudes 72°50"22'E to 72°52"36'E and sits approximately 10m above sea level. The area of this ward is 13.5 Sq.km. Fig. 2 map of study area was obtained from Disaster Management Department, MCGM.

Fig. 2: H/East Ward Map, Mumbai, India.
[Source: Disaster Management Department, MCGM]

A. *Rainfall pattern*

Mumbai is in the tropical region with the Arabian Sea on the west and the Western Ghats on the east. The city receives a strong spell of southwest monsoons between the months June to October. The average annual rainfall of Mumbai is 2140 mm.

The historical daily rainfall data for years 2001 to 2015 was obtained for this study from the India Meteorological Department (IMD), Santacruz and 15 minutes interval rainfall data of BKC fire station rain gauge from Disaster Management Department of MCGM. The data was analyzed and observed that 2005, 2010 and 2011 had fairly high rainfall exceeding all other years with annual average at 3322.2, 3439 and 3224.6 mm respectively, far exceeding the annual average of 2140 mm. The daily and hourly data were further studied excluding 2005 years rainfall which was an extreme case and it was observed that 19 June 2015 had the maximum daily rainfall and 28 July 2011 had the maximum hourly rainfall of 67.31 mm. This exceeds the maximum hourly rainfall recommended by BRIMSTOWAD report of 50mm as well.

B. *Catchment Delineation*

Catchment delineation means joining contour lines on a map to identify a catchment boundary for collecting rainwater over a natural drainage area. Quantum GIS (QGIS) 2.14 software suite were used to delineate the catchment area. QGIS is a free and open-source desktop geographic information system application that provides data viewing, editing, and analysis. For carrying out the project work the

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H/East ward area is further delineated using GRASS – Watershed delineation within QGIS. The procedure for delineating is followed by the paper Watershed Modeling for QGIS. (https://luckysciencespirit.files.wordpress.com/2012/11/watershed-modeling-for-qgis.pdf)

Procedure to create Catchment area

Start QGIS software suite and make a new mapset using the **Grass Plugins** and set geographic coordinate to WGS84. Open the set mapset to get your project files and Import Digital Elevation Model (**DEM**) file of the study area. Now open the GRASS Tools and select the option **r.in.gdal** from the Modules list. Input the DEM and name your output raster file in the open dialog box. Click Run to import it in GRASS GIS.

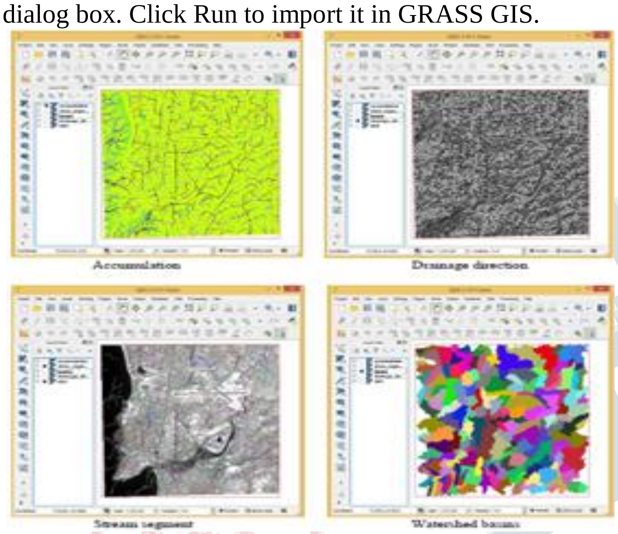

Fig. 3: Catchment delineation output files of study area

Now select **g.region.multiple.raster** from Module to set your DEM region and click on Run after importing your DEM file. Now search and open **r.watershed** in the Module for analysis. Input your DEM file and also the threshold value. The threshold is the minimum size for each basin and is calculated by using formula, Threshold = Area of smallest subbasin / Cell size. Cell size is the area depends on the resolution of your DEM. If your DEM resolution is 30m then your cell size should be 30m*30m =900 m2. Give a short name for all the Outputs and click Run. Outputs are shown in the Fig. 3.

C. Digitization of Building Roof

Digitization in QGIS is one of the most basic tasks. Quantum GIS has great ability to digitize the raster image. The high-resolution satellite image was adopted for digitizing all the building rooftops of the catchment area using QGIS tool. This high-resolution image was downloaded from Mappuzzle software by using Google map satellite as the base map. Before digitizing the roof, the downloaded image should be properly georeferenced in the WGS 1984 Geographic coordinate system within QGIS.

Process for digitizing building rooftops in the catchment areas: (G. Dadhich et al. 2016)

Open the QGIS suite and add the raster layer which has to digitize. Set the coordinate system to WGS 84 to make the raster image viewable in QGIS. Now we can start the digitization of various building rooftops by creating New shapefile layer from layer toolbar and select the layer type as a polygon. Name the attribute of the layer and select class type as text data. Save it as rooftop **area.shp** as a Shapefile and hit ok. Now the layer is displayed in the layer panel. Set the layer in editable mode by selecting toggle editing button. Now click on the add feature button to make a new polygon section of the visible building rooftop of the image.

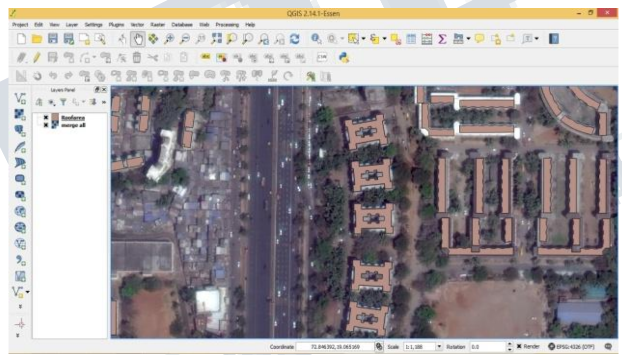

Fig. 4: Digitization of Polygon layer of study area

Once you digitized the rooftop segment, right-click to finish. Insert the information such as name, class, etc for the newly digitized rooftop feature in the pop-up attributes and click ok. Now to create the polygon for another new roof again tap on add feature button. Right-click on the digitized rooftop area and choose properties to set the color, transparency as needed for the polygon layer and hit ok. Now click on save layer edits and also the toggle editing button to save the digitized rooftop area polygon layer as pictured in Fig. 4

VI. ANALYSIS

This study emphasizes predominantly on Quantum Geographic Information Systems (QGIS) and Microsoft Excel application to perform the analysis. The study area i.e. H/E ward, Mumbai is quite vast hence tedious for data collection. This study has tried to ease out calculations for rainwater runoff. In this study area, two catchments are considered having areas 165 ha (yellow) and 91.2 ha (orange) respectively as shown in Fig. 5 based on the flooding spot

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provided by MCGM (Municipal Corporation of Greater Mumbai)

Fig. 5: Catchment basin selected for studying project work within study area

The roof areas of each and every building within the study area have been calculated in QGIS.

Table I: Classification of buildings according to roof area

Categorized roof area of building (sq.ft.)	Catchment 1		Catchment 2	
	No. of buildings	**Total surface area of rooftop (sq.ft.)**	**No. of buildings**	**Total surface area of rooftop (sq.ft.)**
0-2000	118	167122.8	82	99159.9
2000-7000	97	354790.0	45	178035.0
7000-12000	17	144605.0	17	138475.0
12000-17000	6	89314.0	6	85876.0
Total	238	755831.8	150	501545.9

The calculation of all selected building's roof areas is categorized into four size classes, as the larger the roof area, the more potential for runoff prevention (Refer Table I) and modeling of rooftops in QGIS are shown in Fig. 6.

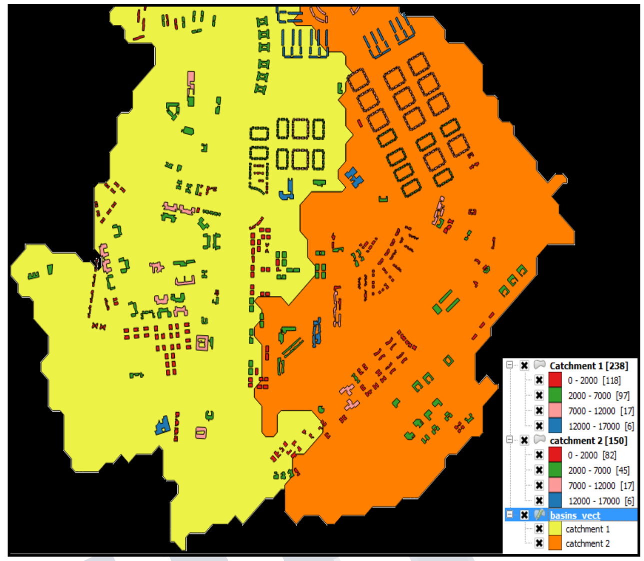

Fig. 6: Categorization of building- roof area in QGIS

VII. RESULT

A. *Runoff Coefficient*

The runoff coefficient (C) is the ratio of the total quantity of runoff generated to the total quantity of precipitation received and is a dimensionless coefficient. Because of development growth that is bound to happen during the 50-year time period, it will be very hard to renew the underground drainage system once they are placed. Hence, it is suggested by National Disaster Management Authority Government of India that all upcoming stormwater drainage systems should be designed by adopting **a runoff coefficient of up to C = 0.95 for calculating peak discharge** using the rational method. (National Disaster Management Guidelines: Management of Urban Flooding, 2010)

The Mumbai city has been already densely concretized and major recommendation in the BRIMSTOWAD report is to change the **coefficient of runoff as 1** from earlier value of 0.50.

So the runoff coefficient of **C= 1** has taken for building rooftop and **0.95** for whole catchment excluding rooftop.

B. *Assessment of Peak discharge during rainfall*

For assessment of Peak discharge during rainfall, there are 3 parameters which were used for calculating the discharge i.e. total roof area, rainfall intensity, runoff coefficient. Calculations are done by using Rational Method Equation and results are shown in Table II.

$$Q = C * i * A$$

Where Q = Peak discharge, cfs (cubic feet per second)

C = Rational method runoff coefficient

i = Rainfall intensity, mm/hour

A = Drainage area, ft^2 (square foot)

Note: Three rainfall intensity taken for study

1) 25 mm/hr – current design rain value (existing SWD).

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2)50 mm/hr – BRIMSTOWAD recommended design rain value.
3) 67.31 mm/hr – maximum hourly rain recorded in 2011.

Table II: Total volume of stormwater discharge from the entire catchment

Catchment (C)	Total volume of stormwater discharge from building's rooftop (ft^3/hr)			Total volume of stormwater discharge from area other than building's rooftop (ft^3/hr)		
	25 mm/hr	50 mm/hr	67.31 mm/hr	25 mm/hr	50 mm/hr	67.31 mm/hr
C 1	61994.08	123988.16	166912.90	1324997.83	2649995.66	3567424.00
C 2	41137.30	82274.59	110758.10	725834.53	1451669.07	1954237.00

VII. CONCLUSION

To study the detention properties under short duration rain and prolonged duration for different rainfall intensities were analyzed and calculated. Stormwater drainage system which can be designed will have the capacity to carry the volume of water discharge from the total catchment area as per the above said calculations. If the drainage system fails to meet this capacity there is a risk of flooding. In order to avoid the flood and increase the sewer capacity, rainwater should be detained on the rooftop during the peak flow to decrease the volume of water entering the drainage system. The future analysis will be carried out which will rely on the proper application of control flow weirs on the digitized rooftop and a hydraulic model will be designed.

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