

Mitigation of Urban Flooding by using Green Infrastructure in Surat, India

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Abstract

Urban flooding is a serious and growing development challenge. Against the backdrop of demographic growth, urbanization trends and climate changes, the causes of floods are shifting and their impacts are accelerating. This paper describes the flood risks faced by Surat, one of India's most commercially successful and also most flood-prone cities. The city is located on the lower basin of Tapi River, 94 km downstream of Ukai dam and flows into 15 km far Arabian sea. Hence, city is prone to flooding not only from heavy precipitation in and around the city but also from heavy precipitation upstream and from high tides downstream, causing loss of life, damage to homes and disruption to businesses.

Reducing the risks from upstream depends on better water management in a water catchment area and dam reservoir located far outside the city authority's jurisdiction and in another state. However, this research aims to review alternative techniques for reduction in increasing stormwater run-off caused due to fast growing urbanization of the city with more area getting paved with concrete and impervious surfaces not letting the water to soak into the ground. Therefore, this paper focusses on comparative analysis of effectiveness of each technique implemented by increasing green area in catchments and delaying and retaining the part of the run-off to help reduce flooding.

Keywords: Surat, River Tapi, Stormwater Run-off management, Urban Flooding, Green Infrastructures, Flood Reduction Plan

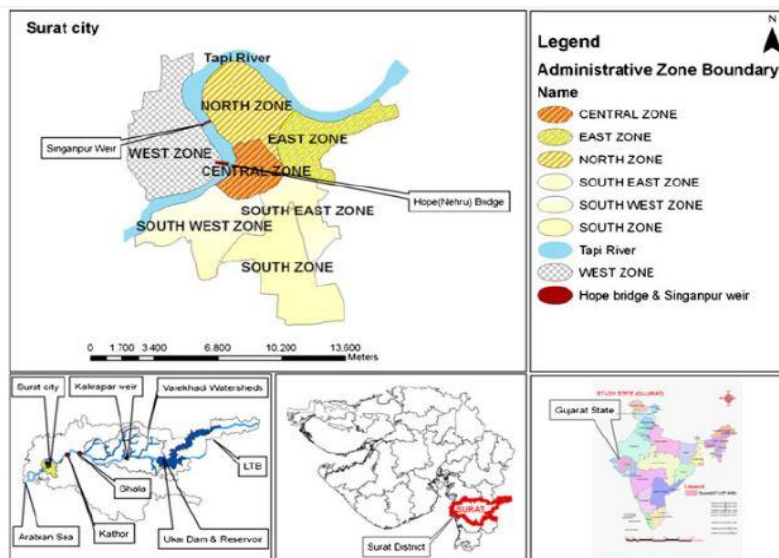
1. INTRODUCTION

Surat is located in the western part of India in South Gujarat region, is a very dynamic city with a fast growth-rate due to immigration from various parts of India. The city of Surat is situated at latitude 21deg12'N and longitude 72deg52'E on the bank of river Tapi having coastline of Arabian Sea on its West. It has a population estimated at

around 45 lacs. It has a summer temperatures ranging from 37 deg C to 44 deg C. Annual average rainfall is around 1,200 millimetres, with around 90 per cent of this falling between June and September and with very little rainfall between December and May. The city is located on the bank of the river Tapi with a walled city at its center. The topography is controlled by the river and is flat in general and the gentle slope is from north-east to south-west. The city is known for its textile trade and diamond cutting and polishing industries. Surat Municipal corporation area is about 326.51 sq.km which was 112 sq.km before extension of city. (July 2006). (Surat Municipal Corporation, 2015)



Area of Surat and Location Of river Tapi. (Bhakuni)



Location Map of Lower Tapi Basin(LTB), Ukai Dam, Surat City with administrative Zone Boundary.

Source: (Surat Municipal Corporation, 2015)

2. CAUSES AND EXTENT OF OVERALL IMPACT OF FLOODING

The Tapi River is divided in three zones, i.e. Upper Tapi basin, Middle Tapi Basin, and Lower Tapi Basin (LTB).

The portion between Ukai Dam to Arabian Sea has been considered as LTB, mainly occupying Surat and Hazira twin city along with tens of small towns and villages along the river course. The Surat and Hazira twin cities are downstream of Ukai Dam almost 94 km distance and are affected by recurrence floods at regular intervals. LTB receive an average annual rainfall of 1200 mm, and these heavy downpours result into devastating floods and water loggings mainly between Ukai dam and Hazira town downstream.

Flooding remains Surat's most persistent long-term vulnerability, especially as climate change affects the water cycle. Recent years have seen fewer rainy days in the year, but more intense rainfall on those days, increasing the flood risk. On top of that, rising sea levels are expected to cause higher tides that could cause Tapi to flood more frequently.

The main reasons for flooding in Surat depend on heavy rainfall and discharge due to high water levels from Ukai dam. Therefore, the flood problems of the river system are inundation due to over flowing of the banks. High tide during certain period from Arabian sea also play significant role in flood formation for this city. (Sudhakar BS A. K., 2015)

Surat is usually affected by two types of floods: Tapi River flood and Khadi flood. Tapi river flood occurs due to heavy inflow of rainfall in Tapi basin while Khadi flood occur due to heavy rainfall in city and tidal effect of the sea.

2.1 Tapi River Carrying Capacity and River Basin.

Due to construction of Weir cum cause way on river Tapi reservoir is formed on upstream side of river which led to stagnation of flowing river water. The stagnation of river water give rise to growth of algae and weeds hence raw water quality get deteriorated which causes problem in intake well as well as in subsequent treatment process. Moreover, sewage discharge from some of the area has created terrible impact on river water quality on upstream of river. Also, Sewage discharge enhances the growth of algae, weeds and other vegetation which causes synergistic effect on river water quality.

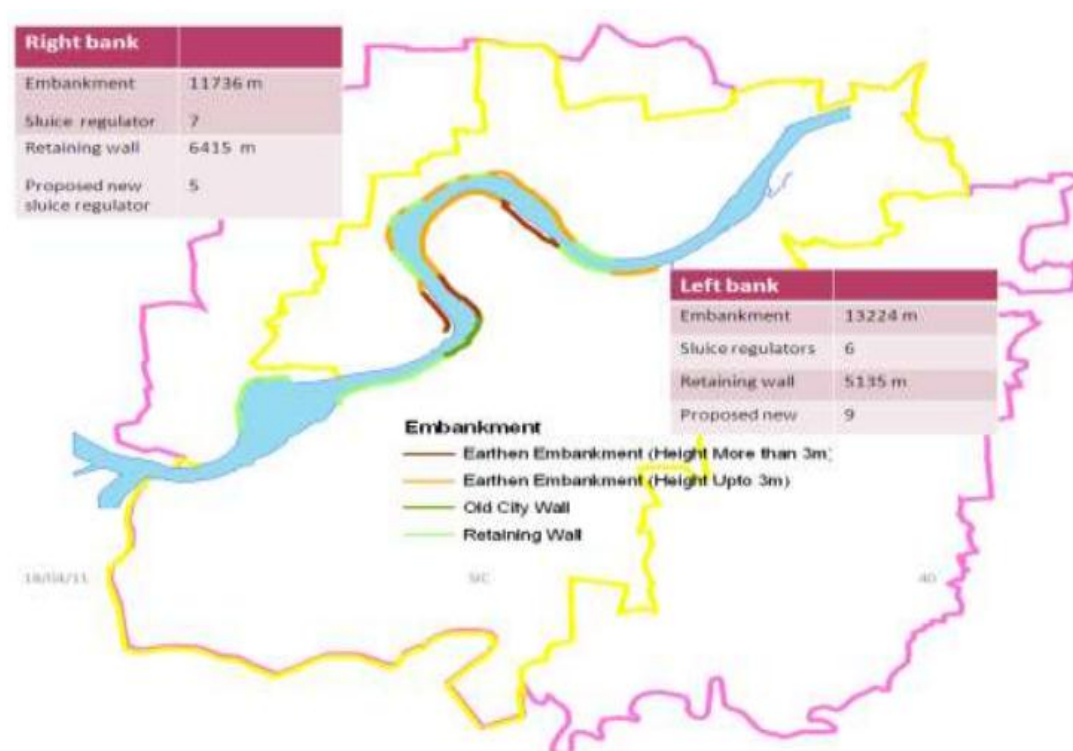
Due to tidal influences, river water becomes brackish in the downstream of weir in river Tapi. Owing to these problems, the bore water of adjacent area becomes salty and not fit for drinking. (1)

(1) - (Integrated sustainable urban water network using statistical and analytical heirarchy process modeling technique: a case study of surat city)

Hence, Tapi River near Surat is reported to have been significantly reduced from 10 to 3.5 lacs due to: encroachment in the flood plain areas, silting in the river-bed, and afflux caused by the Singanpore weir constructed on the river very close to the city.



Shift in River Tapi and storage of water at weir cum cause way, hence shrinkage of river downstream due to siltation.



Embankments and Retaining Walls

Source: (G. I. JOSHI, August 2014)

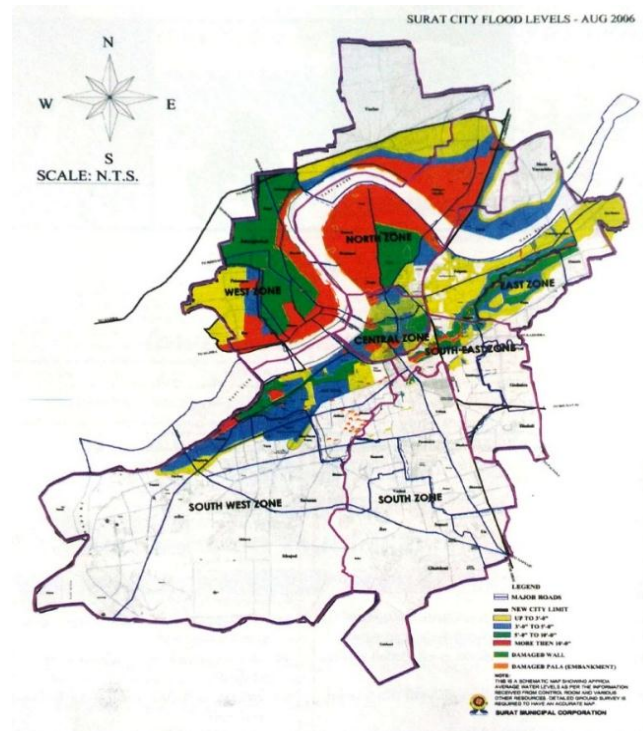
2.2 Flood of 2006

Owing to unprecedented heavy rains in the year 2006, it was clearly the year of major flood disasters for Gujarat. The State had not witnessed such widespread floods in all the major rivers of the state in its recent history. There was the unprecedented flood in Tapi river at Surat on August 7, 2006 caused by sudden release of large quantities of water from Ukai dam. The water level in the river at Surat crossed the previous highest level of 12 meters (of 1968 flood) and reached 12.5 m, submerging more than 80% of the city under water. More than 20 lakh people—almost two third from low income areas—were trapped in their own or neighbors' houses without food, drinking water, milk, electricity and communication with outside world four days and nights. Scavengers from other cities were mobilized to clean up the mess. About 150 people lost their lives and the economy of the vibrant city came to a standstill. (2)

(2) (Centre for social studies(CSS),Surat and Department of human resources development(DHRD), 2006)

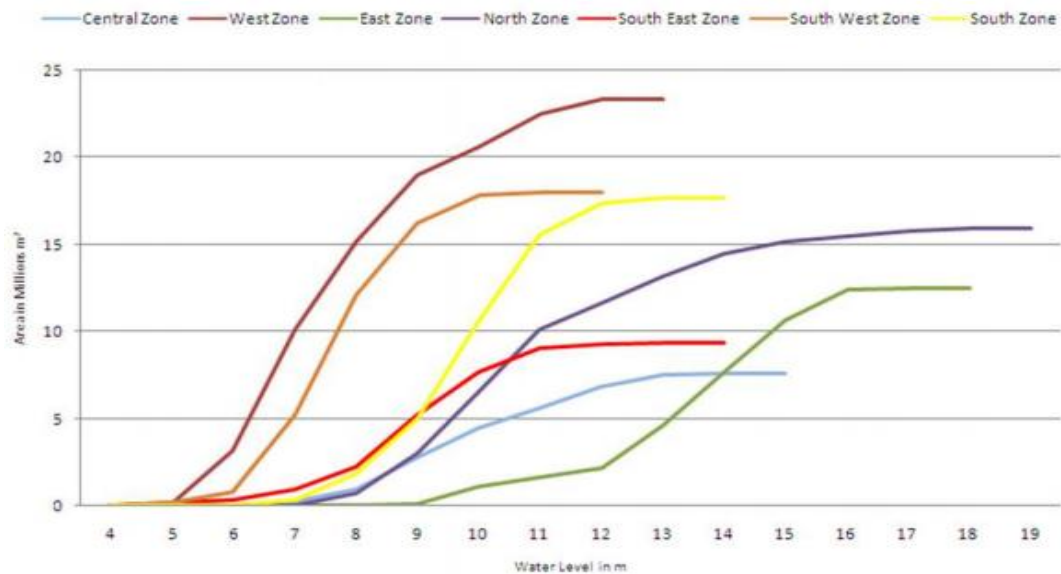
2.3 Causes of Flooding in Surat City

Causes	Consequences
Deficient urban drainage system	The incapacity to absorb the rainfall and run-off water by the pipe or local drainage network during extreme precipitation episodes might cause sewer overflow.
Failure of Ukai dam to release water	Management failed to take action to release water time to time and late warning and emergency call to the people lead to flooding in year 2006.
Deforestation	Surat is one of the fast-growing city in country, this had led to deforestation which is another major cause of land erosion, landslides and loss of natural defensive system against flooding disasters.
Impervious surfaces due to urbanization processes and effect of city growth.	The growing urbanization of cities results in the lack of permeability of the soil. Impervious paving surfaces reduce the infiltration capacity and are the major cause of saturation of the drainage systems and urban floods.
Land use and building in flood-prone areas	Land use and building in floodable areas increases the negative effects of a flooding episode.
Effect of tides and Siltation-Coastal Flooding	Arabian sea is located at around 15 km from the city, this effect the city with backlash of sea water depending upon the tides resulting into siltation and hence, flooding.



Flood level demarcation of 2006

Source: (Surat Municipal Corporation)



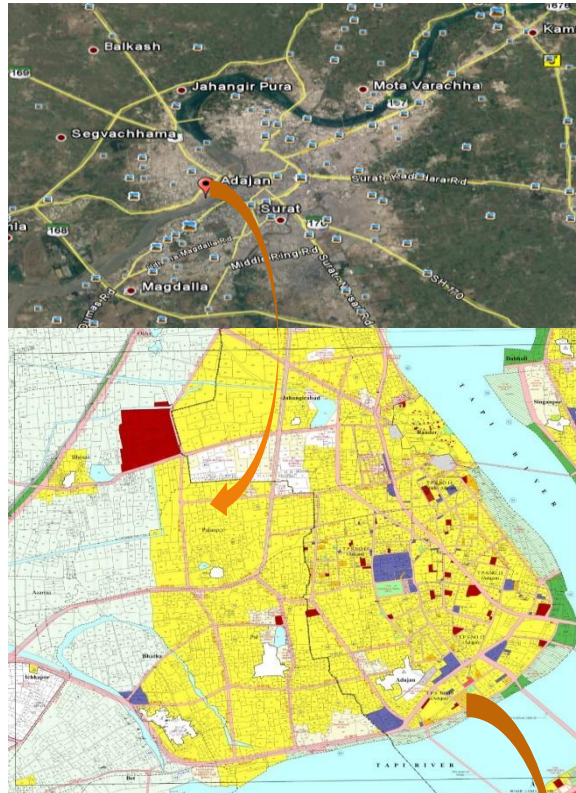
Different zones of Surat city submerged in water.

Source: (G. I. JOSHI, August 2014)

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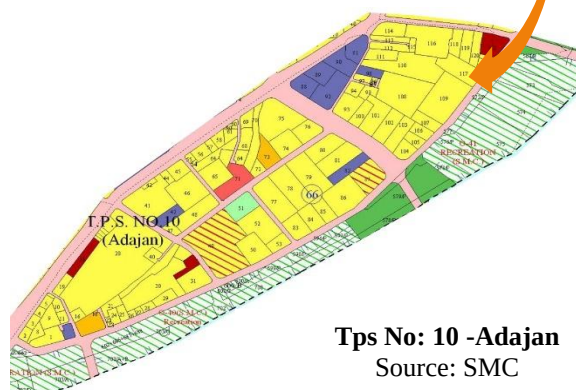
3 STUDY AREA

It was not feasible to take all zones of the Surat Municipal Corporation into consideration; hence Tps no 10 (adajan) of west zone is selected to study as it is the most flooded area of the city with an average elevation of 8 m from sea level.



Development Plan of West Zone

- Yellows: for residential uses such as single-family and town houses.
- Browns: for multi-family and high-rise residential
- Reds: retail and commercial uses
- Purples: for industrial uses
- Blues: institutional and public facilities
- Greens for recreational uses
- Grays for industrial utilities



Tps No: 10 -Adajan
Source: SMC

The depth of water in west zones area was 2 m to 4 m, which demarcated in flood hazard map. Out of 23.34 km² area 23.30 km² would be under water in West zone if river reaches to 12 m height near Nehru Bridge. South zone, South-West zone, South-East zone and Central zone are also low rise area of the city all this zone would not survive longer for flood of equal frequency as 2006. North and East zone are high rise area of the city and most of its parts are settled at higher level than 12.5 meter. Accordingly, these two zones can survive against danger of flood up to some extent compare to another zone of the city.

The proposed retrofitting of ADAJAN RIVER FRONT RESIDENTIAL AREA (As per smart city area based proposal) has a low commercial activity and high number of high rise and single family bungalow as seen in developmental plan and Town development scheme. Hence, high potential to propose alternative green strategies to mitigate flooding.

4 STORMWATER MANAGEMENT

Traditionally, flood mitigation infrastructure has relied on cement and concrete in the form of dams and storm water systems just like Ukai dam in case of Surat, but with natural disasters ushered in by climate change, traditional defensive approach to combat flooding may not be enough.

Stormwater Management means to manage surface run-off. It is essential in urban areas where run-off cannot infiltrate because the surfaces are impermeable. Cities are replacing the permeable land with impervious surfaces. The problem gets aggravated by the fact that drains do not have sufficient slope to draw water from surface water and channelize it.

The storm water during rainy season causes drainage problem and often roads are damaged by rainfall runoff. This problem is serious in big cities and industries, where most of the open area is covered by roads or some concrete structures without proper drainage. The water on roads during rains remains stagnant for hours together due to poor storm water management and resulting of drainage area hampered.

Storm water harvesting along both the sides of roads with the help of suitable, simple structures, would not only control storm water hazards in cities, but will enhance ground water availability 8 to 10 times compared to natural process of rainfall infiltration.

Based on normal rainfall and peak rain fall intensity, the storm water harvesting system is designed in such a way that 70-80 % runoff of roads and paved area is sent back to ground water regime after natural filtration process. (Jain)

4.1 Integrating Stormwater Into the Built Environment:

As per resident's reference guide to stormwater management of Kansas City, Missouri, the stormwater management is identified by three steps i.e.

1. Slow it down

2. Spread it out
3. Soak it in.

As per the guide, these solutions say, instead of building more (drains, pipes, roads) we have to build less keeping areas soft and vegetated with native plants, and even dismantle what we have built. While doing so we have to be careful of not letting the increased water table affect our basements, tunnels, and building foundations. For conventional twentieth-century engineering logic, this de-construction method is counter-intuitive and will be strongly resisted as a solution by most civic authorities, but it is the global recipe for storm water management, and is being successfully implemented by enlightened municipal bodies all over the world. The urban flooding will get worse, much worse, and the only solution is de-construction and establishing green infrastructure are the major strategy for mitigating urban flooding. So, making it necessary to implement this at a near zero cost today in a distributed manner by getting people to effectively create rain gardens, green roof, bios wales, and water storage tanks or recharge wells. (3)

(3) (A RESIDENT'S REFERENCE GUIDE TO STORMWATER MANAGEMENT, 2015)

5. ALTERNATIVE TECHNIQUES TO MITIGATE FLOODING.

5.1 Bios wales

Bios wales are an alternative option for concrete gutter and drainage sewer, it is a linear vegetative channel which help slow down the run-off and percolate into the ground.

As it is linear in nature, its more appropriate for and suitable for parking lots, sidewalks where there is not steep slope.

Dense vegetation helps to infiltrate run-off effectively, hence native plants are preferable.

Also, if permeable material like gravel is added below the channel can increase the storage capacity of run-off.

To ensure that a bio swale continues to operate effectively, it must be inspected periodically to ensure that the channel is adequately vegetated and that there are no blockages. (Naturally Resilient Communities)

Bio swales are capable for retrofitting situation and a landscape feature.

Bios wales are generally 3 feet (min) to 7 feet (max) with an ideal slope of 4:1 and check dams if required for steep slope. It is capable to handle run-off of not more than 6".

Green Gutters are narrower green street with max width of 3 feet, rate of removing pollutants is low but is preferable as a buffer between road and sidewalks.it is capable of handling run-off of not more than 3".

(Delhi Drainage Master Plan, 2013)

5.2 Green Roof

Green roof also known as “Living roof” is a thin vegetative cover over a roof to collect, filter and store rainfall, so as to retain and delay the rain water to end up getting discharged in stormwater drains. Hence, it prevents waterlogging and eventually leading to flooding. They typically include a waterproof membrane, drainage and filtering layers, growing media (soil), irrigation, and plant materials.

Green roof can be incorporated in any building roof top, considering the roof structures should not have slope of more than 25 percent. Structural Load consideration is of vital importance to construct green roof specially to retrofit the existing buildings as they can add tremendous load to the overall structure.

Both the dead load of green roof and live load of people needs to be determined before implementation. Additional reinforcement may be required to support the green roof for existing buildings. Studies have estimated payback period from green roof through energy savings to be anywhere from zero to 20 years. (Naturally Resilient Communities)

5.3 Permeable Paving:

Permeable surfaces are surfaces which allow water to percolate or travel through their structure into the underlying ground layer, thereby relieving pressures on traditional stormwater management system. Permeable pavements are typically designed to handle as much as 70-80% of annual rainfall.

(Jovian Designs, 2010)

Types of Pavers:

1. Permeable Asphalt (Applicable for sidewalks, low traffic area)
2. Permeable Pavers (Applicable for parks, government common areas)
3. Grass Pavers.

Permeable Surfaces serve as more environmentally conscious, low impact development materials to rainwater runoff control. Although some surfaces have higher porosities than others, they all work to restore the in-situ hydrology of a site by reducing runoff, filtering and treating infiltrating runoff.

6 CASE STUDIES

Significant adaptation examples to urban flooding implemented by different cities

6.1 Rotterdam, Netherlands

Challenges faced to mitigate flooding in Rotterdam were Security, quality, water storage and lack of public spaces to manage storm water. Hence, measures taken were

- To improve water quality and ecology: identify the areas that do not meet the

quality standards (GIS), establish a criteria of wastewater collection, progressive disconnection of storm water outlets from the drainage system, deal with storm water by changing the traditional idea of presence of water in cities.

- Water storage and lack of space: water squares in low-lying public spaces as temporary open water storage facilities. The rest of the time is dry place and the main use is an attractive recreational area with playgrounds, benches, vegetation, etc...

Expected outcomes

Tackle the water problem –floods and fresh water scarcity– and the lack of public spaces with a mixed solution: water squares, water, underground storage for sewage overflow, sponge roofs, and resilience profiles combined with GIS data to set new targets for ecosystem services. 34.9 m² of green space per person and higher life expectancies.

(Rotterdam Waterplan 75-81, 2007)

6.2 Arlington, US

Challenges were to Increase water quality and manage storm water. Accordingly, measures taken were

- Eight rain gardens to reduce storm water volume and prevent sediment and nutrient pollution.
- Eight infiltration trenches under two local avenues to reduce the amount and speed of runoff water.
- A large underground storm water storage and infiltration facility.
- Redesign and recovery of a local lake park as a regional level pond, known as “Como Park”. (Arlington Region Watershed District, 2007)

6.3 Surface Water Management and Urban Green Infrastructure, London

The review discusses about integration of various green infrastructure and storm water management practices in UK and other international countries with its relevant positive impact on the city.

GSI Measures for Impervious surface reduction methods	% of GSI performance standard attained by this measure
Green roofs	59-70%
Permeable Pavement Surfaces	60-100%.
Bio retention Cells	85%

The Author highlights Green Stormwater Infrastructure Categories and Credits for developments or stormwater disconnections in Seattle.

Stage of control	Examples of GI related measures
Prevention	Good housekeeping on the site and using only licensed pesticides, herbicides and fertilisers on plants and in garden. Increasing the permeable area.
Source	Green Roofs on building, directing roof runoff on to lawn areas
Site	Grassed Swales, detention /infiltration
Regional	Wetland, Retention ponds

The place of GI in the SUDS management train for water quality record
(R . M. Asley, 2010)

6.4 Green Roof as a Storm Water Management Tool in Mumbai by Suchetta Mathew

The researcher aims to calculate the reduction in volume of run-off quantity by retention through intensive green roof in retrofitted building of mumbai. 3' X 3' green roof model was made and reading were taken based on different scenario of 80% green roof available and 50% green roof available. Also highest rainfall recorded for a day and hourly basis along with the rainfall intensity was noted.

Description	3" Green roof	6" Green roof
Detention per Sqm	20.6 litres	29.44 litres
Retention per Sqm	17.99 litres	21.45 litres
Threshold Rain for 1 Sqm	11.47mm	17.36 mm

Summary of Results from model study

The study showed effectiveness of green roof to mitigate flooding by 12-20% depending about the roof area available for green roof, the thickness of green roof and intensity of rain. Also for retrofitted building, it is highlighted to propose extensive green roof with 6" thickness.

6.5 Permeable Surface Stormwater Management Feasibility Study by Jovian Designs, London in 2010 was done by Daniel Bittman, Aniruddha Dhamorikar, Stevan Dixon, Jenna Simpson and Syed Zaidi London.

Runoff Coefficients for different surface typologies			
Surface	Runoff Coefficient	% Runoff per sq.	% Infiltration per sq.
Conventional Asphalt	0.9	90%	10%
Conventional Concrete	0.9	90%	10%
Conventional roof	0.9	90%	10%
Permeable Asphalt	0.4	40%	60%
Porous Concrete	0.4	40%	60%
PICP	0.25	25%	75%
Extensive Green Roof	0.5	50%	50%

It aims to do comparative analysis and feasibility of implementing of different types of pervious pavement along with green roof in different scenario. This is to include the permeable surfaces in urban design guidelines in the city of London. The study was based on a baseline case with 20 hectares of city area. Comparison of runoff reduction for convention and permeable surfaces of Pavement and Green Roofs.

6.6 Using Green Infrastructure to Mitigate Flooding in La Crosse, WI

(United States Environmental Protection Agency, 2014) By- 2012 green infrastructure technical assistance program City of La Crosse, WI

This report highlights the evaluation of potential of green streets to mitigate flooding in the Johnson Street Basin.

The project consisted of five steps. First, a detailed EPA Storm Water Management Model (SWMM) was developed to represent runoff generation and conveyance in the Johnson Street Basin. Second, three green street designs were selected for further analysis. One of the selected designs added bio retention to the right-of-way, while two of the selected designs added permeable pavement. Third, the applicability of each design within the basin was determined.

Summary of Road Properties				
Category	Unit	Major Roads	Local Roads	Alley
Percent of street	(%)	8	63	29
Average width	(feet)	49	37	17
Number of driving lanes	(#)	4	2	1
Is there on-street parking?	(Yes or No)	Y	Y	N
Where is parking?		Within driving lanes	Dedicated parking lanes	NA
Parking on 1 or 2 sides?	(#)	2	2	NA
Maximum Extent of Bioretention				
Category	Unit	Major Roads	Local Roads	Alley
Percent street length converted to bioretention	(%)	None	30	0
Width of bioretention	(feet)	NA	8 each side of road	NA
Maximum Extent of Permeable Pavement				
Category	Unit	Major Roads	Local Roads	Alley
Percent street length converted to permeable pavement	(%)	80	90	100
Width of permeable pavement	(feet)	8-10	16	4



Street Assumptions and green infrastructure capability

7 CONCLUSION

Effect on hydrological cycle is the resultant force due to increased impervious surface area which is a consequence of urbanization. This increased proportion of impervious surface creates shorter lag times between the arrival of rainfall and consequent high runoff rates and total flow volume. As a result, municipality's storm water management system may be put under increasing pressure in order to compensate for this additional

volume of runoff. The alternate, non-conventional techniques like green roof, Permeable Pavement, Bio swales can result in environmental and social benefits and eventually less pressure on municipality. A Review of the current literature on permeable surfaces, green roofs and stormwater management approaches and techniques was conducted. All the research was primarily focused on the typologies, water retention capacity under different scenario, durability and costing. This review paper summarizes the current status of the issues related to urban flooding in Surat with its cause-effect impact to the city and the alternate green techniques in terms of green infrastructure, Storm water infrastructure adopted all over the world to mitigate the flooding. Surface Analysis for the site survey with its surface type and percentage along with its water retention capacity was calculated as baseline. Thereafter, researchers have created different scenarios for different alternative surface type like permeable surface and its relevancy to flood reduction run-off. Also, the research updates about creating a framework on policy making for floodplain areas. Studies have been conducted at onsite level, neighborhood level and district level with a common principle of slowing down the run-off in terms of Green Roof, spread it out with bio swales and soak it underground by pervious pavement. Based on Literature review and site condition, incorporating Green Roof can work well as selection of study area as TPS 10(Adajan) is a flood plain area and majorly with row houses and residential areas with very less commercial activities. Green Roof is an effective stormwater measure with reduction of run-off from 12-20% with respect to thickness to green roof, available total roof area and rain intensity. Besides Green roof, there are internal lanes(alleys) of 4.5m to 6 m to access the row houses and bungalows which can be permeable. Hence, scope of application of different types of permeable pavement can help mitigate waterlogging and eventually flooding by 40%. Bios wales can handle 6” of runoff and can work well as the main roads are 45 m wide and secondary roads of 24 and 18 m wide. Hence, constructing swales with an underdrain can help reduce the impact of water logging as the soil of Surat is deep black soil with high clay content which has a poor drainage taking long time to percolate into the groundwater.

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