Project Urban Living Lab

IMAGINE panaji SMART CITY DEVELOPMENT LTD.

FLOOD MITIGATION PLAN

FOR PANAJI

Green Strategic Partnership India-Denmark

ROYAL DANISH EMBASSY New Delhi

MINISTRY OF FOREIGN AFFAIRS OF DENMARK

This publication has been produced as part of the Project Urban Living Lab in Panaji (PULL), with the financial support of the Danish Ministry of Foreign Affairs, Royal Danish Embassy, New Delhi. Its contents are the sole responsibility of Oxford Policy Management, Transitions Research, and The Energy and Resources Institute (TERI) and do not necessarily reflect the views of the Danish Ministry of Foreign Affairs, Royal Danish Embassy, New Delhi.

PULL is a sandbox to test new approaches and solutions for sustainable and liveable cities in collaboration with residents, policymakers, public bodies, businesses and academia. It has been set up under a Memorandum of Understanding (MoU) between the Royal Danish Embassy in India (RDE) and Imagine Panaji Smart City Development Limited (IPSCDL), drawing on an earlier MoU on Sustainable and Smart Urban Development signed between the governments of Denmark and India in April 2018. It is being implemented by Oxford Policy Management, Transitions Research, and TERI.

Editorial and Design
Oxford Policy Management (India Office)
Transitions Research
The Energy and Resources Institute (TERI)

Authored by
Dinesh Ramanathan, Ulrik Lassen, Gonzalo Fuentes Dellepiane, Benjamin Holm and Mirlinda Sulejmani

Published by
Project Urban Living Lab (Oxford Policy Management, Transitions Research and The Energy and Resources Institute), 2021

To Cite This Report:
Ramanathan, D., Lassen, U., Fuentes Dellepiane, G., Holm, B., Sulejmani, M. (2021). *Flood Mitigation Plan for Panaji.* Project Urban Living Lab

For More Information

MINISTRY OF FOREIGN AFFAIRS OF DENMARK
ROYAL DANISH EMBASSY
New Delhi

Danish Ministry of Foreign Affairs,
Royal Danish Embassy, New Delhi
Plot number 33 B,
Dr. S Radhakrishna Marg,
Chanakyapuri,
New Delhi 110021, India
Tel.: +91 11 4209 0700
Fax: +91 11 2460 2019
Email: delamb@um.dk
Web: www.indien.um.dk

Oxford Policy Management

Oxford Policy Management (India office)
4/6, Sirifort Institutional Area, August Kranti Marg, New Delhi. 110049, India
Tel.: +91 (0)1148 081 111
Email: info.indiaoffice@opml.co.uk
Web: www.opml.co.uk

TRANSITIONS RESEARCH

Transitions Research,
362/B, Coma Vado
Aldona, Bardez - 403508
Goa, India.
Email: hello@transitionsresearch.org
Web: www.transitionsresearch.org

teri THE ENERGY AND RESOURCES INSTITUTE
Creating Innovative Solutions for a Sustainable Future

The Energy and Resources Institute,
Centre for Urban Planning and Governance Sustainable Habitat Programme,
Darbari Seth Block, IHC Complex, Lodhi Road, New Delhi 110003, India
Tel.: +91 11 2468 2100; 2468 2111
Fax: +91 11 2468 2144 or 2145
Email: pmc@teri.res.in
Web: https://www.teriin.org/cities

FLOOD MITIGATION PLAN FOR PANAJI

Executive Summary

The Project Urban Living Lab in Panaji (PULL) is India's first urban living lab. It is a sandbox to test new approaches and solutions to complex urban challenges for sustainable, future-proof cities in collaboration with residents, policymakers, public bodies, businesses and academia.

Since 2000 flooding has taken the top position amongst disasters with a share of 55% followed by cyclone (22%), extreme temperature (11%), landslide (7%), earthquake (4%), and drought (1%) as per a study of disasters in Indian sub-continent[1]. 2292 cities and towns in the country are located in districts which have seen at least 11 flood events over the 18 years of data analysed between 2000-2017. Of the Smart Cities in India 56% of them are in districts with flood events higher than the mean. Coastal floods accounted for 1% of the flood events, while riverine foods accounted for the maximum events.

Panaji city has its share of flooding instances in the recent past has been flagged as a vulnerable to rising sea level as well due to climatic changes. In this context, this thematic plan on Urban Flooding examines the causes of urban flooding, explores sustainable nature based solutions for mitigation and provide a road map to achieve resilience. A set of early action interventions are identified to be integrated with the ongoing improvement works under the Smart City Mission. Medium and long-term interventions are identified to make Panaji a flood resilient City.

[1] Decoding the monsoon floods, SEEDS and CRED, New Delhi, January 2018

Table of Contents

List of abbreviations

City Corporation of Panaji (CCP)
Imagine Panaji Smart City Development Limited (IPSCDL)
Non-Governmental Organisation (NGO)
Project Urban Living Lab (PULL)
Public Works Department (PWD)
Resident Welfare Associations (RWAs)
Royal Danish Embassy (RDE)
Urban Local Body (ULB)
Water, Sanitation and Hygiene (WASH)

Introduction

Panaji, the capital city Goa, is a low lying coastal city surrounded by the Arabian Sea to the west and is located at the mouth of the estuaries of the Mandovi and Zuari rivers. The city is prone to cyclones and heavy rains, resulting in flooding which is increasingly becoming more common.

Historically, many of the low-lying areas of the city consisted of ponds and marshes which provided a buffer against the flooding of the Mandovi River. Embankments addressed any water runoff from flooded creeks and prevented soil erosion. While mangroves in the outer embankments acted as bio-shields and wave breakers to protect the coastlines from any tidal action.

Over time the low lying areas of the city, which were the marshes and watersheds, have been reclaimed for infrastructure development. Thus the catchment area of the rivers and lakes has been greatly/significantly reduced; resulting in run-off water entering the city areas. This has also disturbed the hydrology and ecology at the mouths of St Inez and Ourem creeks. The open and porous spaces on roads and pavements, which allowed water to seep through, have been replaced by concrete.

The incidence and severity of urban flooding events are likely to increase, causing damage to urban infrastructure and disruption to livelihoods. A report on climate resilient infrastructure in Panaji found that critical infrastructure in areas including Altinho, Mala Lake, Fontainhas, Ribandar and La Campalaz ones are likely to be affected by future floods. Most recently, the Cyclone Tauktae and the subsequent flooding in the city has underlined the necessity for Panaji to implement both short and long term flood mitigation actions.

100%

of Panaji's streets have stormwater drains

Drains on one or both sides of street based on data analysed.

94%

Annual Rain falls in 4 months

3100mm Average Annual Rainfall for Goa Region, June -Sep months receive 2914mm rainfall

Source: IMD


Deltin Caravela
Pride Casino
Deltin Royale | Casino in Goa
Goa Museum
Caravela Cafe And Bistro
Atal setu
Suryakant Ras Omllette
Reis Magos Church
Reis Magos Fort
The Art Park, Campal
Panjim Market
Panjim Church
JosephBarPanjim
Union Bank of India
Kala Academy Lighthouse
Kala Academy
Mandovi River
Military Hospital
Football Ground
Ritz Classic Panjim Gymkhana
Mandovi Riverfront Promenade
The Black Sheep Bistro
Parade Ground
Casino Carnival
Cream Choc Gelato
Perfect Cup Coffee Roasts & Deli
Bank of Baroda
Vivo Service Center
Narkar Kakulkars of Goa
Shankar Devsthan
Central Bank of India
Hanuman Temple
Models Legacy
GOA SCIENCE CENTRE & PLANETARIUM
Corporation Bank
Directorate of Agriculture
Stevens Dumpale
Government Polytechnic
Goa Reserve Police Administrative Block
Police Quarters
Shri Ram Mandir
Primary Health Centre, Panaji
Kamaleshwara Datta Mandira Taleigao
Syndicate Bank Goa Panaji Branch
RTO Panjim
Convention Centre
St. Francis Xavier's Chapel
Panaji Bus Stand
Our Lady of Velankanni Chapel
Sati Bhavani Temple
STC
Shri Hanuman Temple
India Meteorological Department
North Goa Planning and Development Authority
Chief Minister's Official Residence
Cafe Bodega
Mangrove Boardwalk
Town & Country Planning Department
Ritz Classic Patto
Shram Shakti Bhavan
Passport Office
Ghanashyam Govind Kamat Memorial Hospital
Rio de Ourem
The Chief Electoral Officer, Goa
Inspectorate of Factories and Boilers, Institute of...
Directorate Of Sports & Youth Affairs
McDonald's
Mum's Kitchen

Topography of Panaji

Goa's capital city, Panaji, is located on the banks of Mandovi River. The city is bound by the Rua de Ourem creek to the east, the Mandovi river to the north, the hillock of Altinho to the south east and the St Inez Creek and Taleigao village in the west. The general elevation of Panaji varies from sea level to over 50 m at the Altinho hills; most of Panaji is between 3-5 m above MSL.

The area of the city is approximately 8.19 sq km with a population of approximately 70,000 and with a floating population of 150,000. The city receives an annual rainfall of 3,100 mm and humidity levels range between 70 – 95%.

Drainage of Panaji

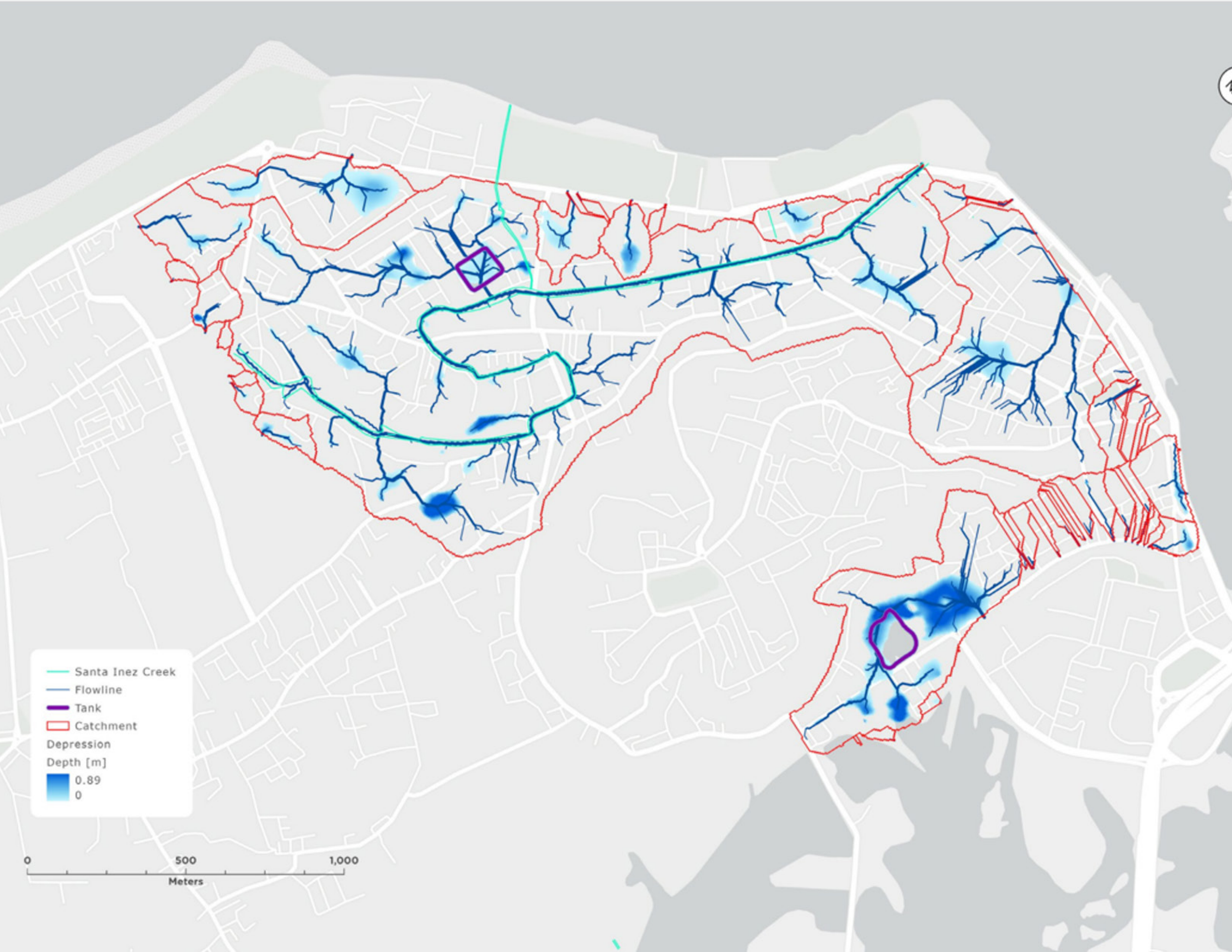
Panaji is drained by three natural, partially navigable creeks - Chimbel, Ourem and Santa Inez and more than 60 minor creeks. Except the higher ground found in Altinho, Mala, Boca de Vaca and Fontainhas, the city of Panaji is mostly situated on the reclaimed land of the low lying flood plain of the Mandovi estuary.

The St Inez Creek is an arterial waterway that originates from either the Kazan fields or wet lands of Panaji. Though the watershed of St Inez Creek extends up to the Naglai hills, the drainage from fields gives origin to the creek near Cambrabhat. The St Inez Creek meanders through the western side of Altinho hills for a length of 5.89 km before it opens up into the Mandovi River near the Inox Complex. The creek dates back to records of 1829 as a drainage spine of Panaji. It is important not only from the heritage aspect, but also environmentally as the creek ensures natural drainage of the city. Originally it was backwaters that were surrounded by developments, however today, the edges of the creek have been built up for most of its length through the city. The creek passes through 24 culverts, numerous bridges have been built across and the banks of the creek have been converted to residential and commercial land use.

The Ourem Creek, found to the east of Panaji, is a tidal estuary of Mandovi River and drains the Mala and Fontainhas areas of Panaji.

As Panaji developed into a new capital city, a massive network of surface storm water drains were built during the 1930's. The city is generally well laid out in a grid pattern with its roads arranged in east-west and north-south directions. Almost all the roads within the City have kerb side drains to capture and convey the surface runoff. These side drains range in size from 0.3 m x 0.3 m to 0.5 m x 0.5 m (width x depth). The drains around a block are built with flat slopes and the gradient difference can be measured between the blocks. This type of design typically aids in the slow movement of water. These shallow drains drain into deeper underground drains scattered around the city, which then either drain into the Mandovi River or the St Inez Creek. These deeper drains are typically laid underneath the streets and are completely covered. The only locations where they have openings is where the shallow drains connect to them. The outlet of these drains are at levels which are influenced by the tidal levels in the Mandovi River.

Building bye-laws also stipulated that floor of the buildings have to be at least 0.2-0.6m above the road level to enable proper drainage. The roofs of the buildings were to connect to these drains through gutters.


Santa Inez Creek
Flowline
Tank
Catchment
Depression
Depth [m]
0.89
0
0
500
1,000
Meters

The reclaimed lands in Panaji is heavily covered by asphalt and concrete thus leaving very little surface for percolation of storm water. Bhatlem, Santa Inez, Campal and Miramar are losing their wetlands and reducing the capacitance to contain floods. Constructions in Tambdi Mati, Bhatlem have come up right on the banks of the Santa Inez creek. As the land area of Panaji are getting built and covered with concrete surfaces, a slightly higher intensity of rainfall causes the city to get flooded.

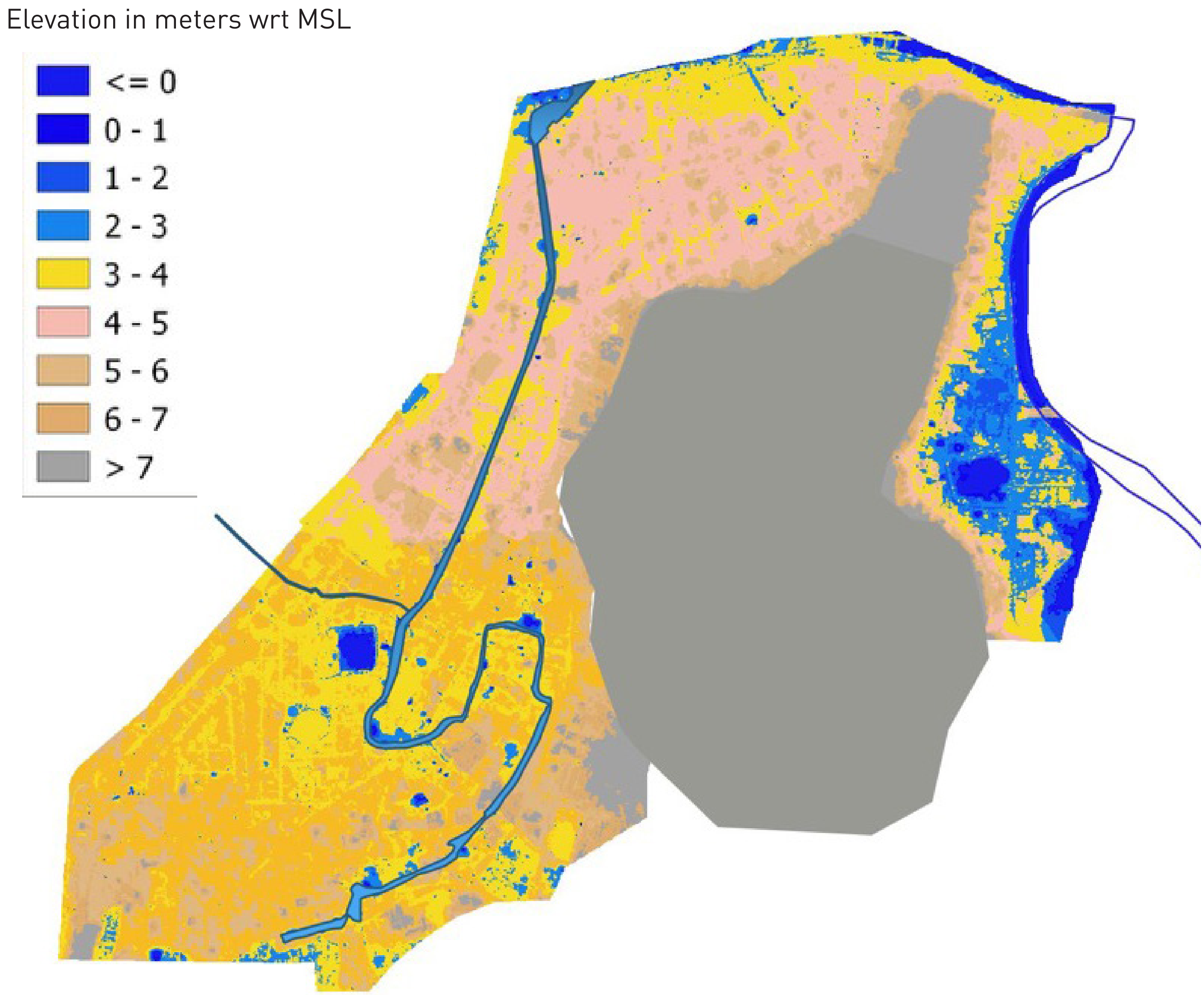
But over time as the courtyards and other open spaces within the blocks were built-up, the drains weren't concurrently upgraded to capture and convey the increased flows. At many places in Panaji that the present day road levels are at or above many floor levels of some of the old buildings standing. The incremental practice of overlaying the roads with fresh weathering coat over a period of time has resulted in the level of road rising up, and leaving the adjacent buildings and properties vulnerable to inundation. This also creates local sinks between major roads and minor roads

In present day, most of the kerb drains are covered with concrete slabs. There are vent holes and groves on these slabs for aeration and percolation of surface water into the drains. Such openings are not very efficient in evacuating the surface runoff from the surface into the drains. Clogging of these holes with common debris, silt, municipal waste such as various types of plastic wastes, paper, paper cups, etc. are very common issues. As the surface runoff moves with a velocity, such clogged and small openings do not help in capturing this runoff into the drains.

100%

of Panaji's streets have stormwater drains

Drains on one or both sides of street based on data analysed



Today in Panaji most of the kerb drains are covered with concrete slabs. While there are vent holes and grooves on these slabs for aeration and percolation of surface water into the drains, these openings are not very efficient in evacuating the surface runoff from the surface into the drains. Another common problem is these holes often become clogged with common debris, silt and municipal waste including various types of plastic waste, paper and paper cups. As the surface runoff moves with a velocity, such clogged and small openings do not help in capturing this runoff into the drains and leads to flooding.

Past Studies

2012	The Goa State Infrastructure Development Corporation (GSIDC) was tasked with the development of Mala Lake as part of improving the tourism infrastructure in Panaji. The project envisaged the cleaning up of the existing area, construction of drainage channels, approach roads, sewage systems - to be completed in two phases.
2013	An Urban Vulnerability Assessment was conducted by the City Corporation of Panaji (CCP), in collaboration with ICLEI and the German Development Agency (GIZ). The aim was to identify the climate impacts and related vulnerabilities in terms of geographical areas and urban actors in the cities. And also, to identify prioritised urban systems or sectors for future action which will help the city develop climate resilience.
2014	Under the central government's Challenge Fund, the Charles Correa Foundation undertook the upgradation and improvement of streets and open spaces in Mala and Fontainhas precincts.
2015	A detailed study was conducted by The Energy and Resources Institute (TERI), granted by USAID as part of their Climate Change Resilient Development (CCRD) project's climate adaptation small grants programme. The aim was to understand the kind of infrastructure that Panaji has and its vulnerability to climate change and sea-level rise, which would help plan for and implement climate risk management strategies as an integral part of city development.
2015	The preparation of a Revised City Development Plan for Panaji, 2041, was undertaken by CRISIL within the Capacity Building for Urban Development (CBUD) project, which was a Joint Partnership Programme between the Ministry of Urban Development, Government of India and The World Bank The vision was ' to develop the city as a clean, environment friendly and ecologically sustainable with focus on improvement of the city urban infrastructure facilities, tourist infrastructure, conservation of the natural elements and heritage structures by adoption of eco-friendly alternatives and techniques'
2016	As part of Panaji's proposal for selection under the government's Smart City Mission, the CCP and Imagine Panaji Smart City Development Limited (IPSCDL) have identified the Mala Lake neighbourhood as one of the locations for area-based development under the SCM. The proposed revitalis ation of the Mala Lake area envisages to revive the lake as a tourist attraction while creating employment opportunities related to tourism and aquaculture for the area's residents. Specifically, beautification of the lake, pedestrianis ation along its boundaries and the development of nature trails and recreation facilities are part of Panaji Smart City's plan for Mala Lake (see Figure 2).
2020	As part of flood mitigation measures, the Water Resources Department (WRD), Government of Goa has carried out desiltation of drainage channels leading up to the Mala Lake. The WRD has also submitted a detailed project plan for the desiltation of the Mala Lake to IPSCDL.
2020	Panaji is one of six coastal cities selected under the National Cyclone Risk Mitigation Project (NCRMP) Phase II for development of a Hydro-Meteorological Resilience Action Plan (HmRAP). This will be a key document in guiding decision makers of Panaji to improve the city's resilience and reduce risks to hydromet related hazards, with a critical focus on incorporating information into planning and service delivery. The proposed HmRAP project, initiated by the NDMA and funded by the World Bank, will be developed by Royal Haskoning DHV with JV partner Taru Leading Edge.

Need for Planning

While there have been numerous planning and urban studies carried out in the past on Panaji by various departments and agencies, none have adequately addressed nor focussed on the subject of urban flooding. The past studies have highlighted vulnerability of Panaji as a coastal city to climate changes, and sought to find the necessary infrastructure to meet the challenges of sea level rise. The City Development Plan 2041 focuses on a host of urban infrastructure issues including the conservation of the city's heritage, natural environment and tourism in order to develop Panaji a clean, environmental friendly and ecologically sustainable city. However, these studies have not addressed the issues of seasonal urban flooding that the city has to cope with with every monsoon and the increasing intensity of the floods/climate and frequency of natural disasters.
Panaji has always been prone to flooding, due to its location in the past, the inundation of marshy fields by nutrient rich sediments brought by the river during floods were beneficial to the agricultural economy. But with the changed landscape from agricultural fields to an urban built up landscape and changes to the socio-economic nature of the city, flooding poses major financial, social and environmental risks to the city. The built up landscapes in the urban city has resulted in a different set of flooding problems in the form of localised inundation during rainfall events, which cause many challenges including the inconvenience to movement of people, damage to property and commerce. The management of this urban flooding requires focus and measures to mitigate the risk of damage.

Traditionally the mitigation of urban flooding was considered as an infrastructure issue, requiring large and expensive infrastructure projects to move the water swiftly away from the problem areas. However, over time and best practices examples have evolved from across cities around the world. Urban flood management is a complex process requiring adequate planning and proper studies to arrive at ecologically sustainable solutions that converge with the local needs. Although the improvements may take time to show results they must involve multiple stakeholders to understand the requirements and need for these projects and be part of the change as well as clear, well thought out policy interventions.

This document is not meant as a project report that provides a set of solutions that can be implemented to mitigate the risks of flooding. Rather, this document aims to provide a plan that outlines a series of steps to be followed, including 'next step to reports', which could guide projects and programmes which in turn would give specific solutions to mitigate the flooding issues of Panaji.

Objectives of Plan

Vision

The overall vision is to collaboratively develop an active stormwater management programme with stakeholders, to reduce surface runoff in a sustainable manner by incorporating components into all Panaji city projects, in order to achieve reduction of urban flooding from annually/seasonally to once in 5 years by year 2030.

Goals

The following objectives to be achieved through an active stormwater management programme:

Sustainable Development

- Nature-based approach for stormwater management
- Surface water run-off control in sustainable manner including harvest, detention, infiltrate and safe conveyance
- Public infrastructure renewal; which include SuDS, LIDs, NbS toolkits
- Economic sustainability in infrastructure development
- Urban space quality improvement – enhance urban ecology and biodiversity
- City resilience enhancement – micro-climate changes
- Enhancing Liveability in the City

Development of Stormwater Management

- Technical Innovations for Stormwater Management
- Public participation in preparation of a Management Plan
- Scientific governance for operation, maintenance and management of infrastructure including interdepartmental cooperation and proactive management
- Disaster resistance – Early warning and disaster management through information dissemination

Flood Management Action

The overall vision and approach to Panaji, specifically for the areas around St Inez Creek and Mala Lake, is formulated from an inherent sustainability perspective, where terrain and nature based solutions (NBS) are connected in order to re-establish and mimic a pre development natural system. The intervened areas, including the restoration of the edge and banks of the Creek as well as the surroundings of Mala Lake, will be multi-functional and promote open space and parks, to ensure that co-benefits, such as enhanced micro-climates, added recreational value and flood risk reduction, are maximised.

Data Collection and Analysis

This section identifies the various data required for a pan city study and provides commentary on the availability of these data sets.

Physical Characteristics

Various secondary datasets from government departments including IPSCDL, CCP, IMD in order to identify the main drivers of flooding in the city.

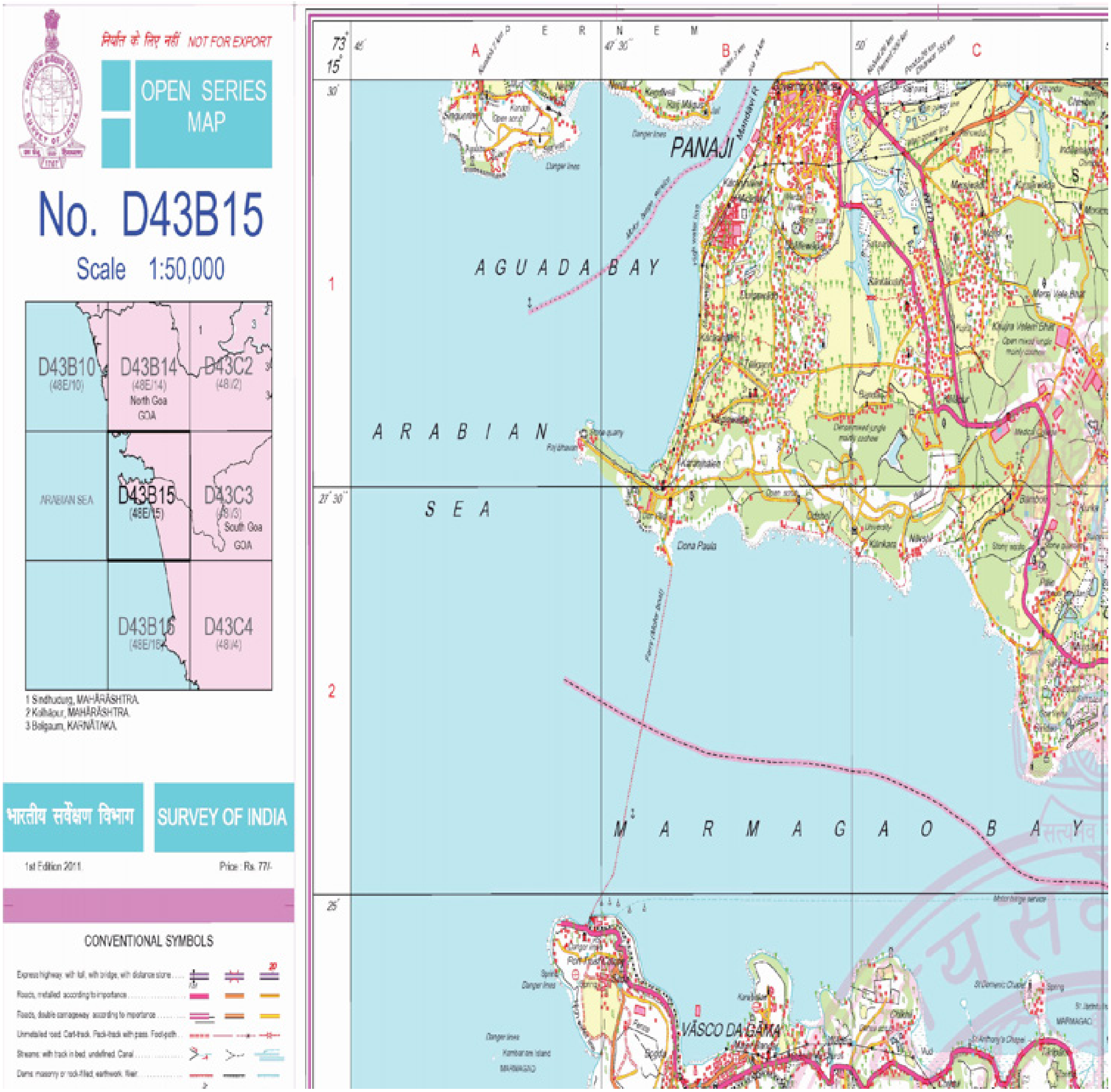
Topographic Data

In order to ascertain the topography of Panaji City, topographic sheets of Panaji and surrounding areas were sourced from the Survey of India. Panaji and surrounding areas are included in sheet index D43B15 and the PDF format of the Topographic sheet is available under the Open Map Series from Survey of India website at a scale of 1:50,000. The data included in the sheet is compiled from a 1:25000 survey carried out in 1962-64 and updated for major details during 2005-06.

A rapid assessment of the drainage of the urban area can be carried out using the contours or Digital Elevation Model (DEM) of the area. The creation of DEM is carried out through surface levels captured by traditional surveying methods or through advanced methods such as satellite images and LiDAR surveys. Satellite images for Panaji are available from National Remote Sensing Centre, a Government of India undertaking which is the nodal agency for all satellite products available from Indian and foreign national satellites. For the creation of a DEM, multi-band images are needed which interprets the surface levels. The Cartosat-2S images are not stereo and do not have multi-bands which makes them not suitable for developing DEMS.

Open Series Topographic sheets
Survey of India
(last updated 2005-06)

NRSC -Satellite Images
Under **GIS based Master Planning** for AMRUT Cities, NRSC has prepared draft base map at 1:4000 scale using high resolution satellite data (ground validation pending)


निर्यात के लिए नहीं NOT FOR EXPORT
OPEN SERIES MAP
No. D43B15
Scale 1:50,000
D43B10 (48E/10)
D43B14 (48E/14) North Goa GOA
D43C2 (48 I/2)
ARABIAN SEA
D43B15 (48E/15)
D43C3 (48 I/3) South Goa GOA
D43B16 (48E/16)
D43C4 (48 I/4)
1 Sindhudurg, MAHĀRĀSHTRA
2 Kolhāpur, MAHĀRĀSHTRA
3 Belgaum, KARNĀTAKA
भारतीय सर्वेक्षण विभाग
SURVEY OF INDIA
1st Edition 2011
Price : Rs. 77/-
CONVENTIONAL SYMBOLS
PANAJI
AGUADA BAY
ARABIAN SEA
MARMAGAO BAY
Dona Paula
VASCO DA GAMA
A
B
C
1
2

Information gathered from discussions with the NRSC office, DEM of 1 meter resolution are available from foreign satellite sources. The minimum order area is 25 sq km and this type of high resolution DEM is supplied only for Government projects under the prevailing policies.

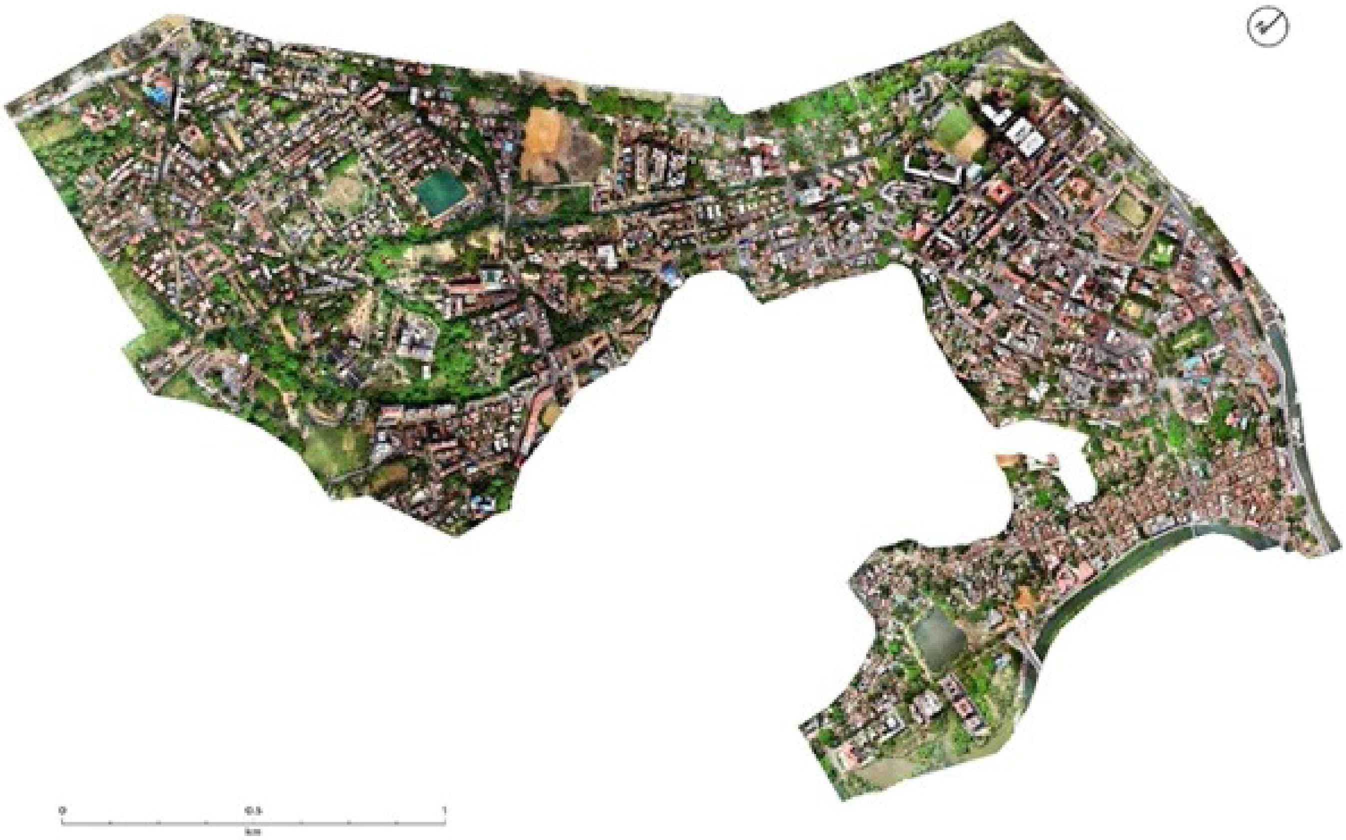
The Cartosat-2S images can be processed to ascertain the impervious surfaces, for example such as roads and building foot-prints, in an urban area which contributes to surface run-off.

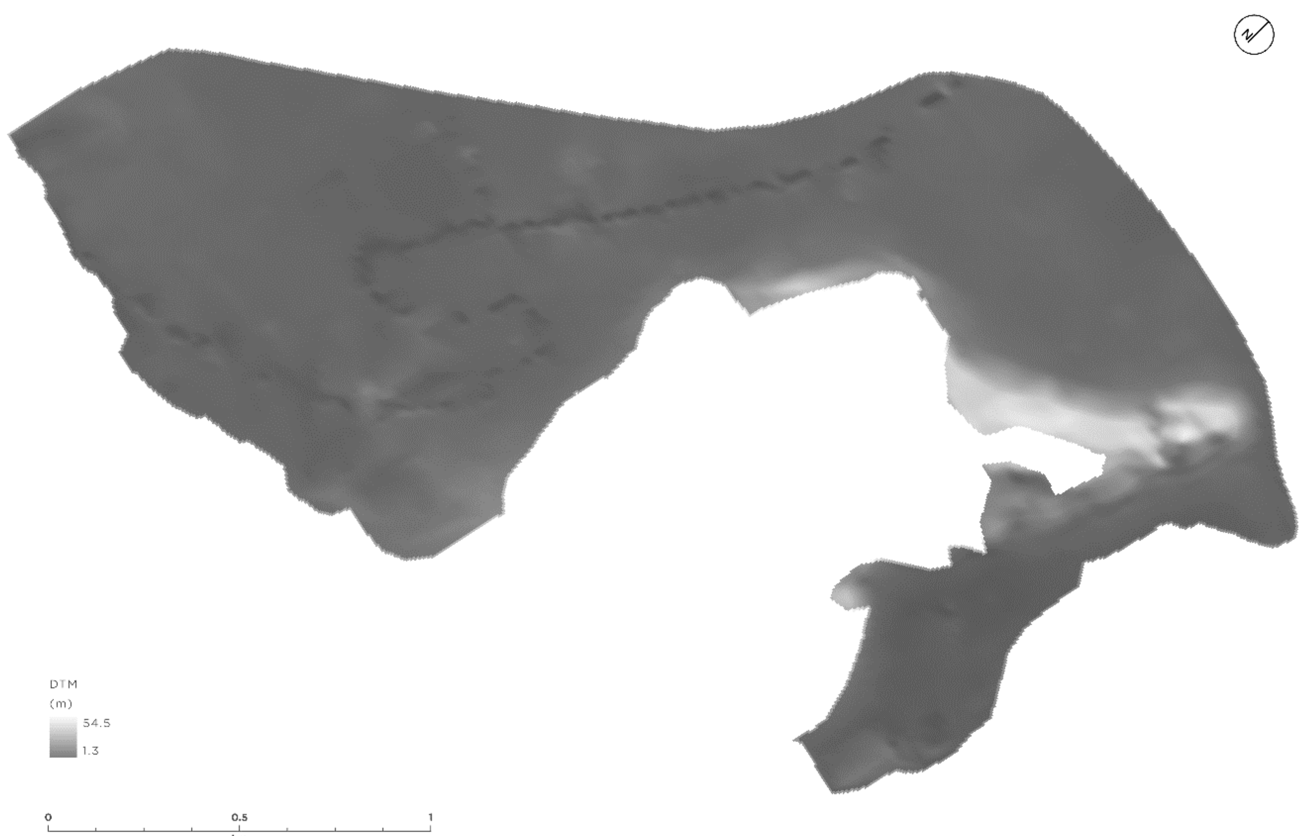
Preliminary discussions were held led by this study team with various stakeholders for data collection and to gain insights of what can be put to use for further understanding the storm water flooding issues and challenges in Panaji. From these discussions, the study team concluded that no recent comprehensive physical survey of the city area had been carried out nor was any data, from reliable sources, available.

It was also confirmed that no comprehensive map of existing storm water drains, sewage networks and water supply infrastructure, which can be accessible in a soft format that was compatible with GIS software, existed. It is understood that as part of a City Development Asia initiative, some of the sewage and water supply network details have been digitised based on existing hand-drawn and hard copy maps, but the storm water drains were not included as part of such datasets.

In order to understand the basic extent and characteristics of the drainage pattern for the city, a rapid assessment to gain data was considered essential. For this purpose, the study team conducted an aerial drone based Light Detection and Ranging (LiDAR) survey for a limited area of Panaji, coupled with a ground based survey to collect information about the drainage infrastructure details of the city.

Sl. No.	Product Type
1.0	**PAN)0.65)/Mx(1.6m) (Cartosat - 2S)**
1.1	Geo referenced/Ortho Kit 9.6 km x 9.6 km
1.2	Ortho rectified 9.6 km x 9.6 km
2.0	**COLOR (0.65m) (Cartosat-2S)**
2.1	Merged 9.6 km x 9.6 km
3.0	**PAN (0.5m)/Mx (2.2m) (Kompsat)**
3.1	Geo referenced (PAN/Mx) 15 km x 15 km
3.2	Geo references (Bundle) 15 km x 15 km
3.3	Ortho rectified 15 km x 15 km
4.0	**COLOR (0.5m) (Kompsat)**
4.1	Merged 15 km x 15 km


0
0.5
1


DTM
(m)
54.5
1.3
0
0.5
1
km

The survey collected data on physical features for St Inez Creek area including roads, storm water drain details, cross sectional details and visible outfall pipes that drain into the creek. All levels are accurate to the nearest 10 mm.

Existing maps denoting agricultural areas, buildings and important infrastructure were collected from IPSCDL .

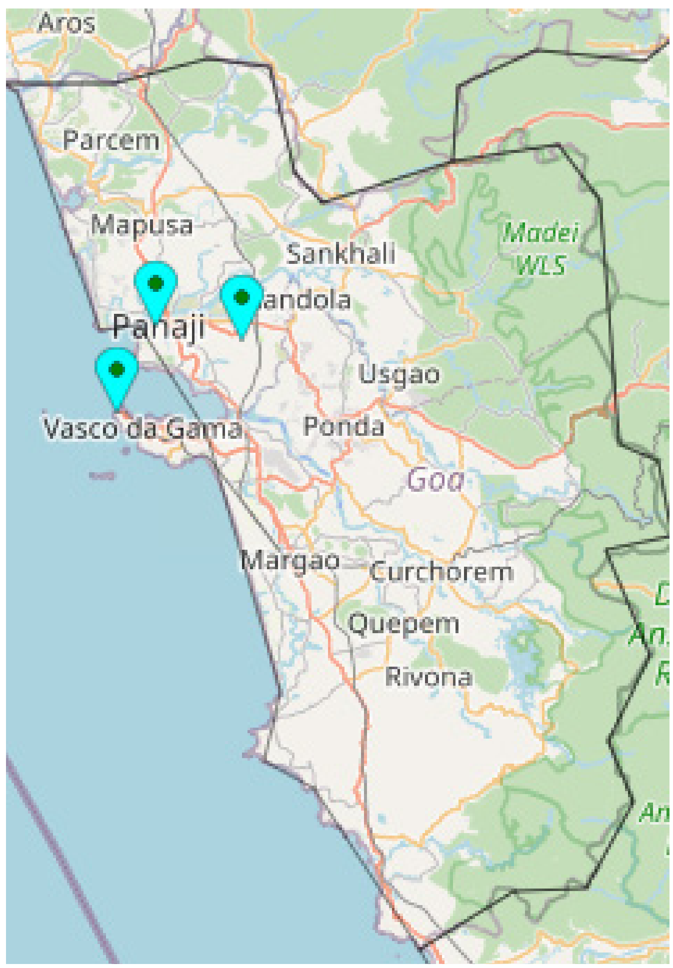
DEM Analysis

The data collected from the LiDAR survey was processed to create a Digital Elevation Model (DEM) of the Panaji Area. The resulting DEM was analysed with software tools to study the surface slope and drainage patterns of the area. In specific areas where there was higher recurrence of flooding events, the DEM was used to study the profile of the roads and drainage. The preliminary findings are presented in the following sections under case studies.

Rainfall data

Rainfall data for Panaji and the state is collected and archived by the Indian Meteorological Department (IMD). There are two stations in Goa which have continuous 30 year hourly rainfall records found in:

1) Panaji
2) Mormugao



The rainfall data from these stations is available through the IMD Data portal at http://dsp.imdpune.gov.in/ and this data can be accessed following registration at this site and submission of request.The data charges are based on the records available.
Based on our enquiry in the data portal, the following information was made available:
A review of existing study reports identified hourly rainfall information collected from IMD for a period of 17 years. This data was the Self Recording Rain Gauge (SRRG) Storms data of

St.Index No.	Station Name	Type of Data	Year From	Year To	Available Data Year[Days*]
43196	MORMUGAO (15°23’E 73°49’N at 5.2m above MSL)	Houly Data	1980	2020	2008[730], 2007[730], 2006[730], 2005[665], 2004[732], 2003[730], 2002[728], 2001[730], 2000[731], 1999[727], 1998[730], 1997[730], 1996[732], 1995[700], 1994[730], 1993[730], 1992[731], 1991[730], 1990[730], 1989[730], 1988[732], 1987[729], 1986[730], 1985[730], 1984[732], 1983[715], 1982[729], 1981[709], 1980[731], Missing years: 12 years (2009-2020)
43192	PANAJI (15°29’E 73°49’N at 6.0m above MSL)	Houly Data	1980	2020	2019[730], 2016[732], 2013[729], 2010[717], 2008[732], 2007[696], 2006[716], 2005[725], 2004[732], 2003[596], 2002[730], 2001[730], 2000[732], 1999[730], 1998[638], 1997[730], 1996[732], 1995[727], 1994[730], 1993[730], 1992[732], 1991[730], 1990[730], 1989[730], 1988[732], 1987[730], 1986[730], 1985[730], 1984[732], 1983[720], 1982[730], 1981[708], 1980[732], Missing years: 7 (2009, 2011, 2012, 2014, 2015, 2017, 2018)

* 2 records – hour and rainfall per day, for a year 365x2=730 records

Rainfall Data Analysis for City of Panaji, Goa

Sl. No.	Year	Month	Date	Sl. No. of Storm in a particular day	Duration of Storm: No. of Horizontal Divisions	Duration of Storm: Time (min)	Duration of Storm: Time (hrs)	Qty. of Rainfall: No. of Vertical Divisions	Qty. of Rainfall: Rainfall in (mm)	Rainfall intensity "I" (mm/hr)
1	2	3	4	5	6	7	8	9	10	11
	1997	June	9	1	1.13	17.00	0.28	9.20	4.60	16.43
			10	1	3.13	47.00	0.78	54.60	27.30	35.00
			11	1	4.53	68.00	1.13	46.60	23.30	20.62
			12	1	0.33	5.00	0.08	2.40	1.20	15.00
			15	1	0.20	3.00	0.05	2.80	1.40	28.00
				2	2.13	32.00	0.53	16.00	8.00	15.09
				3	3.33	50.00	0.83	37.20	18.60	22.41
				4	0.33	5.00	0.08	6.60	3.30	41.25
				5	2.00	30.00	0.50	23.00	11.50	23.00
				6	0.33	5.00	0.08	6.40	3.20	40.00
			16	1	0.67	10.00	0.17	4.40	2.20	12.94
				2	8.27	124.00	2.07	2.00	1.00	0.48
				3	0.47	7.00	0.12	6.00	3.00	25.00
				4	0.40	6.00	0.10	2.40	1.20	12.00

Panaji for the years 1997 to 2013 from Indian Meteorological Department (IMD).

The information was accessed from the report titled 'Final Detailed Project Report for Development of St. Inez Creek', March 2014, WAPCOS Ltd., prepared for City Corporation of Panaji. The SRRG tabulated data obtained from IMD is presented in Annexure 2 of this report.

The tabulation is of the individual storm events with duration depth and intensity is calculated in column 11. However, the SRRG data points were not able to be reproduced from the report as there were missing pages and non-continuous time collection periods were also observed. Therefore raw data will need to be obtained from IMD for any and all future studies.

Analysis of Rainfall Data

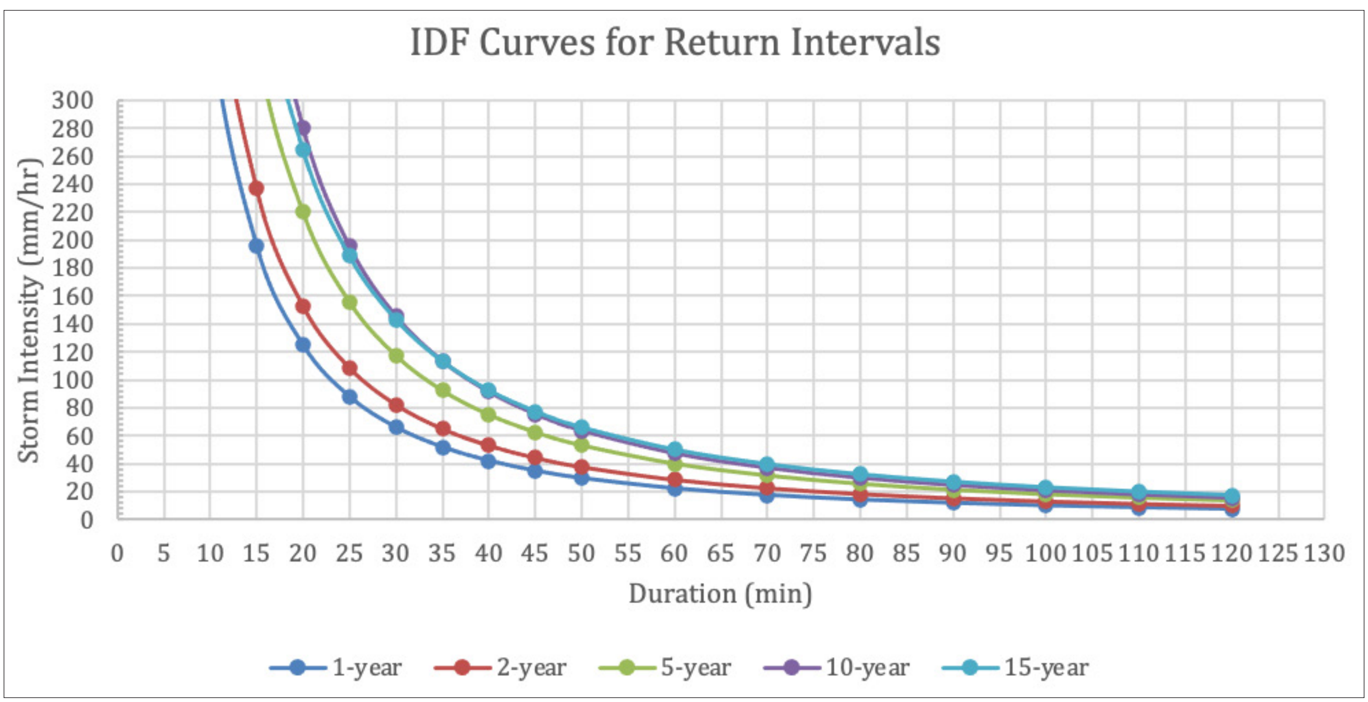
A preliminary analysis of the rainfall data was carried out to ascertain the Intensity Duration Frequency relationship of typical rainfall occurrence in Panaji. The level of protection for an area depends on the importance of the drainage area, socio-economic conditions of the city, availability of funding for infrastructure and any constraints or availability of space for construction of drains or other necessary infrastructure to evacuate the water from the catchment. The intensity and duration of rainfall events are fixed, based on historic rainfall data. The frequency or a design return period of a storm is an average period of time after which a certain storm event of intensity and duration can reoccur. From a planning perspective, the design return period of storm is a factor that should be judiciously adopted in estimation of storm runoff. All the subsequent estimations of the runoff, the sizing of various stormwater infrastructure components to convey the runoff etc. are based on this design return period that is adopted. Hence from a city's perspective, the level of protection a city receives from flooding occurrence depends on the Design Return Period of a storm it selects.

Duration	Intensity of Storm (mm/hr)												
	10	15	20	25	30	35	40	45	50	55	60	75	90
	(No. of storms of intensity or more for a period of 18 years)												
5	2247	1874	1481	1085	832	618	483	359	286	222	179	109	73
10	1765	1436	1083	745	537	370	255	158	110	77	47	14	9
20	1312	1028	752	485	353	232	156	97	66	47	31	7	3
30	636	454	318	202	141	92	58	39	22	16	9	3	2
40	346	236	166	105	75	48	32	20	8	6	3	1	0
50	261	168	114	72	48	30	20	13	3	3	2	1	0
60	178	97	60	38	22	12	7	4	1	1	0	0	0
75	126	67	41	25	14	8	4	3	1	1	0	0	0
90	95	42	22	12	7	4	0	0	0	0	0	0	0
120	71	30	15	6	3	2	0	0	0	0	0	0	0
150	50	19	9	5	3	2	0	0	0	0	0	0	0
180	33	8	4	3	2	2	0	0	0	0	0	0	0
240	26	5	3	2	2	2	0	0	0	0	0	0	0
660	17	4	2	2	2	2	0	0	0	0	0	0	0

Add number of storms of all exceeding intensities to the preceding /lesser intensities storms.
Add number of storms of all exceeding durations to the preceding / lesser duration storms.

The frequency analysis of such events tabulated is reproduced below:

Historical time-series data on the intensity, duration and frequency of rainfall from the Indian Meteorological Department (IMD) for a 17 year period.



Certain guidelines are provided by CPHEEO in its Storm Water Management Manual (2019) which are based on the population of the city. As per the guidelines, for Panaji, which has a population of less than one lakh residents (100,000), the design return period of a storm is determined once in two years.

This means that the level of protection from flooding should be given for all such rainfall events which have a chance of occurring yearly, and that certain rainfall events which have the frequency of occurring once every 2 years, have the potential to cause flooding in the catchment area. Further, for cities like Panaji, where the infrastructure is already developed, it may not be always feasible to design/retrofit the storm water drains for the recommended return period. In such cases where redesigning/retrofitting is not feasible as per recommended return period due to city profile/site constraints, efforts should be made to adopt recommended return period by adopting 'Best Management Practices' (BMP), which include in-situ rainwater harvesting methods within premises/plots, along the storm water channels/conduits and storm retention/detention structures to accommodate the excess runoff.

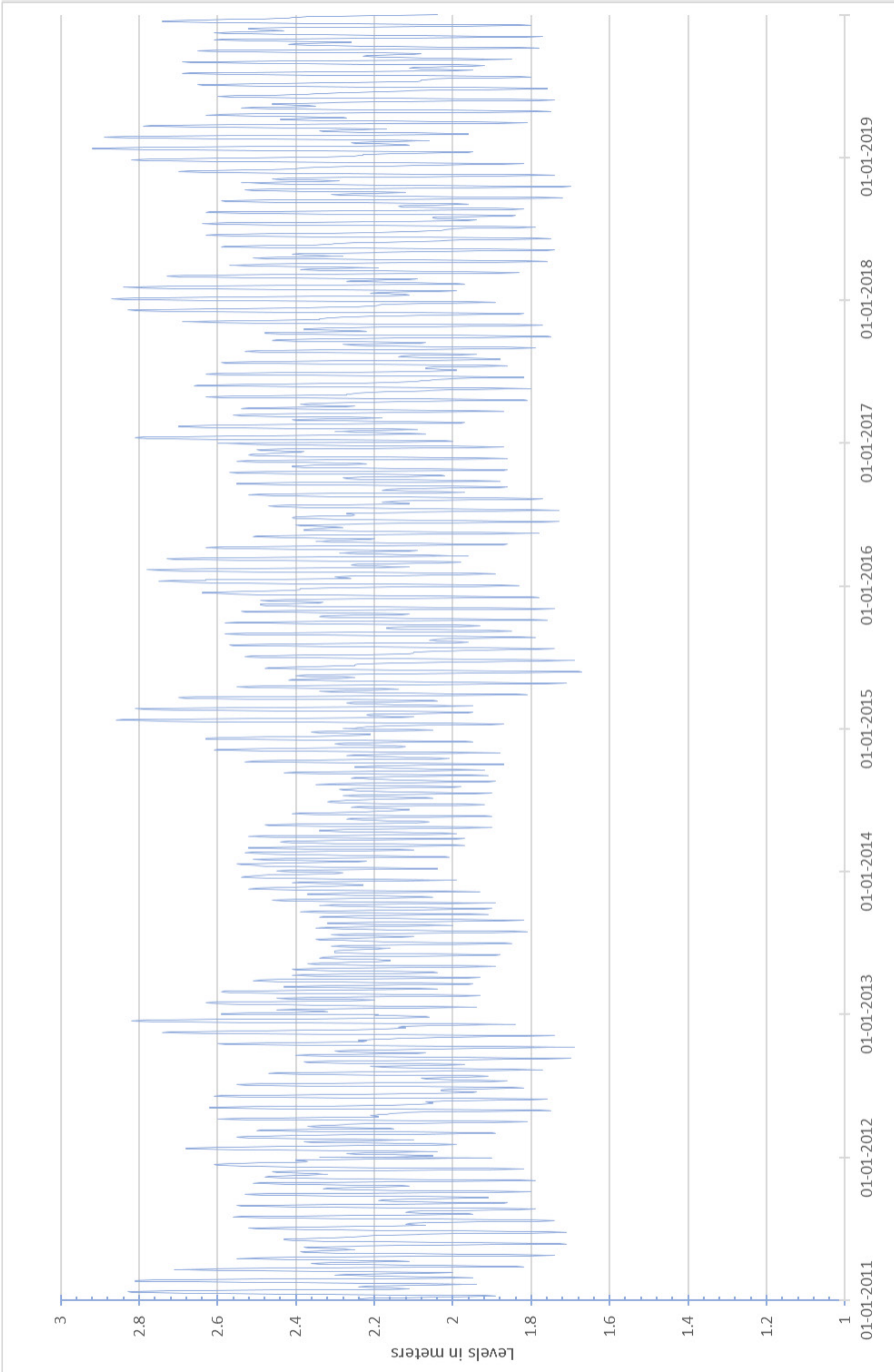
An analysis of past rainfall data and patterns are carried out to determine any certain empirical relationship between the intensity of rainfall, duration of events of such intensity and the frequency of such events. From such an analysis of past rainfall data, Intensity-Duration-Frequency (IDF) curves are developed for a region or catchment. From the IDF curves, for a given rainfall magnitude or more corresponding to a particular duration of time is achieved/or determined.

The rainfall data identified in the old study report had summary tables of the storm events sorted out in various groups of intensities corresponding to the duration of occurrence of storms. This tabulation was taken as is for a preliminary analysis for preparing a depth-duration-frequency analysis The number

Design events are computer models of storms that help engineers predict what typical rainfall events look like in a region: how long they last and how much rainfall will occur during that period. The more rainfall that comes in over a period of time, the larger the storm event is. Large events do not occur frequently

For example, a 2-year design rainfall event for Panaji is about 30mm of rainfall in 1 hour.

Similarly, a 5-year design rainfall event is about about 55mm/hr is likely to occur once in 5 years. This kind of heavy downpour has less chances of occurrence in a year.


Levels in meters
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
01-01-2011
01-01-2012
01-01-2013
01-01-2014
01-01-2015
01-01-2016
01-01-2017
01-01-2018
01-01-2019

of storms were calculated and grouped in intensities of 5 – 10 mm/hr, 10-15 m/hr and so on, corresponding to each group of duration of occurrence. Similarly, the sort number of occurrences of rainfall intensities against corresponding duration for the entire sample size of rainfall data were compared.

Waterway Characteristics, tidal influence

Tidal data for the Port of Marmugoa is published by the Surveyor General of India, Survey of India, Dehradun. The Goa Barge Owner's Association publishes this for its members' use in Goa under permission from Surveyor General of India. The historic tide levels for Marmugoa from 2011 to 2019 were collected for analysis. The tide levels for Panaji location have a correction factor of +0.3 m from those values at Marmugoa and time correction of +20 minutes. The data were adjusted to arrive at the tidal levels at Panaji Port.
The high tide level is of interest for analysis as it influences the free discharge of stormwater drains. An analysis of the high tide levels for the past 5 years shows that the median tidal height during the monsoon months June - September is 2.19 m with a maximum of 2.69 m and minimum height of 1.72 m. On average 50 percent of the days during the monsoon months the tidal height exceeds the median tide height of 2.19 m.

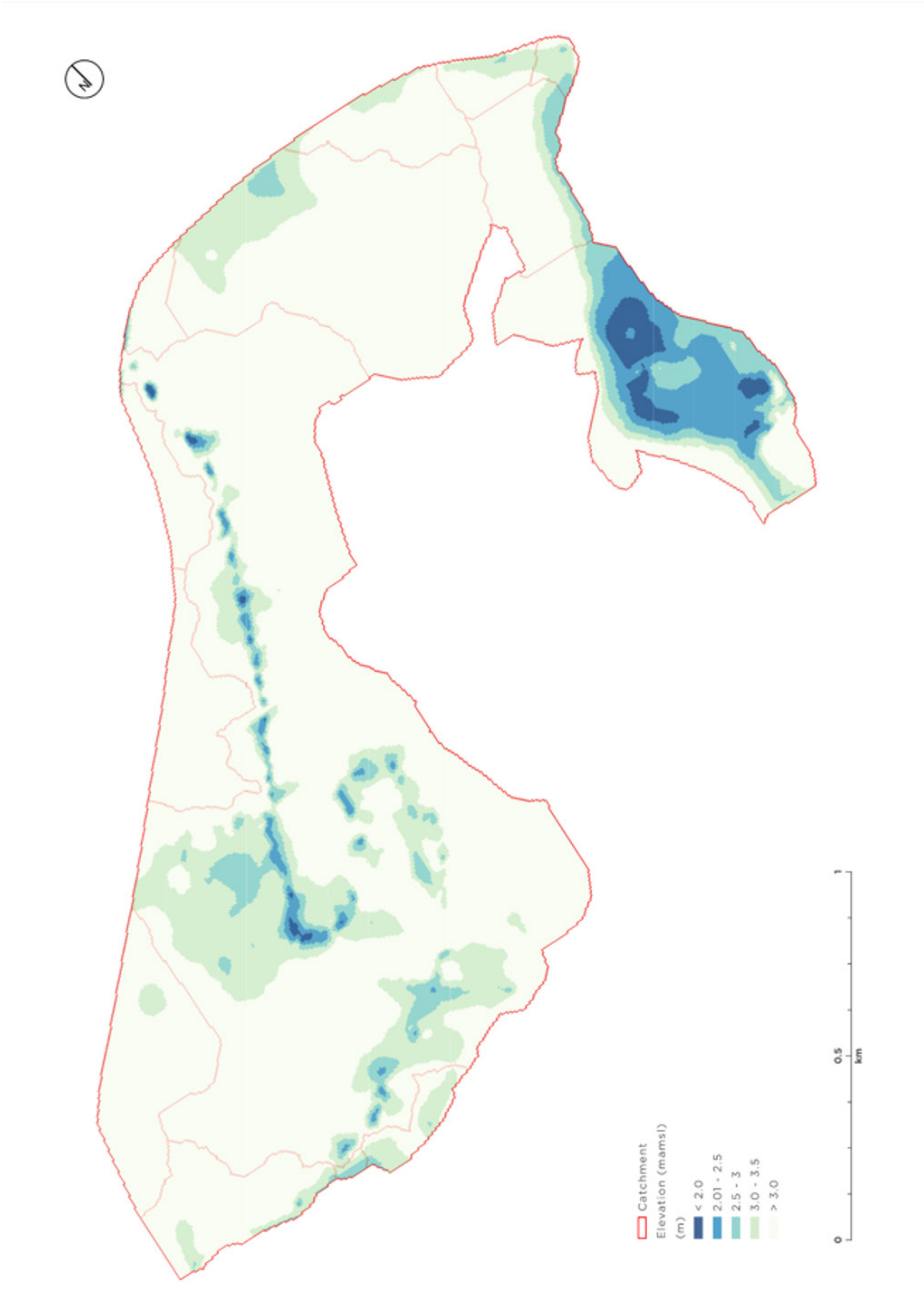
The drains discharging the stormwater runoff from the city area to Mandovi River have their inverts between 1.4 m and 1.9 m with the crown of the pipe between 2 m and 3 m. The outlet of the drains do not have any reverse flow preventing mechanism to restrict tidal ingress into these drains. Whereas those discharging into the St Inez Creek have the inverts at 2.3 m or higher. As a consequence of the drains having their discharge height at or below the high tide height, the tide time and rainfall events are very critical for drainage of Panaji. The drain outlets are partially or completely submerged during the high tide duration. With the drains

2.92m Max. height of high tide

1.81m Lowest height of High Tide

2.35m Median height of high tide

Based on Nine Years of Tide Data 2011-2019


Catchment
Elevation (mamsl)
(m)
< 2.0
2.01 - 2.5
2.5 - 3
3.0 - 3.5
> 3.0
0
0.5
1
km

having no mechanism to prevent tidal water from entering into them, the deeper drains evacuating the rain-runoff waters are filled with tidal water and there is no room for the runoff water to enter or flow into these major drains. With a six hour tidal cycle it means that the drainage of rain runoff from the city areas that drains towards Mandovi river is affected for such a duration. During discussions with the operationsstaff of CCP, they observed that the free flow of runoff water is impacted when tidal height reaches 2.0 m and completely stops at 2.10 m. These tidal heights are observed for over 72 percent of monsoon period which indicates that drainage of Panaji is very vulnerable to tidal heights and any rainfall occurrence during the high tide period is sufficient to cause rain-runoff inundation in parts of the City.

The St Inez Creek is also influenced by tidal height but drains discharging to St Inez have inverts which are almost 1.0 m higher than those found at the Mandovi River. This level difference enables effective drainage even during high tide as the main drains are not completely submerged due to high tide waters. The drains from the Fontainhas areas discharging into Ria de Ourem are at levels between 1.9 m and 2.3 m which again are under tidal influence. The drains from Mala Lake and the surrounding Mala area however are at shallow depths with invert levels as low as 1.2m. These drains get submerged during high tide events as tidal water rises in the Ria de Ourem. The Mala area drains are pumped out, but the capacity of pumps installed are not sufficient for faster evacuation of runoff water that accumulates. This results in inundation near the Mala lake, new Patto bridge and around the BP Fuel station.at 1.2 m. These drains get submerged during high tide events as tidal water rises in the Ria de Ourem. The Mala area drains are pumped out, but the capacity of pumps installed are not sufficient for faster evacuation of runoff water that accumulates. This results in inundation near the Mala lake, the new Patto bridge and around the BP Fuel station.

During Monsoon Months (June-September)
2.69m Max. height of high tide
2.28m Median height of high tide

50.36% of days the high tide exceeds median high tide depth
87.52% of days the high tide exceed level of 2.05m

Data analyzed for monsoon months of June-September -1098 days, between 2011-2019

Sl no	Institution	Key Role in Panaji Urban Space
1	City Corporation of Panaji (CCP)	• City infrastructure • Solid Waste Management • Street cleaning and maintenance • Storm Water Drainage • Street beautification, street furniture and street lighting • Providing permissions for laying of underground utilities • Management of Public spaces including: parking areas, footpaths, parks & open areas.
2	Imagine Panaji Smart City Development Limited (IP-SCDL)	• Nodal Agency for Implementation of Smart City Projects
3	Public Works Department (Roads) (PWD)	• City road development and maintenance • Maintenance of bridges and culverts across waterways • Planning and construction of road-side stormwater drains along with road works • Street beautification, street furniture and street lighting
4	Public Works Department (Public Health Engineering division includes Water Supply & Sanitation schemes/ programmes)	Planning, implementation of infrastructure, operations and Maintenance of • Water supply to Panaji City • Sewerage and sanitation facilities including treatment and safe disposal of treated effluent
5	Goa State Infrastructure Development Corporation (GSIDC)	Improving livability of Panaji City through projects for improving • Pedestrian access and linkages • Promenade along Mandovi River with pedestrian spine • Carrying out studies/DPRs for improvements to various urban improvements
6	Goa State Urban Development Agency (GSUDA)	• Nodal Agency for coordination, monitoring, and implementation of various centrally sponsored schemes implemented by the Ministry of Urban Development and the Ministry of Housing and Urban Poverty Alleviation, Government of India • Planning, development and implementation of improvements to open spaces, gardens, parks in the city area • Also involved in planning and implementation of smart roads in Panaji
7	Water Resources Department (WRD)	Planning, implementation and maintenance of: • Waterways and creeks • Flood water management, operation & maintenance of Flood Pump Stations • Promotion of rainwater harvesting in private properties

8	Greater Panaji Planning and Development Authority (GPPDA)	• Preparation of development plans • Prescribe use of land within its area • Implementation of development plans and schemes • Schemes of development and undertake their implementation • Development regulation including granting permissions • Enforcement of prohibition on cutting of hilly land and filling up of low lying areas
9	Department of Forest, Government of Goa	• In Panaji, manages mangroves along water bodies –including Ria de Ourem, Mandovi River, St Inez Creek • Maintains Campal Gardens, Bhagwan Mahavir Bal Vihar Park

Analysis of existing conditions

Water is necessary for human life and a variety of economic activities. Treating water as a resource and analysing the potential synergies with other layers allows for holistic and integrated planning that maximises co-benefits for all.

However, to identify and prioritise added values and functions it is crucial to look beyond the water component. In that context, it is useful to think of the area as interacting layers of diferent activities and physical features. Analysis and overlay of these layers allow for a better understanding of the interconnectedness and characteristics of Panaji.

Understanding spatial distribution of elements such as land-use, ownership,local businesses, activities and uses is crucial in the design of a Stormwater Masterplan.

Maintenance of drainage system of Panaji is with City Corporation of Panaji

Multiple agencies influence the planning, implementation & management of stormwater system of Panaji

Status of the Storm Water Management

The storm water drainage system of Panaji is managed by the City Corporation of Panaji (CCP). The Technical Division headed by a municipal engineer. The municipal engineer is the nodal person responsible for maintenance of the city drainage system, and is supported by a junior engineer and a supervisor who have stormwater management as part of their job/ work portfolio. Any cleaning or maintenance works required are carried out through contracted-out labour, as and when required. It is also understood that activities including pre-monsoon cleaning of the drains, removal of silt, are carried out every year, however details of the extent of repairs, preventive maintenance to the drain and upgradation of the system were not readily available.

The management of StInez Creek, Ria de Ourem and the wet weather pump station are under the oversight/control of the Water Resources Department. An assistant engineer level officer is responsible for Panaji Division. Dedicated staff for the inspection, maintenance and cleaning of these waterways are not assigned and any maintenance work is carried out through external contractors.

As part of the Solid Waste Management function of the CCP, there are staff assigned for collection of solid wastes, sweeping of common areas in commercial zones, parks etc., these staff are not equipped to maintain the storm water drainage system. While the staff do collect any visible debris in open drains, they are not equipped with tools to clean the covered drains.

Management of stormwater in urban areas goes beyond the physical drains. It includes all built infrastructure in the urban area from which rainwater runs-off, conveys, retains and effectively discharges to the receiving body. In this context the contribution of institutions involved in planning, design, development, implementation, operation and maintenance of various urban infrastructure components is significant. The key institutions and their roles are tabulated. When setting the vision and goals for a comprehensive management of stormwater in the City, identifying and determining the goals set by all the stakeholders and the inclusion and uptake of appropriate actions in respective areas is crucial.

Land use of Panaji

The existing land use for Panaji CCP area has been considered from the Revised City Development Plan for Panaji, 2041, wherein the present urban growth and area allocation earmarked for various land uses as per the URDPFI norms are studied. The city area has 66% of developed area while 34% is considered undevelopable. The city's land use is predominantly residential (50.91%) with a high concentration of commercial land use within the core city area (15.45%). A major portion of the city is considered part of an eco sensitive zone consisting of 4% land under watershed, 4% land under conservation and 25% of the land under natural resources. These lands, totalled, consume 34% of the total city area which is not permissible for urban growth and expansion. The city has no industrial setups, therefore no land is considered under industrial land use.

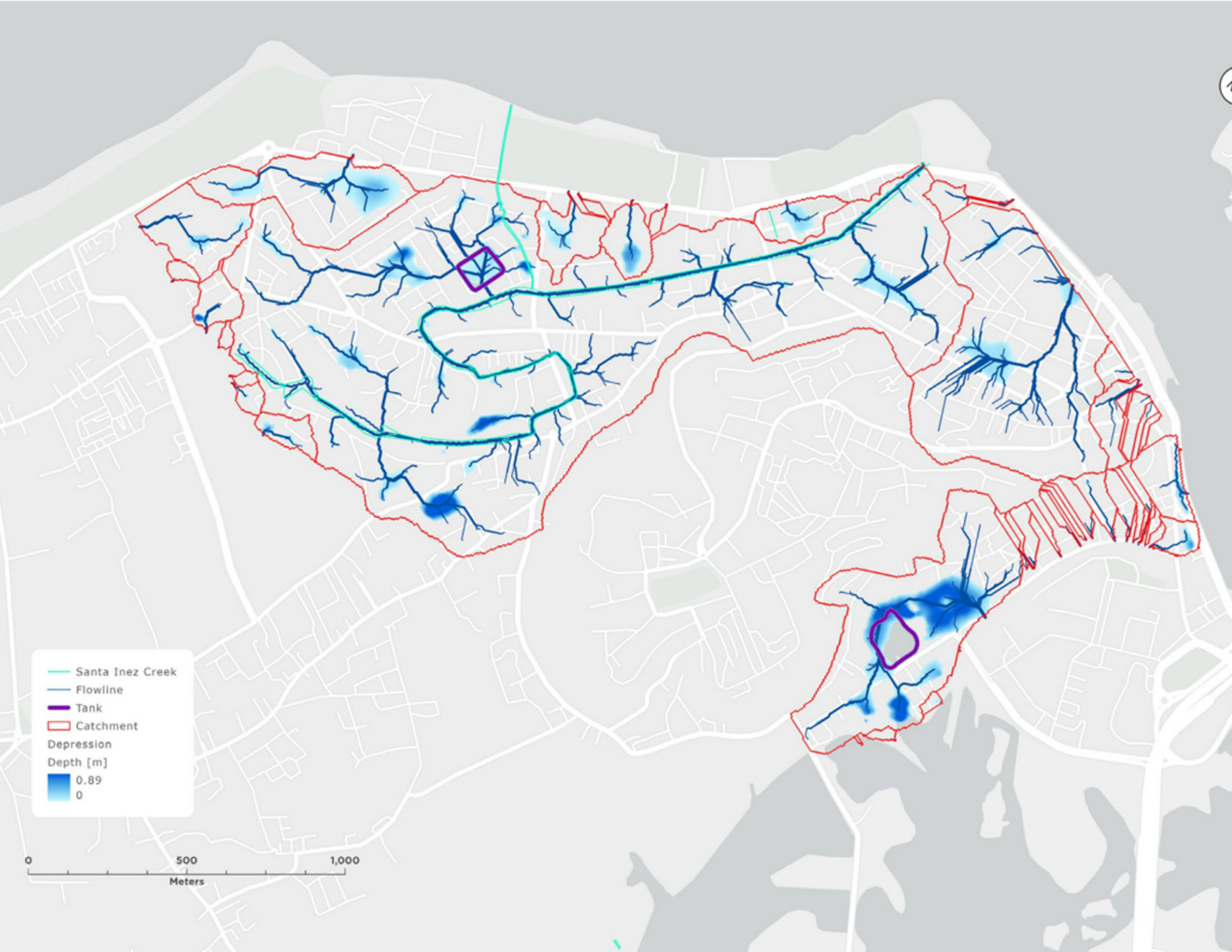
34%

of Panaji area is undevelopable

Sl.No.	Land Uses	Area in Sq.km	Percentage
1	Residential	2.80	50.91
2	Commercial	0.85	15.45
3	Industrial	-	
4	Institutional/ Government	0.75	13.64
5	Transport/ Communications	0.30	5.45
6	Parks/ Playground	0.80	14.55
	Developed Area	5.50 (66%)	100%
7	Natural Resources	2.09	
8	Conservation/ Preservation	0.34	
9	Defence land	0.07	
10	Watershed	0.30	
	Undevelopable area	2.80 (34%)	
	Total (ODP Area)	8. 30 (100%)	

Category	UDPFI Guidelines	Panaji Existing	Benchmark
Residential	40-45%	50.91%	exceeds
Commercial	3-4%	15.45%	exceeds
Industrial	8-10%	0%	Nil
Public & Semi Public	10-12%	13.64%	exceeds
Recreational	18-20%	14.55%	no
Transportation	12-14%	5.45%	no

The limited land availability in the Panaji urban area and the extent of urbanisation that the city has undergone in the past few decades, implies that the City is constantly under pressure to find new areas for development. Due to its physical geographical constraints to expand, vertical growth is inevitable. As well, sustainable methods of land development are not practiced, including the natural drainage surfaces being converted to impervious surfaces (for example cement), resulting in increased rainwater runoff and increasing the number of potential flood points. The limitation of landuse to provide for natural detention and retention basins within the City area further exacerbates the rainwater runoff concerns, leading to urban flooding issues. Such issues are already evident in Panaji with reports of frequent flooding in certain areas during regular monsoon events.



Santa Inez Creek
Flowline
Tank
Catchment
Depression
Depth [m]
0.89
0
0
500
1,000
Meters

Existing drainage system and condition

The present storm water drainage network for Panaji city was planned and implemented around 1938 by the Portuguese. All the major roads are provided with roadside storm water drains further connected to the outfall drains which lead to the n orthern side of the city for ultimate discharge into the Mandovi River at various locations.
The present storm water drainage system can be divided in to four major zones:

- Run off from the Altinho hillock flowing in to the Mala and Fontainhas area of the city further discharging into Mala Lake. From here it flows in to Ourem Creek and finally into River Mandovi.
- Run off from the core city area (northern part) flowing in to Mandovi River through a network of surface drains and deep drains.
- Run off from St Inez areas flowing into the St Inez Creek and then to the River Mandovi.
- Run off from the southern parts of the city flowing in to the Arabian Sea.

The total length of Panaji roadside drains found in the city is 77 km (one sided) which covers the existing road network within the city.

Identification of vulnerable areas and flood frequency

18th June Road

The 18th June Road is the main commercial hub of Panaji City. This one kilometer stretch connects Church Square in the east with D.B. Road on the west, after crossing St Inez Creek. The gentle slope of the terrain is from east to west, but the drains along and across the 18th June Road drain towards the north to the Mandovi River. The 18th June R oad itself has kerb side drains covering every block. These kerb side drains are inter linked and cross the 18th June Road at various points, where they connect to the deep drains laid beneath the city streets.

Two deep drains laid from south (base of Altinho) to n orth (Mandovi River) also cross the 18th June Road. These drains are:

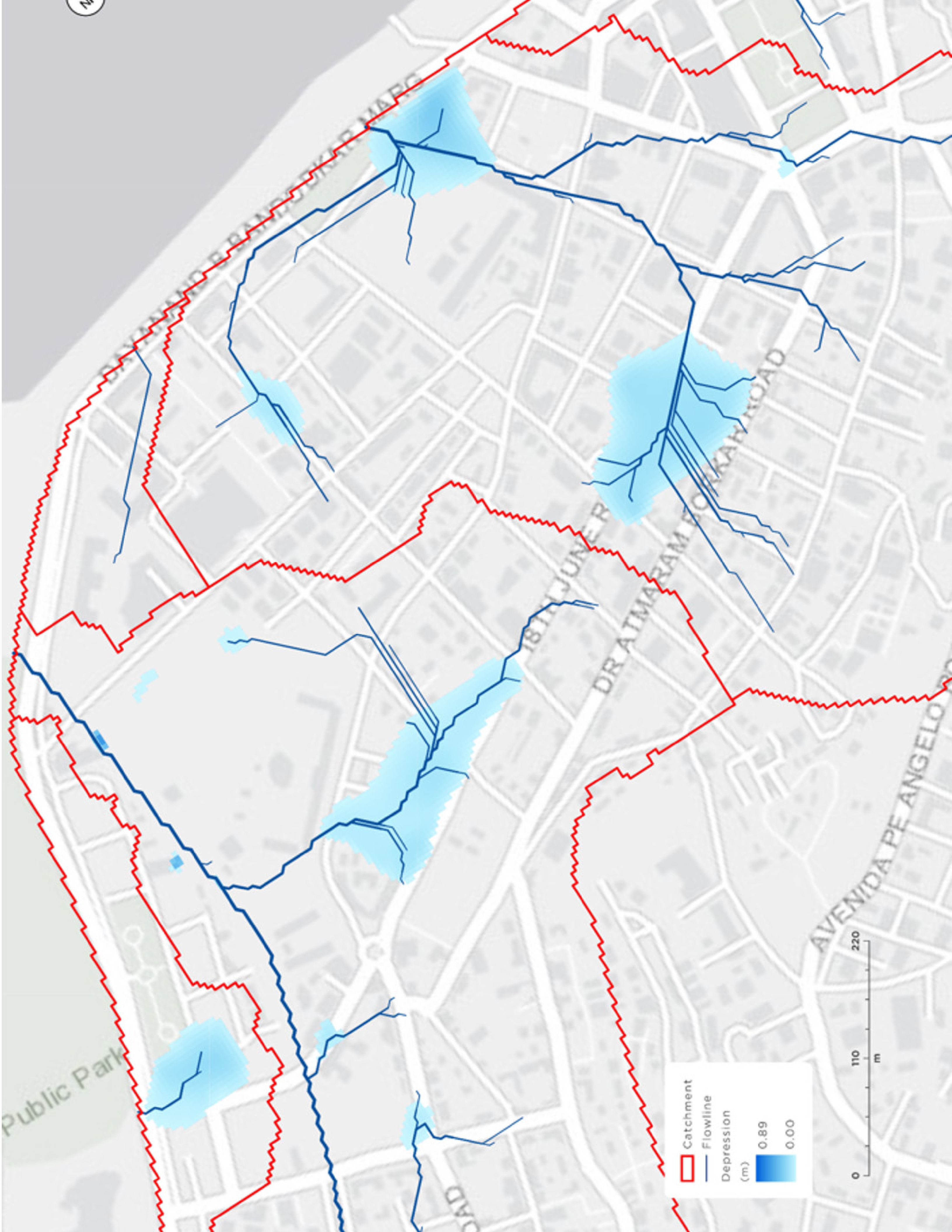
- From Dr Dada Vaidya Road along Dr Pandurang Pissurlekar Road draining near ferry point. At present, the 18th June R oad drains are connected to this deep drain.
- From near Church Square to the Fisheries Department

The influence of tidal ingress into these drains is evident from levels. From the tidal data collected, Panaji experiences tidal influence between 0.4 m during low tide to 2.6 m during high tide.

Another deep drain from Boca de Vaca Spring along Swami Vivekanand Road and traverses along the 18th June Road draining into St Inez Creek near Don Bosco School.

An analysis of the terrain around the 18th June Road reveals that the 18th June Road is at a lower elevation than the nearby areas, therefore acts as a sink when it rains. This level difference results in all the surface run-off from the upstream side (base of Altinho) that

Deep Drains of Panaji	PHYSICAL FEATURES	LEVELS
Boca de Vaca Drain	700 m long, The drain is a rectangular box of 1.5 m x 1.0 m	At Boca de Vaca ~ 4.0 m Discharge to St Inez Creek – 1.43 m
Ferry Point Drain	From CCP & 18th June Road 1.0 m x 1.5 m rectangular brick lined/ CC lined drain	Discharge level at Military Point at 1.43 m (below high tide level)
Fisheries Point Drain	Drains area around Church square to Ferry Point	



DAYANAND BANDODKAR MARG
18TH JUNE R
DR ATMARAM BORKAR ROAD
AVENIDA PE ANGELO
Public Park
ROAD
Catchment
Flowline
Depression
(m)
0.89
0.00
0
110
220
m

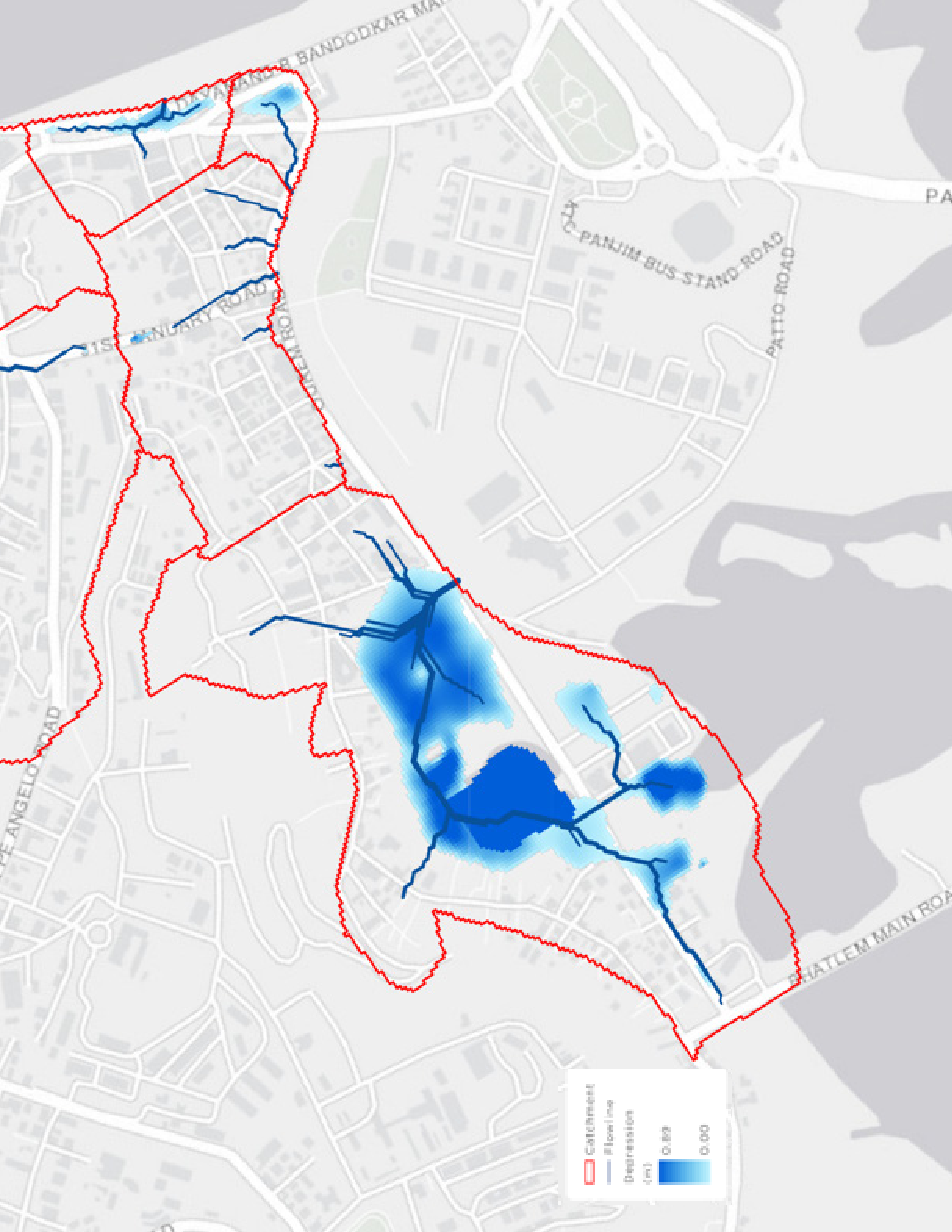
drains towards Mandovi River to collect around the 18th June Road.

The side drains along the 18th June Road are covered and have openings on the cover slabs which allows for water to enter the drain. However, often these openings get clogged with debris and waste materials which further reduces the efficiency of run-off to enter into the drains. The drains itself were observed to be in a deteriorated state with siltation, broken side walls and multiple utilities crossing the drains. These hindrances further reduce the carrying capacity and effectiveness of the drains.

St Inez Road

The stretch of St Inez Road near the St Inez Church is another area that experiences frequent inundation/flooding during monsoon rains. Despite having kerb side drains, this area is prone to flooding. Some observations based on the field work visit and data collection reveal that the occurrence of flooding in this area is largely due to inadequate drainage to evacuate the water accumulating from the drainage catchment areas upstream.

Based on the local terrain, the flow of water is towards the St Inez Church from St Inez circle and the Altinho hill slide as well as from the south side. From there the drainage towards St Inez Creek is through a drain of 150 m length, 0.5 m x 0.5 m in size around the residential blocks. This drain also collects and carries the surface runoff from the residential blocks. The drain was covered and showed a deposit of silt. The extent of siltation indicated greatly reduced carrying capacity of the drain.



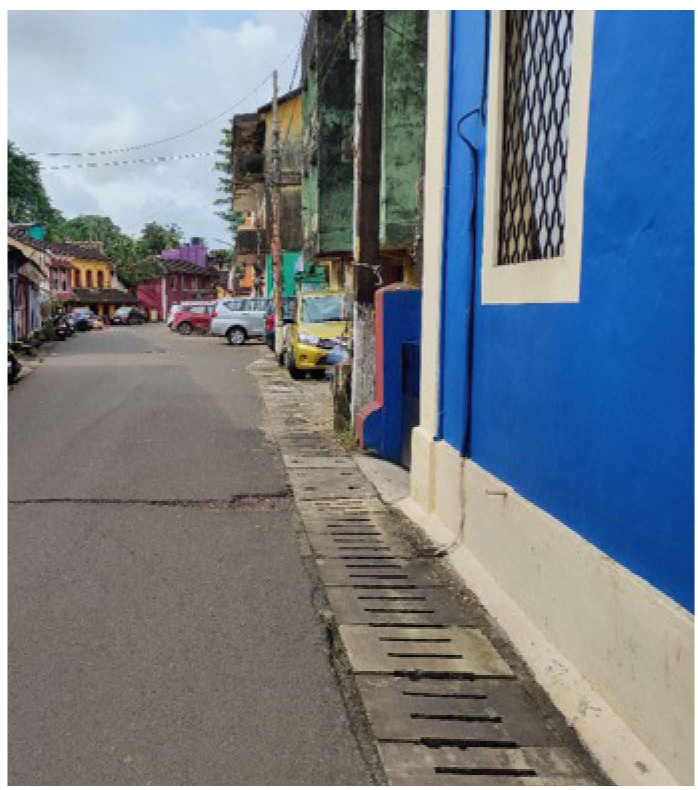
DAYANAND BANDODKAR MA
PANJIM BUS STAND ROAD
PATTO ROAD
31ST JANUARY ROAD
PHATLEM MAIN ROAD
Catchment
Flowline
Depression (m)
0.80
0.00

Mala Area

The Mala area is physically characterised by the Altinho hills to the west, the Rua de Ourem and Ria de Ourem on the east, extends to the Fontainhas quarters to the north and extends till the old highway to the south. A literature review reveals that Mala area grew as a settlement from palm groves. Today, the area is a fully developed residential neighbourhood with the Mala Lake as the only open area. Topographically the steep slopes of the Altinho hills end at Mala and the ground gently slopes towards the Mala Lake. Spread over 16,000 sq. metres,Mala Lake itself was part of the flood plains of Rio de Ourem but has been cut-off from it through man-made interventions.

Hydraulically the catchment of Mala Lake covers parts of Altinho hills, but development of roads and drains has changed some of the natural flows draining into this lake. Most of the drainage of Mala settlement area are drains to the lake through a network of drainage systems. The drainage system itself is old, lacks regular maintenance, is undersized and therefore is largely inefficient in conveying the runoff. The outlet of Mala Lake is through two pipes which are provided with flap gates that prevent back flow into the lake from the drains. The drains are connected to the Rio de Ourem, but the invert level of this drain is at a level that gets submerged during high tide influence from the Rio de Ourem Creek.

Apart from the drains discharging to Mala Lake, a large area of Mala and Fontainhas drains towards the Rio de Ourem Creek through smaller drains. These drains start from the foot of the Altinho and ollow the cross-roads to discharge into the Rio de Ourem Creek. A major part of this drainage connects to the wet weather pump station installed by the Water Resources Department in 2006, as part of its flood control measures in the area. The channelising of Rio de Ourem from its mouth at Mandovi River to the Mala-Patto Bridge by creating edge development has enabled protection of this area from flooding from Rio



de Ourem. However, the drains discharging to the Rio de Ourem are still below high tide level and are constrained from free discharge during high tide periods.

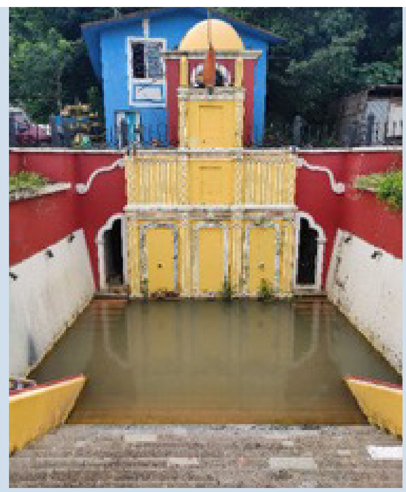
The flood plains of Rio de Ourem between the Mala-Patto bridge and old highway have been victim of the urban sprawl with build-up areas and growing settlements by urban poor. This has resulted a natural flooding phenomenon to a man-made urban flooding problem that causes damage to property and life.

Most of the Fontainhas quarter was built during the Portuguese period and has very distinct character buildings. This area is also considered a protected area in terms of modifications of buildings and any development. Research into the building by laws that prevailed during the Portuguese period published in 1838[1] showed that there were building requirements that stipulated that buildings for habitation were required to have their ground floor at least 0.6 m above the prevalent ground level. This requirement was a logical measure in order to drain the latrines and also to prevent inundation of the living quarters, especially when considering Panaji was on low lying reclaimed land. However, in the present day many buildings in the Fontainhas quarter can be seen having their ground floor below the present road level; which is a key issue resulting in inundation of the living quarters during rainfall events.

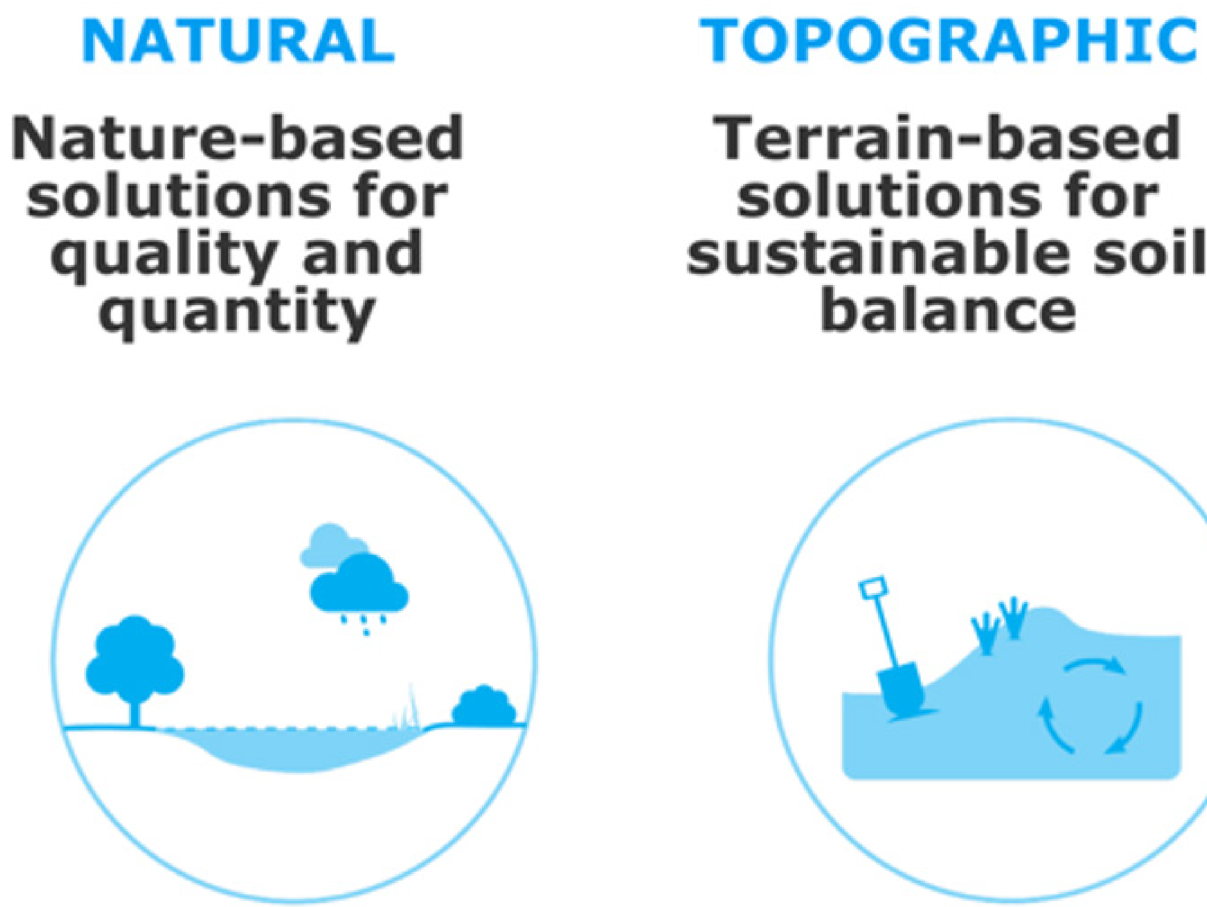
Over the years, the roads have been built and surface weathering layers re-laid to gradually increase the road levels, but the buildings, since they are protected, couldn't be modified. This built-up of the road levels results in localised inundation and flooding of properties in the Fontainhas area.

The flooding observed in Mala area are caused by the following:

- Filling up of Mala Lake prevents the drains discharging to the lake from freely flowing into the lake.
- Overflow from Mala Lake is controlled by the tidal effect in Rio de Ourem Creek and the water level in the drains along Rua de Ourem Road.
- Overflow of Rio de Ourem to its flood plains upstream of the Mala-Patto Bridge potentially causes flooding in the area.
- Run-off from the Mala and Fontainhas areas exceeds the capacity of the drains and finds the streets as a conveyance path.
- Improperly engineered ways of road maintenance and re-laying have resulted in the street levels going higher than the floor levels of adjoining buildings. This results in flooding of properties.

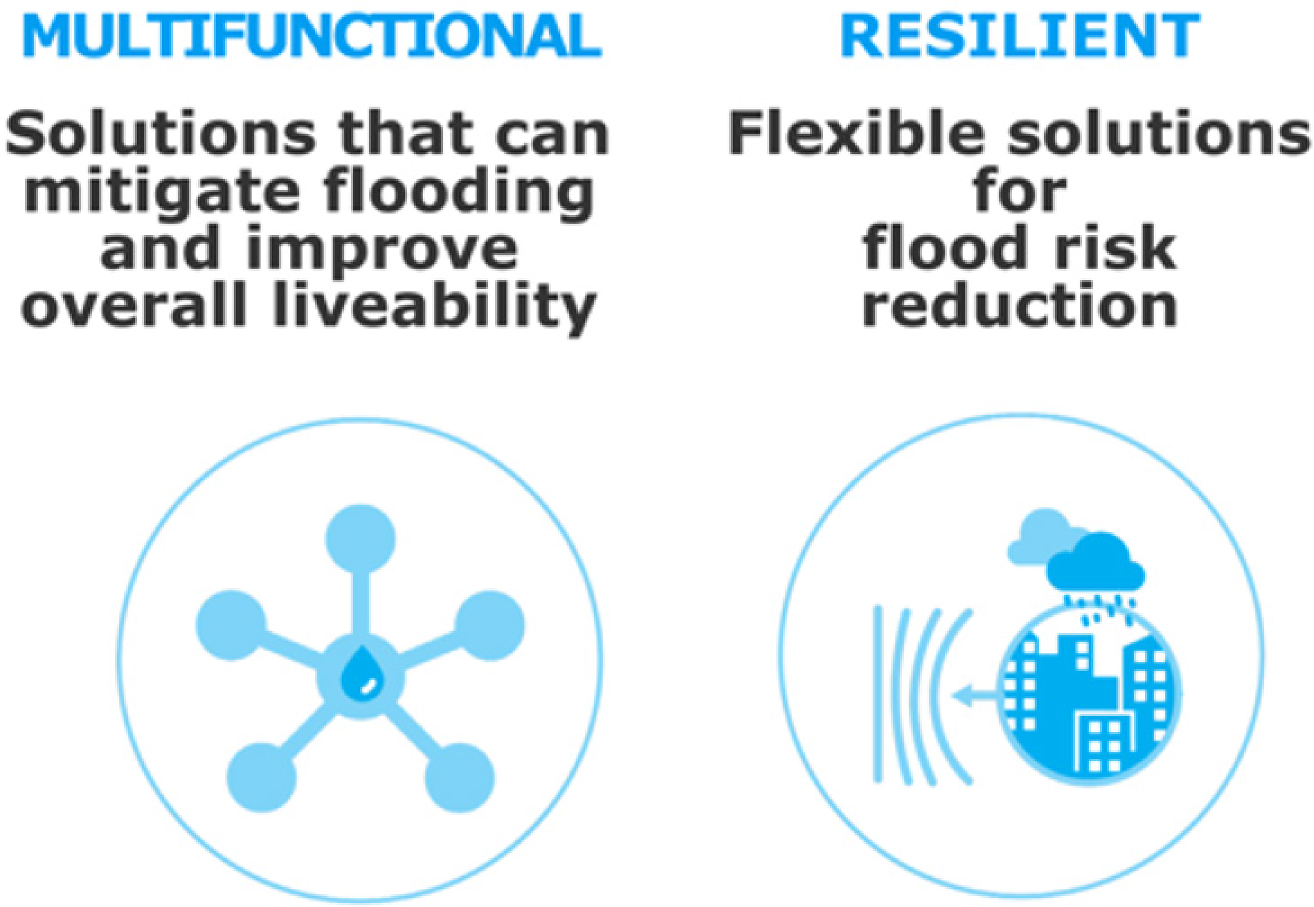


2 Regulamento de Edificacoes (legislation relating to constructions), covering works of construction and demolition of structures in Panaji, Vasco da Gama, Caranzalem, Margao, Mapuca and Curchorem.



Mitigation Measures

There are multiple issues arising from the natural topography, urban growth, design issues, tidal influence, operations and maintenance of drainage systems which result in flooding in the city Panaji. However, there are many best practices that could be implemented to successfully manage the runoff and reduce the impact of flooding on the commercial and residential properties. Any intervention without a comprehensive study could lead to shifting of the problem from one place to another and not achieve a beneficial outcome. A hydraulic modelling of the entire storm water drainage network of Panaji needs to be undertaken in a systematic way to analyse the system, evaluate the various mitigation and determine measures which are necessary to arrive at the optimal set of solutions that can achieve the best impact. Further, the capacity, sizing and prioritis ation of any intervention can be simulated using modleling tools to plan the investments that are required for a comprehensive solution. In Panaji context, the impact of tidal variation also plays an important role in free drainage of the storm water drains. For example, currently the invert levels of the drains draining into the



Mandovi River are below the normal high tide levels, which results in water accumulating in the urban areas during high tide times, thus reducing their effectiveness.

The functional requirements of these systems are to capture, convey, and where possible store (retain or detain) stormwater. Natural cleansing functions will be embedded in storage and conveyance systems to minimize needs for downstream treatment and improve local water quality.

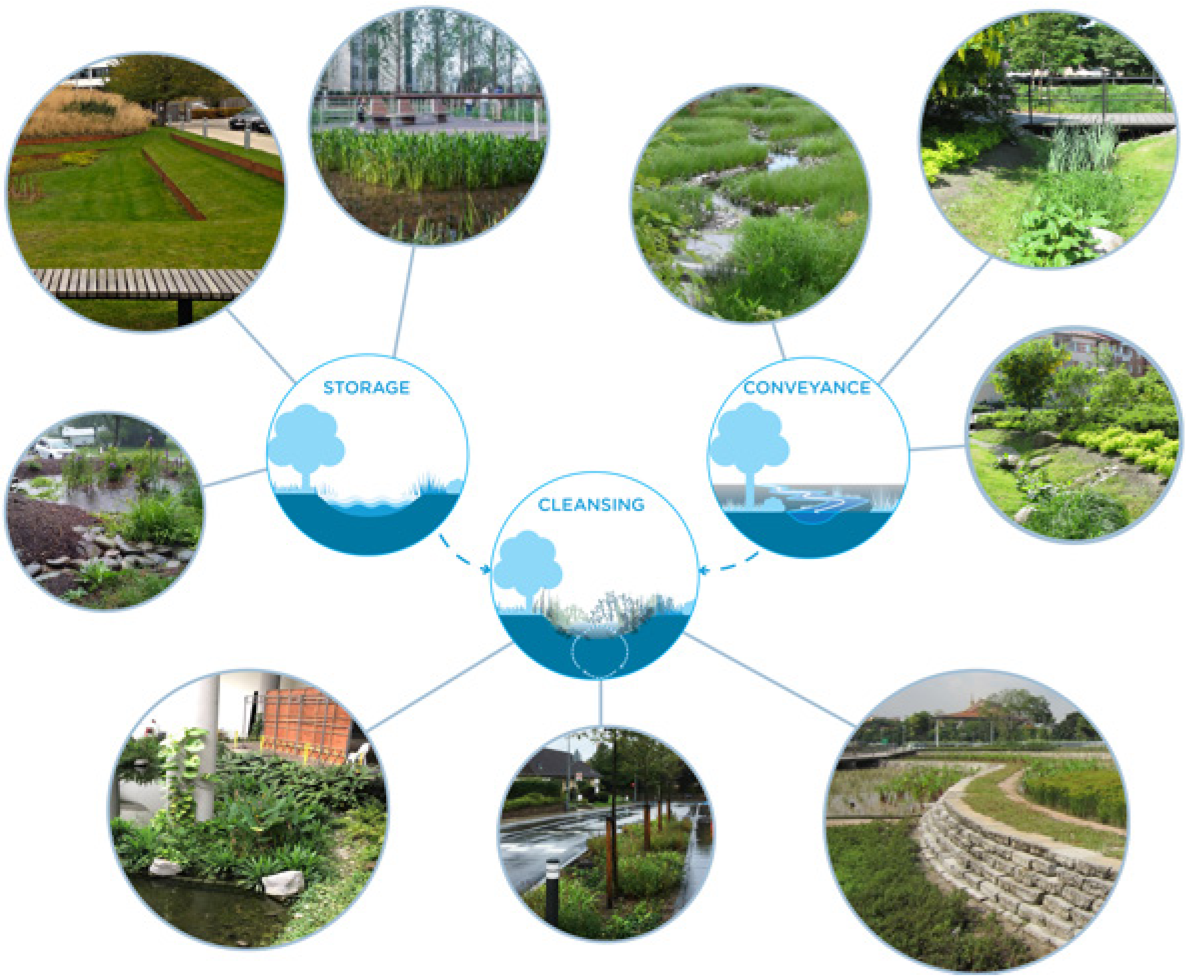
Flood Mitigation Plan

The flood mitigation plan outlined in this section is a broad conceptual layout of a set of activities towards achieving the goals in a sustainable manner. The traditional approach is to move the rain water away from where it falls through conveyance systems and discharging it into water bodies with a network of drains and pipes are most common practices in urban areas. However, over time these practices have proven to be inadequate to convey the rainwater effectively. The changing climatic conditions, patterns of rainfall, rising sea levels, increase in urban sprawl, increase in impervious areas and lack of public spaces to accommodate larger infrastructure elements are all factors which are leading to re-thinking alternate modes of stormwater management from the traditional infrastructure dependent method to capture, convey and discharge.

Nature Based Solutions

A nature based approach for stormwater management promotes sustainability and resilience through terrain based conveyance and storage solutions supported by natural cleansing systems.

A nature based approach offers a feasible, economical and valuable option for communities to cope with the challenges of climate change through terrain based solutions. A multifunctional and highly adaptive network of terrain-based solutions, in combination with traditional stormwater infrastructure can mitigate flooding, while improving overall livability.The key characteristics of NBS approach for stormwater are the reliance on natural solutions to manage stormwater flows and improve ecological conditions and enhance biodiversity.



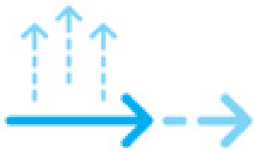
A nature-based approach alters the local water cycle in a systemic way that benefits health and biodiversity for flora and fauna, while improving quality of life for all.

A nature-based approach for stormwater management promotes sustainability and resilience through terrain-based conveyance and storage solutions supported by natural cleansing systems.

A nature-based approach offers a feasible, economical and valuable option for communities to cope with the challenges of climate change through terrain-based solutions.

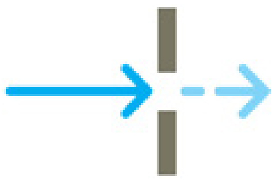
A multifunctional, and highly adaptive network of terrain-based solutions in combination with traditional stormwater infrastructure can mitigate flooding, while improving overall livability.

NATURAL



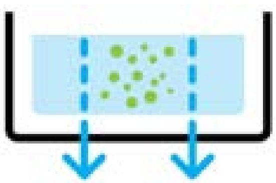
Evaporation
Water changes from liquid to water vapour

Conveyance
To control and transport rainwater to a final recipient



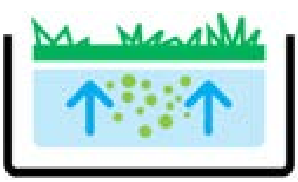
Detention
To reduce rainwater's peak flow

Retention
To keep water volume on site/where it falls

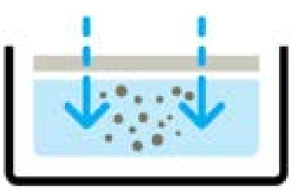


Infiltration
To allow water to seep into the soil and recharge aquifer

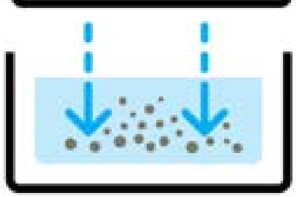
QUALITY CONTROL



Biological Absorption
To nourish plants by absorbing nutrients from water and soil



Filtration
To separate sediments from water by interposing a medium (filter)



Sedimentation
To settle out entrained particles of water flow

Recycle
To recycle nutrients, reuse clean water, ground water recharge etc.

By promoting multifunctional solutions, the overall vision aims to create adaptable natural spaces that can improve the overall liability and provide resilient planning and infrastructure that reduces the risk of flooding both in current and future climate conditions.

Blue Green Infrastructure (BGI) Concept

Blue Green Infrastructure (BGI) concepts connect stormwater management functions (blue) with open space/city nature systems (green) and o□er optimised solutions and co-benefits for urban areas facing the challenges of flooding and climate change. BGI often consists of nature based solutions (NBS) and is terrain based to ensure a high level of sustainability and resilience through reduced pit/pipe infrastructure and flexible flood zones, respectively.
Another term often used in relation to BGI is low impact development (LID), referring to systems and practices that use or mimic natural processes to reduce deterioration of water bodies and enhance aquatic habitats.

BGI performs an important infrastructure role, while contributing positively to the public realm. Social, economic, and environmental values are generated for the local area and BGI has proven to reduce the need for traditional grey infrastructure and provide reduced capital and ongoing maintenance costs for infrastructure owners through co-funding agreements.

When planning, permanent water bodies may be included as part of the BGI network and can provide additional co-benefits such as increased recreational value, biodiversity and habitats and cooler surfaces for reducing urban heat. Integrating blue and green networks in the urban fabric is proven to improve the micro-climate conditions and provide comfortable public realms and connected pedestrian passage through the site.The use of BGI as the primary component of stormwater management systems is based on well-

Co-Benefts:

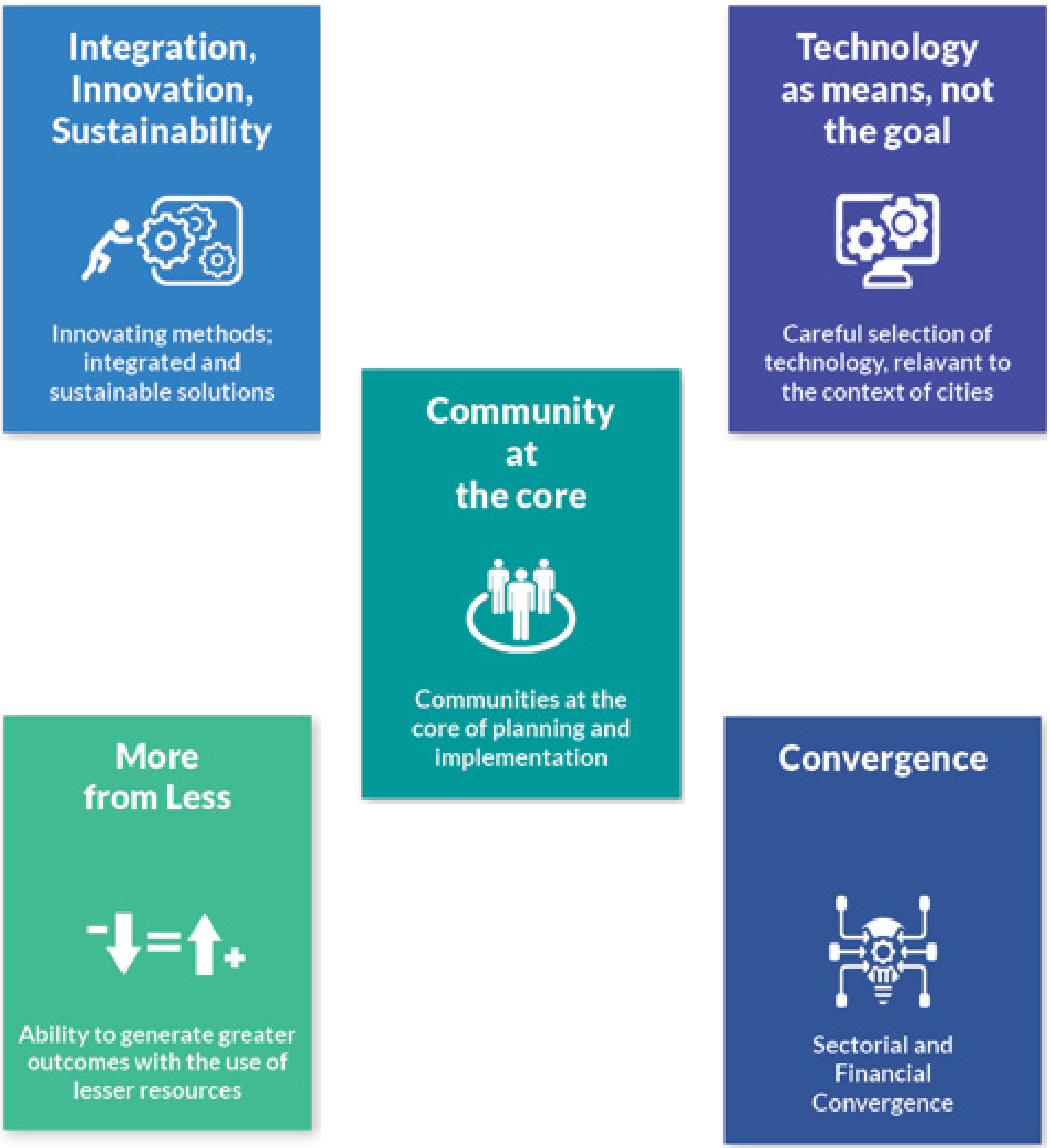
Co-benefits is often used as a term for the additional benefits of blue-green infrastructure, in addition to the primary benefit of flood risk reduction. Multi-functional blue-green infrastructure aims to achieve more urban planning goals and attract more stakeholders, which is crucial in cities with limited space to be shared between many. Co-benefits include improved air quality, added recreational value, improved micro-climate, biodiversity and noise reduction, to name a few. Maximizing co-benefits in stormwater management through use of blue-green infrastructure enhances liveability and social cohesion, while offering opportunities for co-financing to reduce capital & ongoing maintenance costs.

NbS tools help in achieving the Principles of SMART Cities

Integrates clean and sustainable environment around core infrastructure

Improves quality of live to citizens and live-abiltiy index of City

Sectoral convergence to solve issues while improving infrastructure



established and proven concepts.

Blue Green Infrastructure (BGI) Concept

BGI systems can be designed with centralised or decentralis ed components, each with their own specific benefits and limitations. Site-specific conditions along St Inez Creek and Mala Lake, such as sub-catchments, land ownership, and site layouts would inform the best approach when providing a holistic plan.

A centralised system is centered around few major retention/detention areas, often characterised as partially permanent water bodies in the public realm. The focus of the centralised strategy is to convey water to these main storage areas for both water quantity and quality control.

A decentralised system is characterised by many small retention/detention areas distributed relatively evenly throughout the site. The system is characterised by few or no permanent water bodies as part of the stormwater system and typically rely heavily on multifunctional spaces to fulfil the role of stormwater detention, and provide an extended treatment train for quality control.

A mixed approach combines the centralised and decentralised strategies to match the characteristic of the neighbourhoods and surrounding areas, while tackling limitations (e.g. topography, space limitations and massing). The mixed approach allows for flexibility to optimise stormwater management within each of the sub-catchments.

Rain gardens

Bioswales

Cleansing biotopes

NBS+ Traditional Infrastructure

Nature based solutions are naturally sustainable options that also provide both added value and co-benefits to immediate surroundings. In order to improve the overall sustainability, nature based solutions are intended to be generally 'on-terrain' based and designed with respect for the topography to minimise earthworks. These solutions are generally supported by traditional grey infrastructure where there are significant constraints on surface-based infrastructure, or where existing infrastructure is already in place and should be utilised so it does not become a redundant investment. The 18th of June Road can be an example of the integration between BGI and traditional storm water pipes.

Integrating BGI-NBS into to urban realm and open spaces

When planning the network of BGI–NBS solutions is important to consider that each category or element plays a slightly di□erent role in the BGI strategy, due to the hierarchy of the categoris ation and possible physical placements within the catchment (i.e. upstream to downstream).

It is possible to plan a threelayered approach for storm water management. The three layers are thought to maintain the natural hydrological cycle, create amenities and mitigate property damage from flooding, although at di□erent functional levels based on the hierarchies:

(i) The first layer consists of sitewide features such as rain gardens, bioswales and permeable surfaces with the purpose of absorbing small 'everyday' rain events.

(ii) In the second layer, the pocket parks and amenity features such as sport fields are utilis ed to temporarily store rainwater from larger rain events, until the capacity at the points of discharge allows for emptying the stormwater management system into the recipient water bodies.

(iii) In the third layer, the main park features may be temporarily inundated during more extreme rain events to protect infrastructure and other assets throughout the site, until the capacity at the points of discharge allows for emptying the stormwater management system into the recipient water bodies.

NbS meets Sustainable Development Goals

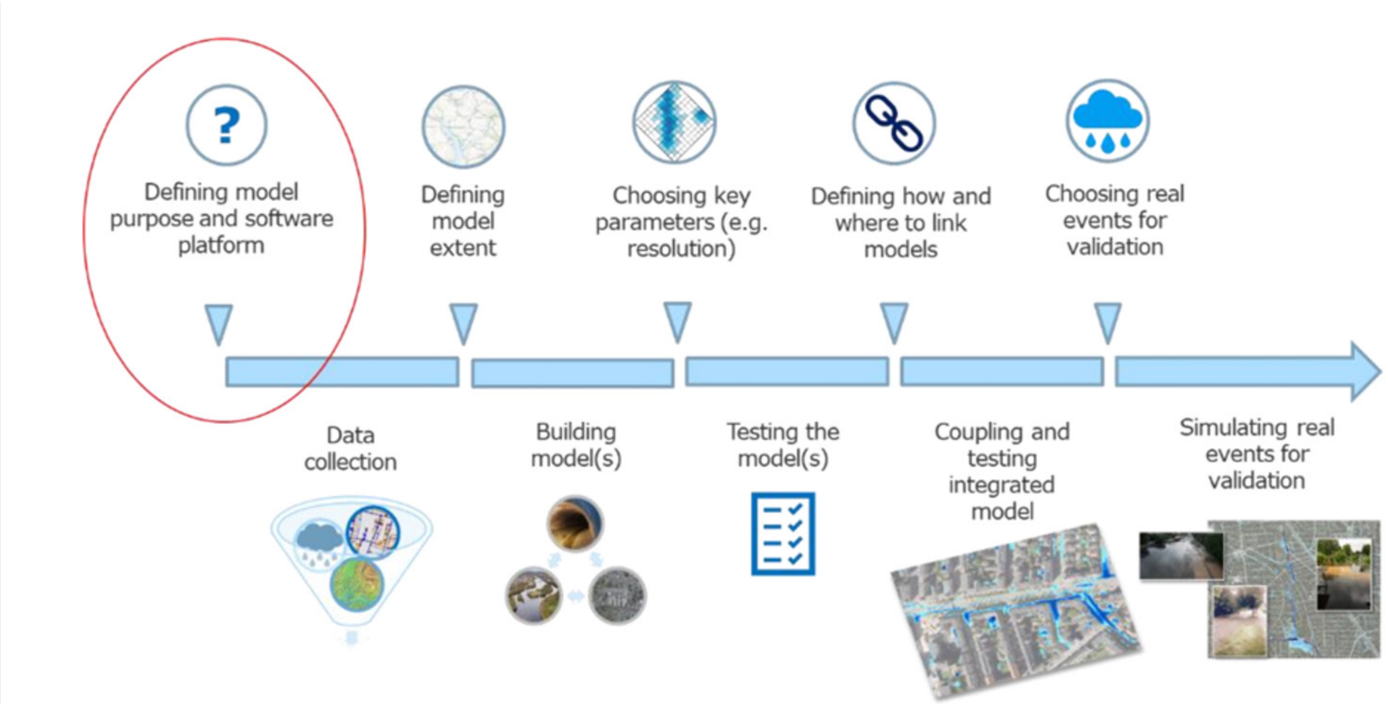
Surface water run-off control in sustainable manner – harvest, detention, infiltrate, & safe conveyance

Public infrastructure renewal – include SuDS, LIDs, NbS toolkits

Economic sustainability in infrastructure development

Urban space quality improvement – enhance urban ecology and biodiversity

City resilience enhancement – micro-climate changes



Hydraulic Modelling

The use of multifunctional open space in stormwater management is a well established and proven concept. The figures shows references pictures from international projects to provide a sense of scale and potential land-use impact and how it may be integrated with the open space.
The BGI toolkits are smaller interventions as compared to conventional infrastructure solutions and therefore it is necessary that these BGI toolkits are adopted at multiple locations to achieve incremental reduction in the runoff.
Hydraulic Modelling has evolved as a tool to aid decision making when the interventions involve expensive investments for infrastructure. It aids in understanding the impacts on the system as a whole, allows for evaluating alternatives and analyses the risks involved with each set of interventions. A hydrodynamic modelling of St Inez Creek is currentbeing undertaken by WRD under the Smart City projects and another GIS based Master Planning of the Panaji City area by IPSCDL. Unfortunately, these two studies do not sufficiently address the urban flooding issues and various incremental improvements being undertaken across the city. Therefore, a comprehensive stormwater modelling study is required to analyse the existing drainage system, evaluate the improvements and assess the various scenarios from an urban flood mitigation objective. The above modelling efforts can be combined into a comprehensive study to have data consistency as well as meet the overall objectives.

The typical process for selecting, building, and testing hydraulic models is illustrated in Figure, ranging from the initial definition of the model purpose to the simulation of real rain events. This process is in the first step of the process of improvements to the flood migration and water management plan and this document will support the decisions that are necessary to proceed along this process.

Important considerations when deciding which modelling approach is most beneficial include:

- The purpose of the model should be considered and defined before settling on a specific approach, to ensure that the model provides the necessary outputs while not spending valuable resources and building models that are more complicated and detailed than what is necessary to meet the demand/

goal.
- The available data (or possibility of collecting additional data) should match the level of detail expected from the model. The accuracy of any hydraulic model is, for the most part, determined solely by the quality of the data which the model is based on. Hence, if limited data is available, a simple model may be the optimal choice.
- Consider who is going to be using the model and if there are any limitations to the technical capacity of the end-users.

Two model approaches include one-dimensional models (1D models) and a two-dimensional model (2D model). The key difference between a 1D model and a 2D model is in the data requirement and available model outputs. A 2D model rely on a detailed terrain model, and while this is often one of the more challenging data items to obtain, it provides the option to produce flood maps that shows the extent and depth of flooding and indicate which assets (houses, roads, infrastructure etc.) that could be exposed to flood damages

Based on global best practices and experiences elsewhere, a combined 1D flood model with 2D model simulating flows on terrain will be the suggested way for Panaji. The 1D Model Approach simulates the creek and receiving water bodies and the combining this with a 2D model of the urban drainage system is necessary to to represent the dynamics of the urban drainage conditions, local flooding issues caused by insufficient conveyance or storage in the secondary and tertiary drainage system.

This approach would allow the user to map the extent and depth of flood events, and potentially quantify damages and more accurately target improvements at the areas where the highest risks are observed

These are broad scope suggestions for a scenario-based stormwater modelling in Panaji, to facilitate the discussions, evaluation and effectiveness of interventions related to urban flooding issues.

This will be an ongoing process that will take place following the production of this document.

A data gap analysis will be necessary to identify any missing data that will be required to build the optimal model. This will include an alignment of expectations that considers the resources that will be allocated to close the potential data gaps and meets the demands of the hydraulic model.

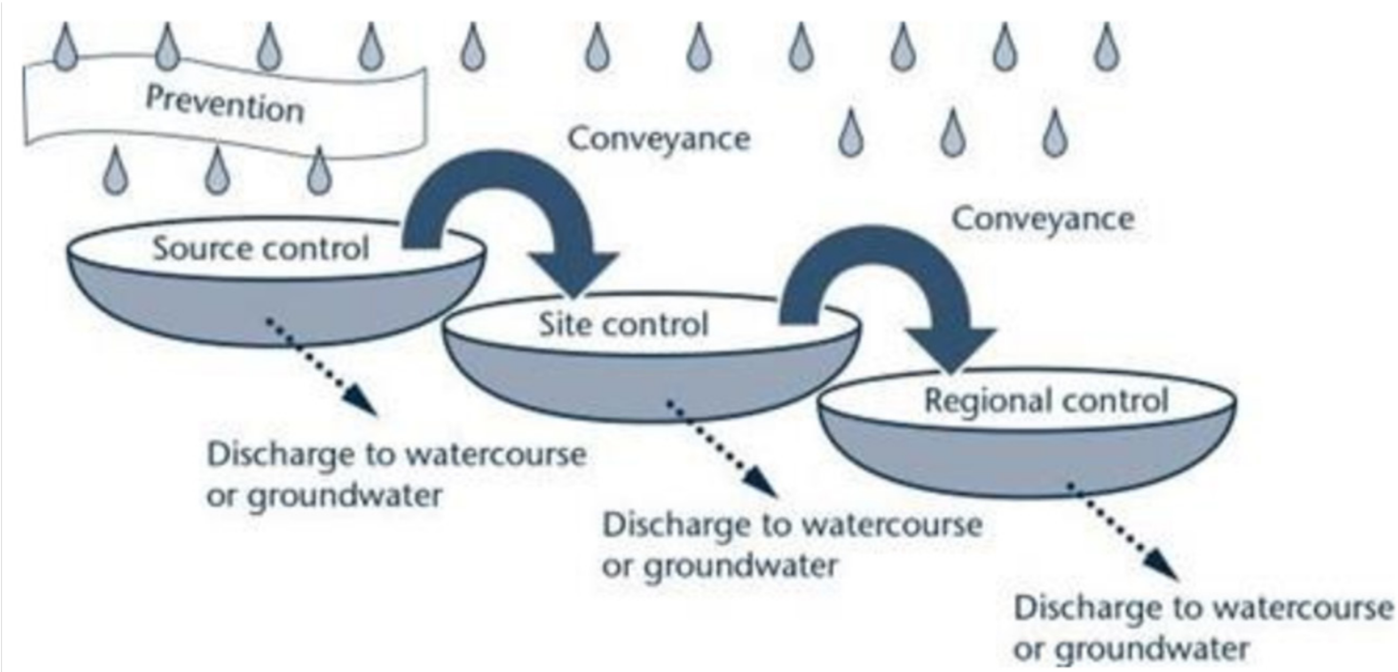
Finally, to build confidence in the results of any of the three modelling approaches a calibration/validation process is required. This may be done running simulations of real events and comparing the results with real conditions. This will require historical rain data as the input to the model and measured water-levels/discharge/flood extent to validate the results.

Key Model Outputs

- Flood maps showing the extent and depth of flooding
- Identification of exposed assets and risk of damages
- When damages are quantified in monetary terms, a cost-benefit assessment may be used to justify or discard proposed interventions by weighing the reduced flood damages against the cost of the intervention
- Flows and water levels in the drainage network during rain events
- Identify critical points of overflow in the drainage network during intense rain events
- Identify bottlenecks in the drainage network, i.e. culverts or bridge crossings with improper dimensions
- Scenarios with altered cross-sections or removal of bottlenecks to quantify benefits illustrate hydraulic conditions in the drainage network 'before-and-after' an intervention
- Climate change scenarios, including rising sea levels and increasing precipitation and how this affects the hydraulics in the creek i.e. more overflow from the creek or limited gravitational drainage capacity
- Scenarios with altered stormwater runoff patterns, i.e. changes in land cover such as reduced/increased imperviousness
- Scenarios with altered terrain
- Scenarios with changes to stormwater control structures such as storage volumes, i.e. the addition of a new stormwater basin or Bluegreen Infrastructure with a storage component, weirs, or sluice-gates

General Data Requirements for Modeling

- Detailed terrain model. PULL has already acquired for about 3.8 sq km of Panaji city the DEM of 1 m x 1 m grid size with 2 cm vertical accuracy through a LIDAR based drone survey. The same level of data capture to be extended to the entire Panaji area for data consistency
- The elevation model should only include the terrain surface and should not include features that does not affect the surface flows significantly e.g. tree canopies or other vegetation
- The terrain model may include buildings, or these can be raised in post-processing if the buildings are digitalised (usually provided as polygons in CAD or GIS)
- River cross-sections, the number of cross-sections will depend on the bathymetry of the creek but importantly it would be required to capture significant cross-sectional change i.e. culverts or bridges.
- Existing stormwater storage infrastructure, both location and dimensions
- Water level time series at the point of discharge (at the mouth of the Mandovi River)
- Dimensions, invert levels of all drains and pipes
- Land cover data (used to estimate runoff coefficients)
- Drainage network catchment delineation
- Historical time-series rainfall and tidal data
- Measured water-levels/discharge in major drains, creeks corresponding to time-series rainfall data


Prevention
Conveyance
Conveyance
Source control
Site control
Regional control
Discharge to watercourse or groundwater
Discharge to watercourse or groundwater
Discharge to watercourse or groundwater

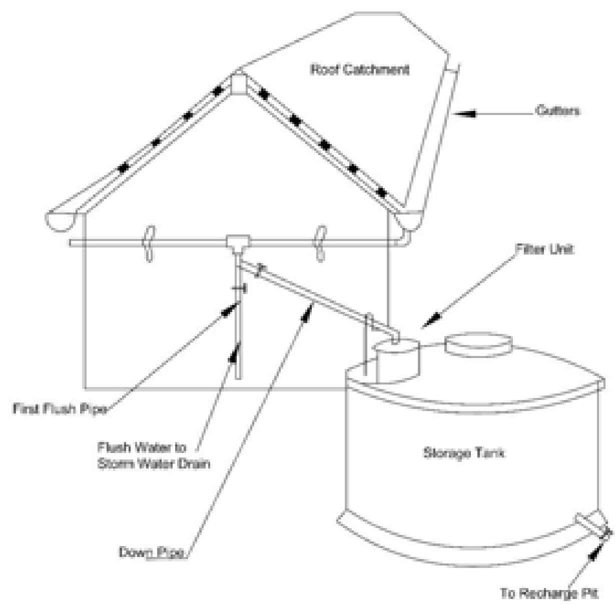
Toolkit for Flood Mitigation

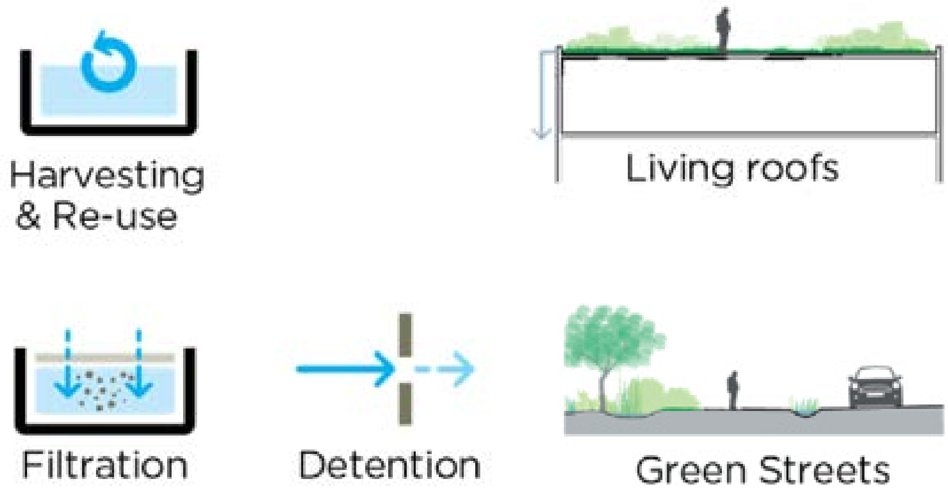
In urban areas the majority of storm water runs off from the impervious surfaces and then have to be diverted towards the storm water drains for efficient removal to prevent flooding. Building roof tops, driveways, parking areas and street pavements are major surfaces that contribute to rain water runoff in urban areas. The building roof tops are generally provided with roof drains which collect and convey the rain water to drains, rain water harvesting units and open landscaped areas that infiltrate the water into the ground water table.

Design considerations, from a rainwater mitigation aspect, is lacking for most of the paved areas such as parking areas, driveways and paved streets in urban areas in India. The recent guidelines brought out by the Central Public Health, Environmental Engineering Organisation in 2019, provide direction for these aspects. There are a few relevant toolkits that can be applied in the Panaji context and are discussed in this section

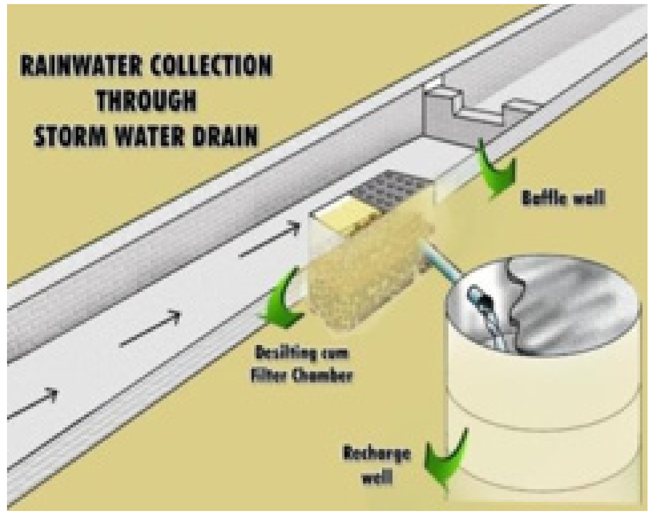
Rainwater Harvesting

Rainwater Harvesting is a proven and well accepted practice in many cities in India as a tool to capture rain water falling in roof tops and permeable areas. Apart from being effective in reducing the runoff, the captured, stored runoff has the potential to meet a portion of a city's annual non-potable water needs. Though this is a small intervention, in terms of the volume of runoff generated in a city, when implemented at every property, building, household level, the cumulative impact achieved is of scale that can be compared at the city level. There are many designs and variations that have been tested and found suitable for Indian conditions, type of building or property, the implementation of the same in a wider context has been a challenge in many cities. The state Goa has also tried in the past to incentivise installation of rainwater harvesting structures at residences, but adequate data is not available to comment on the effectiveness of the programme. With the many challenges faced by cities in finding adequate




Harvesting
& Re-use
Living roofs
Filtration
Detention
Green Streets

and reliable sources of water for its water needs arising out of climate changes, population growth and industrial demand; rainwater harvesting holds a key part of the solution. As cities try to manage their resources in a smart/environmentally friendly way, rainwater harvesting is a smart way to manage the water demand. Cities have to adopt policies that make rainwater harvesting compulsory as part of the building by laws, water policy, and any redevelopment plans including development of public spaces, parks, parking spaces etc.



Living Roofs

Integrating vegetation and storage potential into new buildings and infrastructure acts as a first response in reducing local cloudburst runoff. With multifunctional potential, living roofs replace underutilised hard surface spaces in cities with rain soaking materials and vegetation that can reduce stormwater volumes and improve water quality.

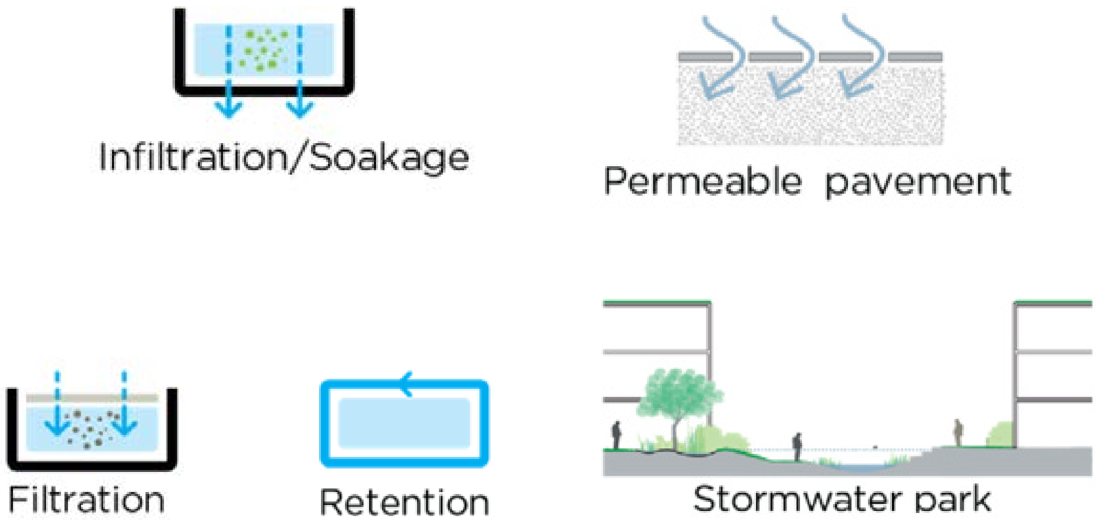
Green Streets

Green Streets are proposed as upstream connections to all cloudburst roads or retention areas. The green streets should be established with a combination of small-scale channels and stormwater planters or permeable paving. Stormwater should be collected, delayed, and then channeled toward the cloudburst roads.

Rain gardens

Can be used in a variety of settings from street medians to small yards — typically feature native shrubs, perennials, and grasses planted in a shallow basin. They are designed to trap and absorb rooftop, sidewalk, and street runoff. In addition to allowing rainfall to evapotranspiration or slowly filter into the ground, rain gardens help recharge underground aquifers, keep

Rain Garden by road side



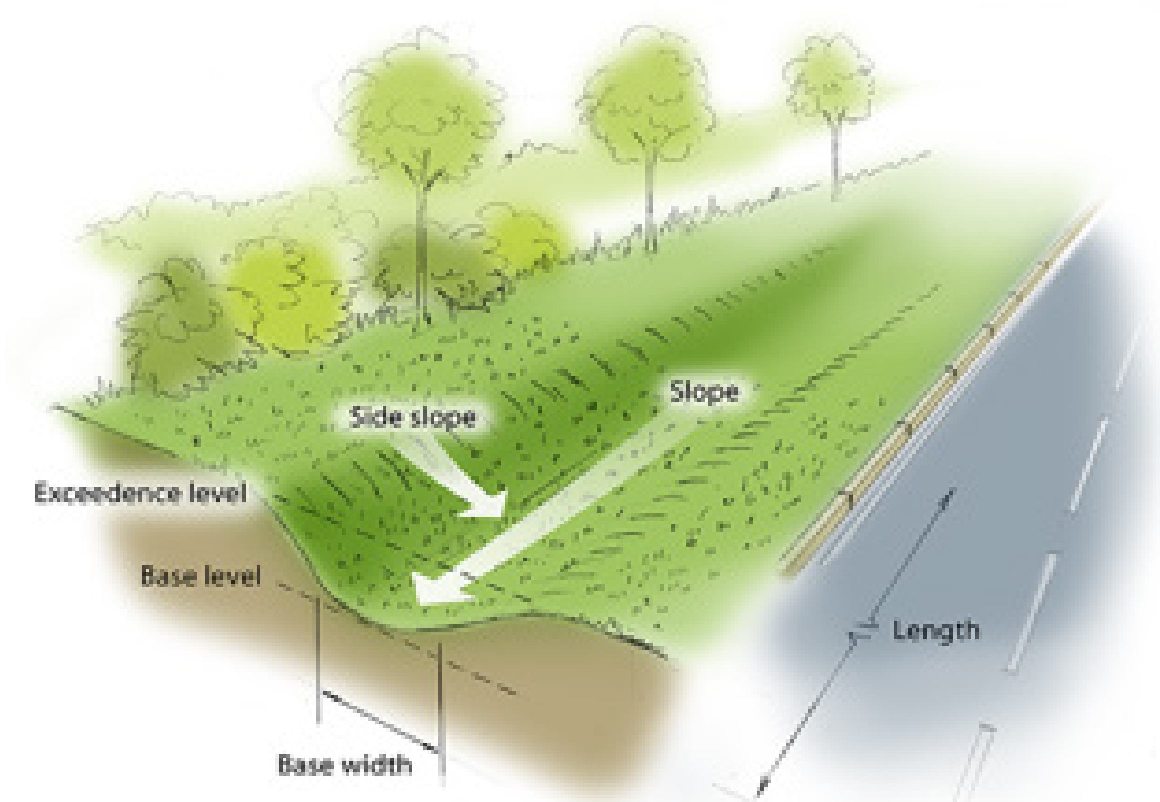
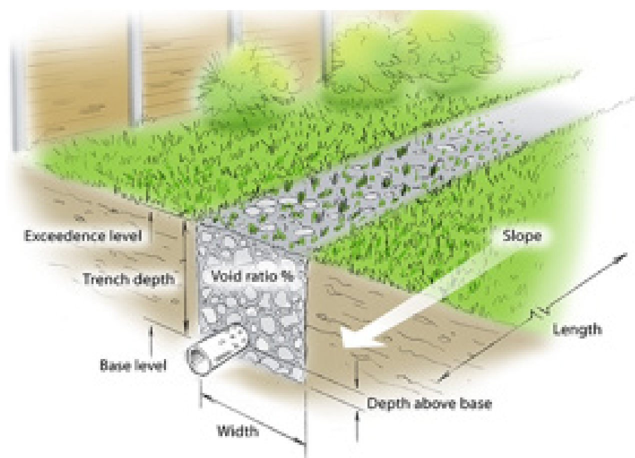


Illustration Source: https://help.innovyze.com/display/infodrainage2020v2/Swale stormwater from reaching waterways and can beautify a street or yard.

Planter boxes, a type of rain garden, are often used in the space between a sidewalk and street. They feature elevated sides and small openings that allow runoff to enter and be absorbed by vegetation and soil. The excess water entering these boxes can be captured into stormwater inlets and the conventional drainage networks. The vegetation in the planter boxes act as filters to trap the sediments carried by the run-off water, thereby preventing sedimentation in the drains. Removal of sediments also improves the water quality in the receiving water bodies as well as prevents clogged drainage points.

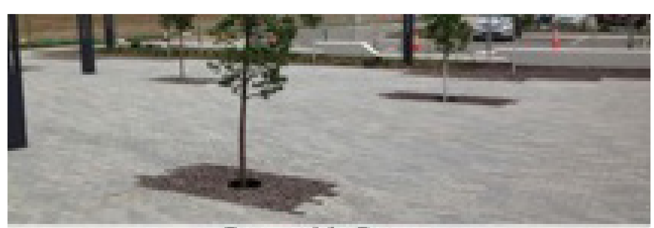
Infiltration trenches

Filter drains and trenches are linear excavations filled with stone that ideally collect surface water runoff laterally as sheet flow from impermeable surfaces. They filter surface water runoff as it passes through the stone allowing water to infiltrate into soil or flow. The purpose of infiltration trenches is mainly to enable infiltration and attenuation of storm water runoff peaks.



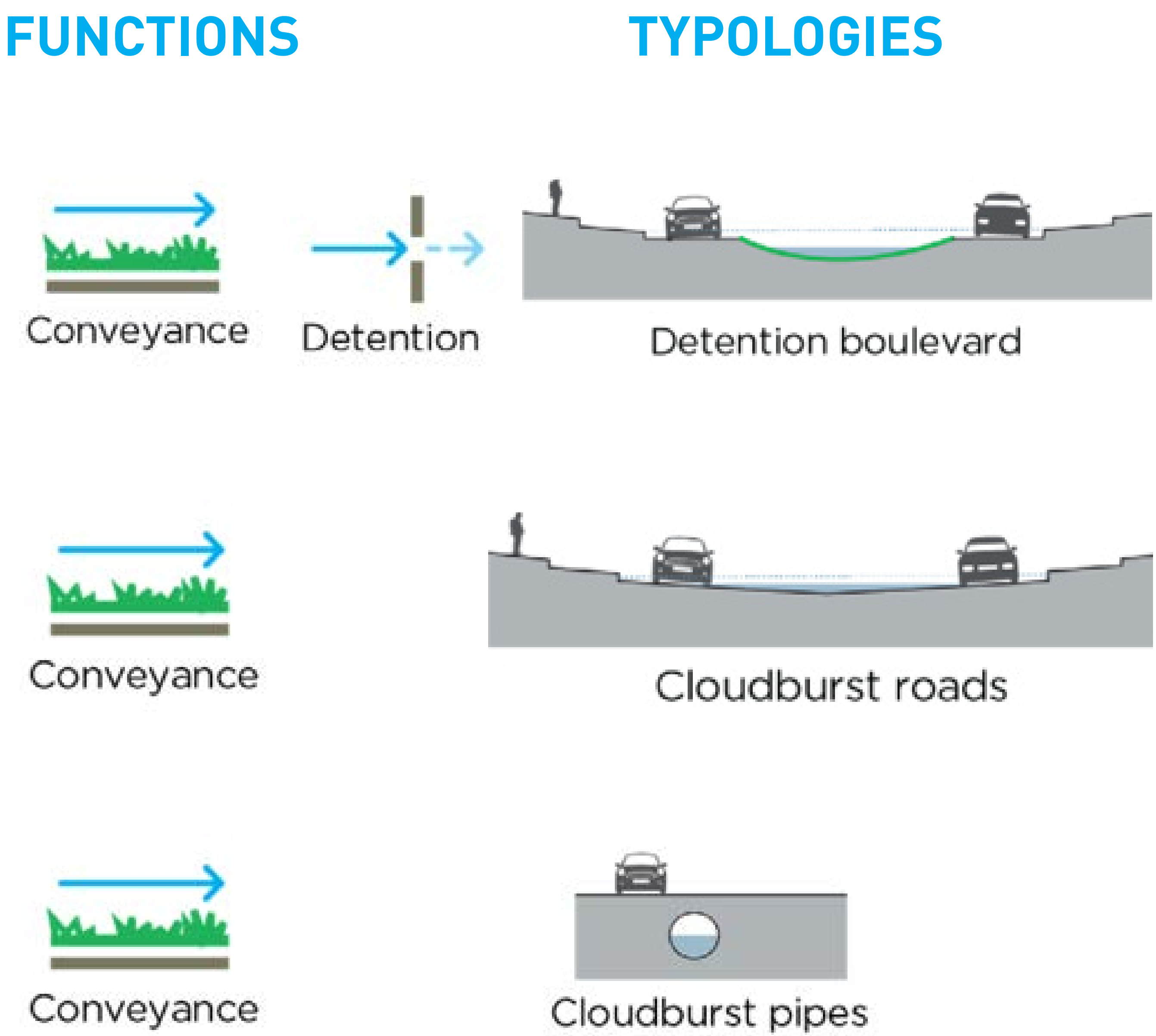
Permeable Pavement

Permeable pavement (also known as porous pavement) allows rainfall to percolate before it runs-off the road surface. It is made up of interlocking blocks or bricks laid in patterns with spaces for vegetation to grow. It also includes no-fines concrete or porous asphalt, permeable pavers, porous pavers, and stabilis ed loose material. The flow of stormwater from the surface to the collection system is slowed through infiltration and is temporarily stored and slowly released by the base course, resulting in detention of the flow peaks. Passive paving systems receive water only from the paved surface. Active paving systems receive additional runoff from external surfaces. Only active systems trigger stormwater management provisions; for this reason, pervious paving is considered as providing retention and detention, but not treatment. Various design configurations of



Permeable Pavers

Permeable Pavers


FUNCTIONS
TYPOLOGIES
Conveyance
Detention
Detention boulevard
Conveyance
Cloudburst roads
Conveyance
Cloudburst pipes

the permeable pavements are possible based on the location and scale of installations. For parking areas, these can be laid at the edges and on areas where the vehicular loading is least. When installed in drive-ways and sidewalks, it creates an aesthetic value addition in addition to functioning as rain water percolation. There are many possibilities of using these permeable pavements in the Panaji area.

Swales

Swales are linear vegetated channels with a flat base that encourage sheet flow of water through grass or other robust vegetation. They collect, convey and sometimes store surface water runoff, allowing water to soak into the ground where soil conditions are suitable.

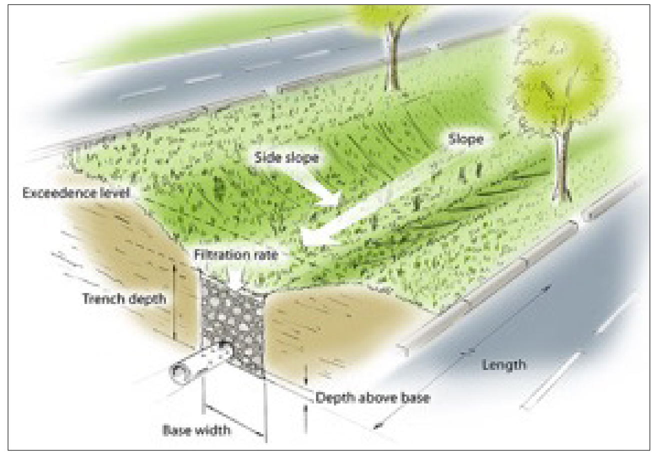
The objective of swales is conveyance of water allowing for infiltration into ground at the same time. These are ideal for residential neighbourhoods where space is available and it enhances the aesthetics of the neighbourhood.

Detention Boulevard

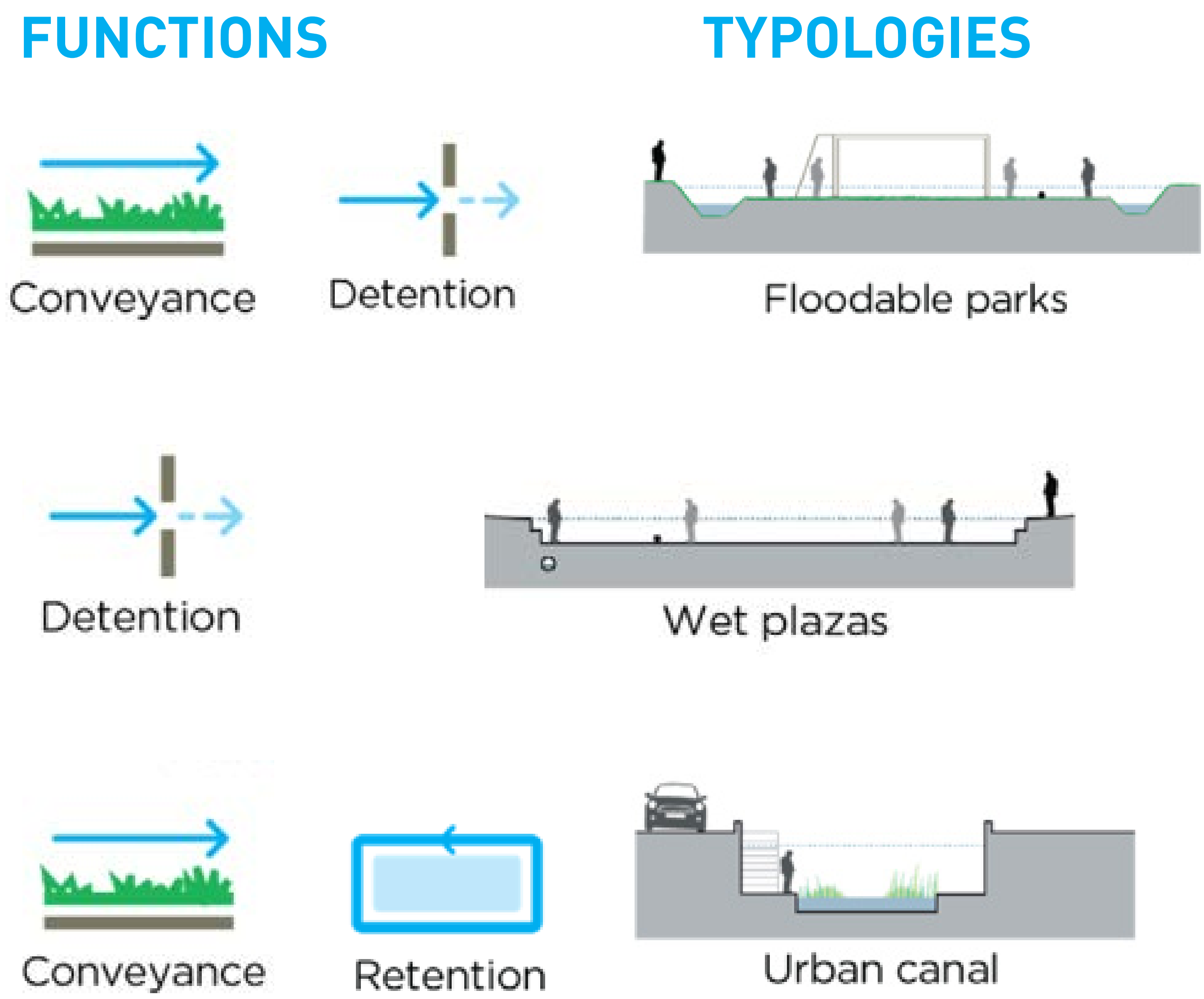
Detention boulevards are similar in scale to cloudburst roads, but incorporate large green, depressed medians that can detain and retain stormwater while allowing regular traffic use of the street. It requires taking away space from existing roads, but can be very effective along larger urban arteries that are underutilised.

Cloudburst Roads

Cloudburst roads are used to channel and direct cloudburst water. These streets can be formed with a V- shaped profile and raised curbs to ensure water will flow in the middle of the road, away from the buildings. In addition, channels and swales can be established at the side of the road so that the water runs in urban rivers or green strips.



Source:https://help.innovyze.com/display/infodrainage2020v2/Infiltration+Trench


FUNCTIONS
TYPOLOGIES
Conveyance
Detention
Floodable parks
Detention
Wet plazas
Conveyance
Retention
Urban canal

Cloudburst Pipes

A cloudburst pipe handles rainwater in the same way as cloudburst roads. This is placed just below street level to ensure connection to other surface solutions. This solution is used if there is limited space for above ground conveyance.

Floodable Parks

Floodable Parks and recreation spaces present the greatest opportunity for large retention spaces within urban areas. They can be located throughout the watershed and receive stormwater conveyance systems or adjacent water bodies. They can provide a combination of hydrological services including, water quality improvements via filtration, retention, detention and infiltration.

Wet Plazas

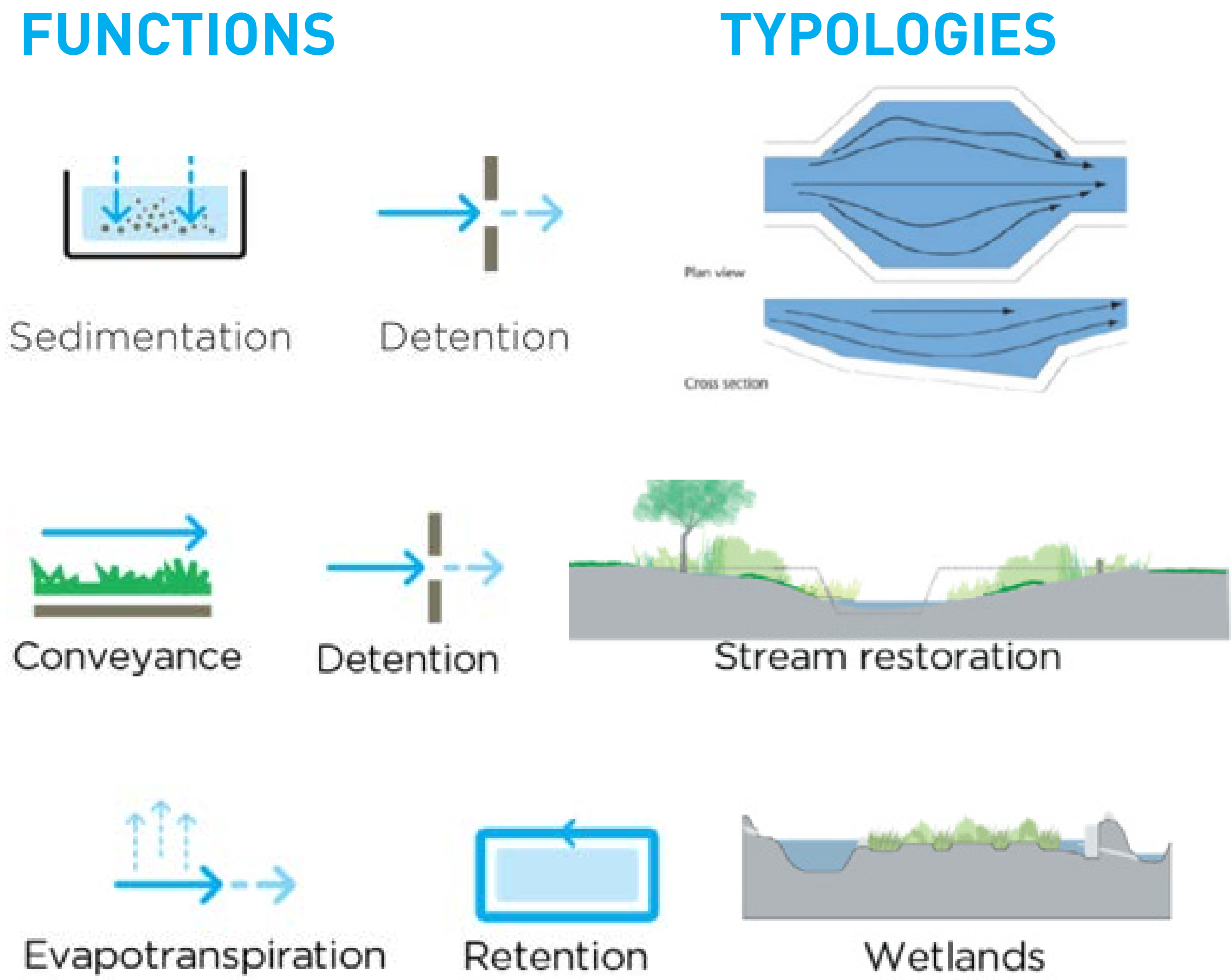
Wet plazas or floodable public spaces are another great opportunity for large retention capacity within dense urban environments. Typically hardscapes with some potential vegetation, these spaces collect, detain and retain stormwater to reduce flooding downstream. Additionally, they can incorporate drainage connections to allow the plaza, courtyard, etc. spaces to return to normal use quickly.

Urban Canal

Urban canals are larger infrastructure projects that typically involve daylighting of a stream or river within a dense urban area. They can be designed to create new and healthy oases in the city while increasing biodiversity and stormwater volume capacity.

Urban Creek

Urban creeks can involve daylighting historic streams, formalis ing existing streams, or creating new streams as conveyance connections between other cloudburst elements. Typically, smaller in scale, urban creeks can reestablish or create new neighbourhood character and social spaces.


FUNCTIONS
TYPOLOGIES
Sedimentation
Detention
Plan view
Cross section
Conveyance
Detention
Stream restoration
Evapotranspiration
Retention
Wetlands

Dredging and prevention of sedimentation

Prevention of sedimentation is crucial as part of the maintenance of a water body. Silt traps are a simple solution to prevent sedimentation to build up in a stream, but require maintenance. Dredging can be necessary in places where sediments are building up due to tidal variation in water bodies.

Stream Restoration

Stream restoration and re-profiling existing urban water edges can help build capacity for stormwater through retention and detention. Additionally, redesign of stream or riverfront parks to allow for seasonal and cloudburst flooding can reduce downstream flooding in unwanted areas.

Wetlands

Constructed stormwater wetlands are ponded areas, densely vegetated with water-loving plants that mimic the treatment processes of natural wetlands with detention, fine filtration and biological absorption, to remove contaminants from stormwater runoff.

Liveable shoreline concept

The concept of a living shoreline builds on natural elements, focuses on biodiversity, natural habitat, and integrates the shoreline into the context of the surrounding environment. A living shoreline is designed with a focus on recreational functions by introducing edges with soft gradients, multiple access points and longitudinal paths for biking, walking, etc. The living shoreline brings multiple social and environmental benefits beyond the direct protective functions. The livable shoreline, includes places for recreational functions and people to meet and interact with nature. Living shorelines have been introduced successfully in Nordic regions and Europe, examples: Køge Beach Park (Denmark), Scheveningen (Netherlands), Nijmegen (Netherlands), Wallasea Island (United Kingdom) and Karmen (Germany). These projects have proven effective in providing room for nature to evolve in and

Inefficient Inlets – Capacity constraints, poor hydraulics, improper positioning

Hydraulically Efficient Inlets –with Green Streetscapes

Kerb & Gutters for conveyance of street flows, Inlets placed to direct street flow to planters

Source: Manual on Storm water Drainage Systems (2019), around urban settlements and in providing increased resilience and liveability in the area, by increasing the protection level of and enhancing the quality of life for ecosystems and human well being.

Gutter

While the road pavement is designed with cross camber for easy flow of water to the sides, the pavement gutter is equally important to feature to route the flow along the edges. A pavement gutter is a section of pavement adjacent to the roadway which conveys water during a storm runoff event. It may include a portion or all of a travel lane. Gutter sections usually have a triangular shape with the kerb forming the near-vertical leg of the triangle. Conventional gutters may have a straight cross slope[1] or a composite cross slope where the gutter slope varies from the pavement cross slope. Gutter Flow calculations are necessary to establish the spread of water on the shoulder, parking lane, or pavement section. Many urban streets in Panaji don't have a defined pavement gutter section. This results in the runoff spreading onto the pavement.
The hydraulic design and other considerations are detailed out in the Manual on Storm water Drainage Systems (2019).

Inlets

Storm water inlets are devices used to collect runoff and discharge it to an underground storm drainage system. Inlets are suitably located on pavements, in gutter sections, paved medians, roadside and at locations of specific requirement. There are three main types of inlets that are suitable for urban areas as specified in the Manual on Storm water Drainage Systems (2019).

Grate inlets -
Grate inlets are horizontal openings covered with one or more suitable gratings through which the flow passes

Kerb inlets - Kerb inlets are vertical openings in the road kerb when they are equipped with the diagonal notches cast into the gutter along the kerb opening to form a series of ridges or deflectors.

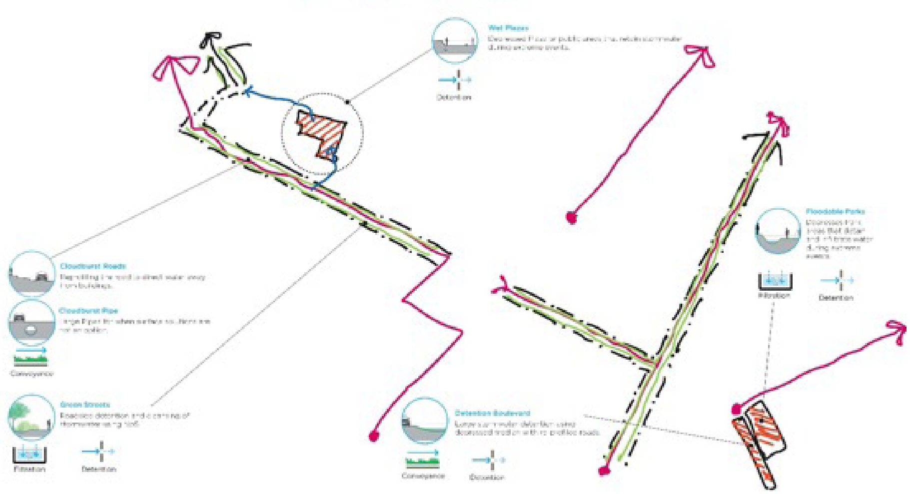
Inlet locations

The storm water inlets, both Catch pits and Catch Basins are essential components of a drainage system that accommodate the storm water from paved surfaces, including kerbs and channels, parks, open space areas and transfer it to subsurface drains for conveyance to the ultimate 'receiving body'. The inlets are connected to open drains by interconnection pipes. Inlets should be hydraulically designed and adequately placed to efficiently drain storm water runoff into the main drainage system.

3 Slope of gutter section from edge of pavement to the kerb-edge. This slope can be same as pavement (crown to edge of pavement) or have a different slope. Wider gutters are provided with a slope same as pavement for 1st section and a deeper depression at the kerb edge to carry more flows providing a composite sloped section.


ROAD
DR ATMARAM BORKAR ROAD


EXISTING PIPES
① CLOUDBURST STREET
② GREEN STREET
③ CLOUDBURST PIPE
DETENTION + RETENTION

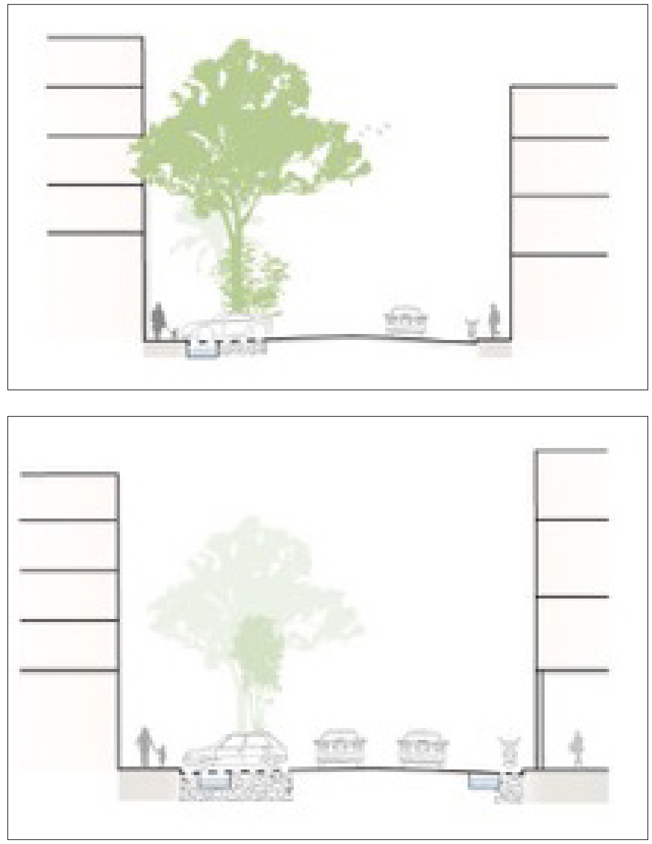

Wet Plazas
Detention
Floodable Parks
Filtration
Detention
Cloudburst Roads
Cloudburst Pipe
Conveyance
Green Streets
Filtration
Detention
Detention Boulevard
Conveyance
Detention

Mitigation measures for the 18th June Road

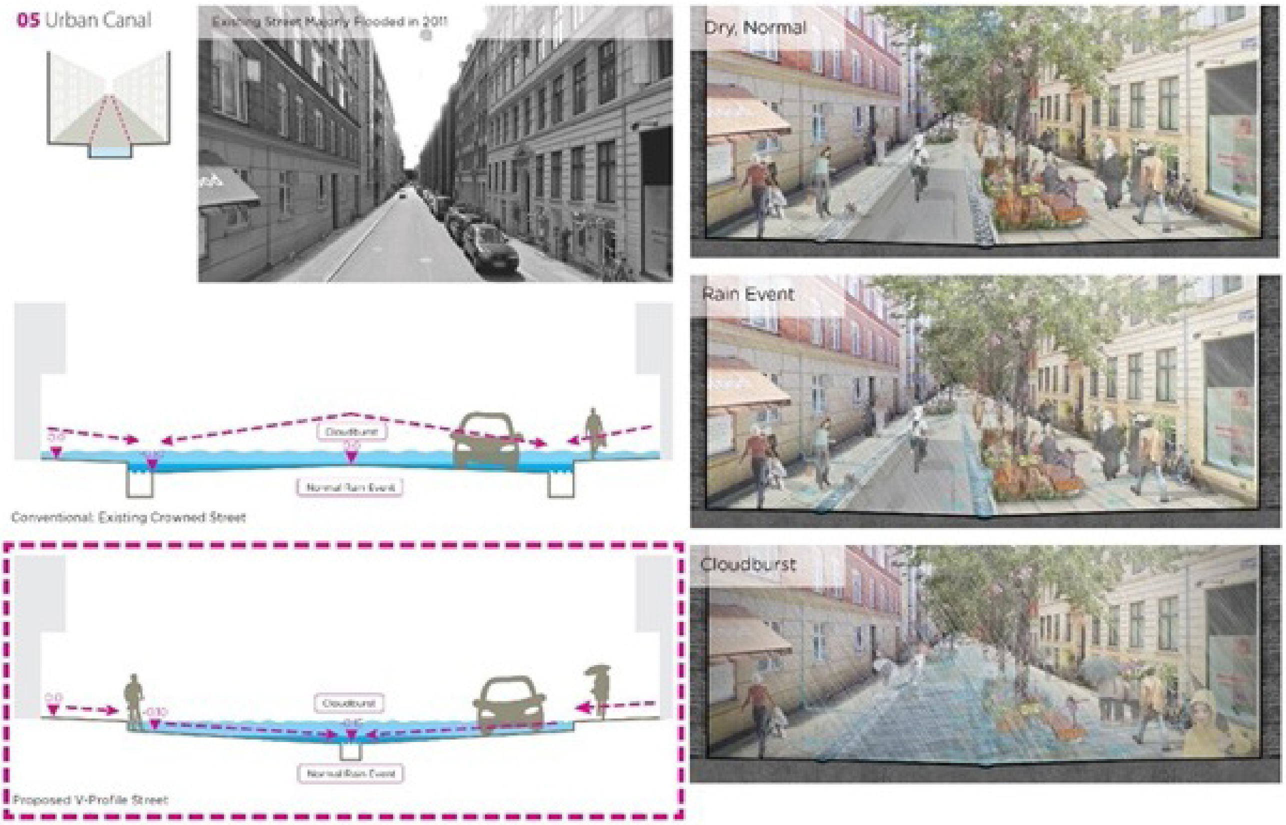
As a first step towards achieving the goal, baselining of the existing conditions, visualis ing of the scenarios though mathematical modelling is important. This helps in prioritising the BGI tools required to achieve maximum impact.

The commissioning of a hydraulic modelling and a storm water master plan has to be considered as the first step, few typical topologies are discussed which could be part of the solution set to mitigate the urban flooding issues. These interventions largely follow the principles of capture where the rain falls, reduce surface runoff, management of the runoff and provide efficient conveyance for the runoff. In an urban context, these can be achieved through a combination of passive interventions combining nature based solutions to improve urban aesthetics and through infrastructure investments which require large investments that may cause temporary inconvenience to the public. As seen in the Panaji context, the drains were built to carry surface runoff from a different land use pattern. Commensurate with land use changes, for example the increase in built-up areas, the drains have not been re-configured to carry the increase in surface runoff.

From the study of the DEM, elevations, catchments, flowlines and depressions, the 18th June Road between SV Road and Dr Pandurang Pissulkar Road forms a localis ed depression. Presently, this area is connected to the deep drain along Dr Pandurang Pissulkar Road drain discharge near the Ferry Point. As observed and based on observations of stormwater management personnel of CCP, the drainage of this area is influenced by the tidal levels in Mandovi River and often inundated when the tidal levels exceed 2.10 m.

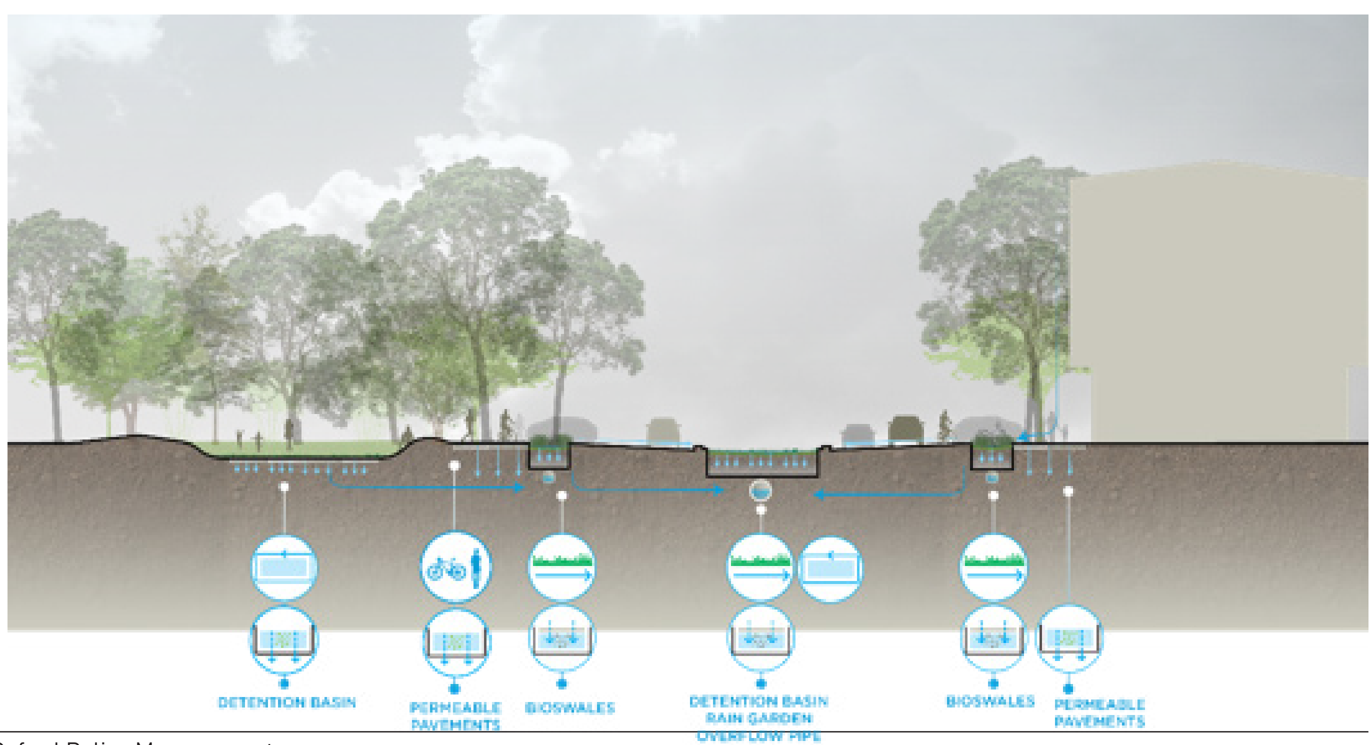


18th June Road Typical Section



Tool: Urbn Canal 'V-Profile'

A V-Shaped road profile challenges conventional traffic engineering, retrofitting Cloudburst Streets by 'flipping' street layouts. The radical change allows street widths to be reduced while increasing retention capacity to handle daily and extreme rain events.

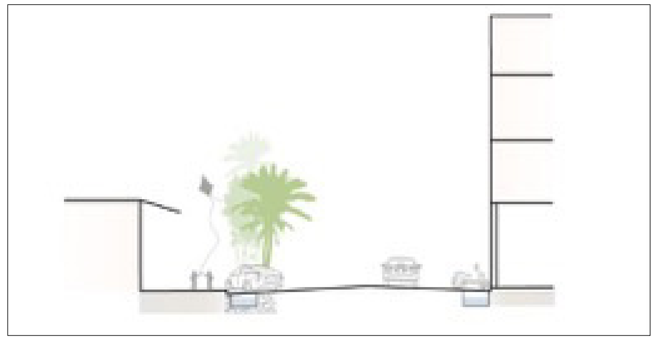


It would be difficult to construct a new drain for the 18th June Road, even as a short term mitigation measure. Instead, to address flooding issues, the carrying capacity of kerb drains can be improved by re-lining the drains, removing utility hindrances and putting in place a robust O&M plan to address the siltation and debris removal.

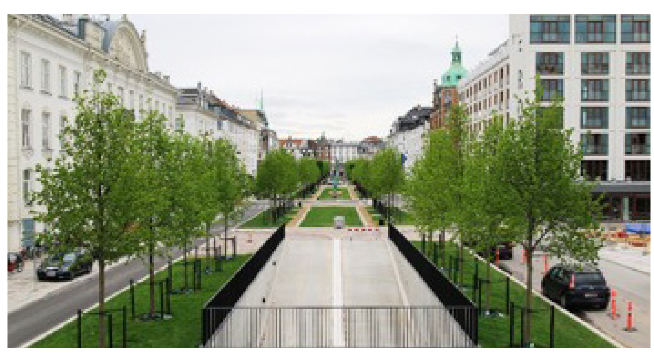
The capacity of the drains also can be improved by connecting the surface drain to the deep drains that cross the 18th June Road at Swami Vivekanand Road and Dr Pandurang Pissurlekar Road. The connection to these drains should also be equipped with flap valves or other devices which can be operated to prevent reverse flow during adverse events combined with high tide situations in the Mandovi River.

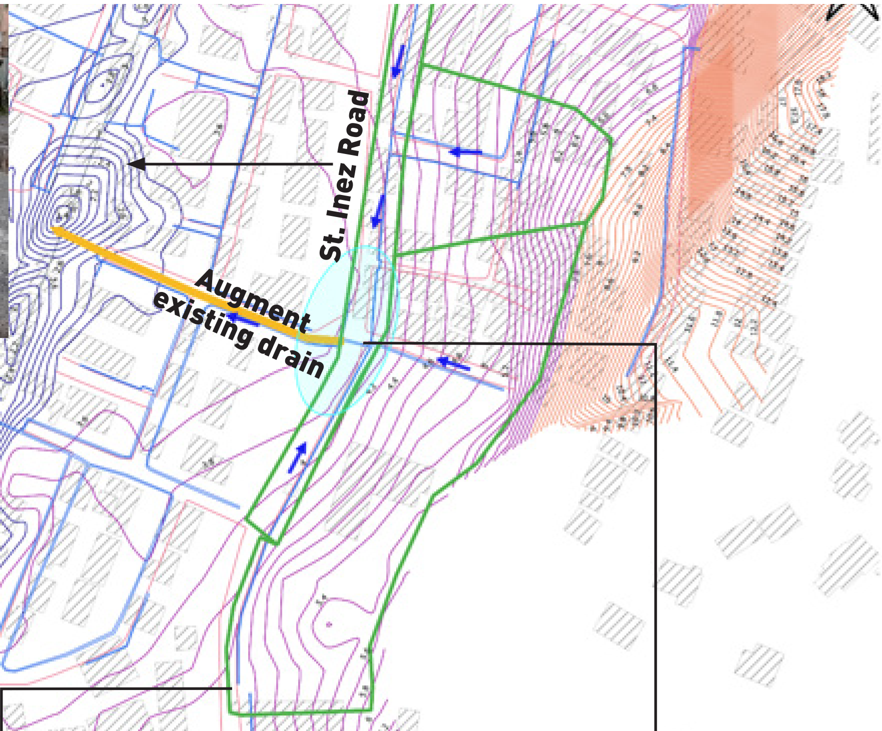
Yet another short-term measure would be to enable surface run-off to flow along the road along Swami Vivekanand Road towards Mandovi River. With some profile correction on SV Road near the Geetha Bakery junction, the road profile slopes towards the military point at Mandovi River. Allowance of 0.2 - 0.3 m of surface flow along the road would evacuate the water from the 18th June Road. Diversion of the surface runoff towards the Kranti Garden (MG Road) is another option. This garden being a public place can be developed as a temporary detention basin to hold the surface runoff during high tide events to minimise impact to the city citizens.

An other passive method of removing flood waters is to pump it out. However, construction of a storm water pumping station needs adequate public space, as well as it takes time to install and commission the necessary infrastructure, including the drains to pump out the water. The site selection and capacity of the storm water pump station has to be technically evaluated based on hydraulic modelling, to determine the level of protection required.
However, as a short-term measure, having portable diesel-powered pumps could be used to remove inundated water from these areas. The CCP could have diesel powered pump sets ready as standby equipment for mitigation of localised flooding issues.
It is understood that 18th June Road is a candidate for interventions to make it pedestrian friendly. This gives an excellent opportunity to implement the above toolkits under such

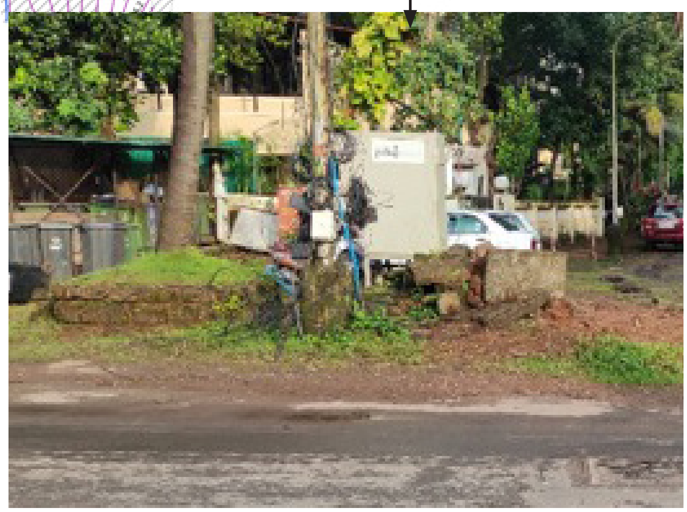


Church Square Boulevard






St. Inez Road – Existing Road Edges


St. Inez Road-Nr. RBI Quarters–Road Island neglected


St. Inez Road -Opportunity for Streetscaping


St. Inez Road -Opportunity for Raingarden

How to mitigate flooding along St Inez Road

The redevelopment of St Inez Road as a smart road is under planning by GSUDA. This proposed development gives the opportunity to implement the toolkits along the stretch of this road.

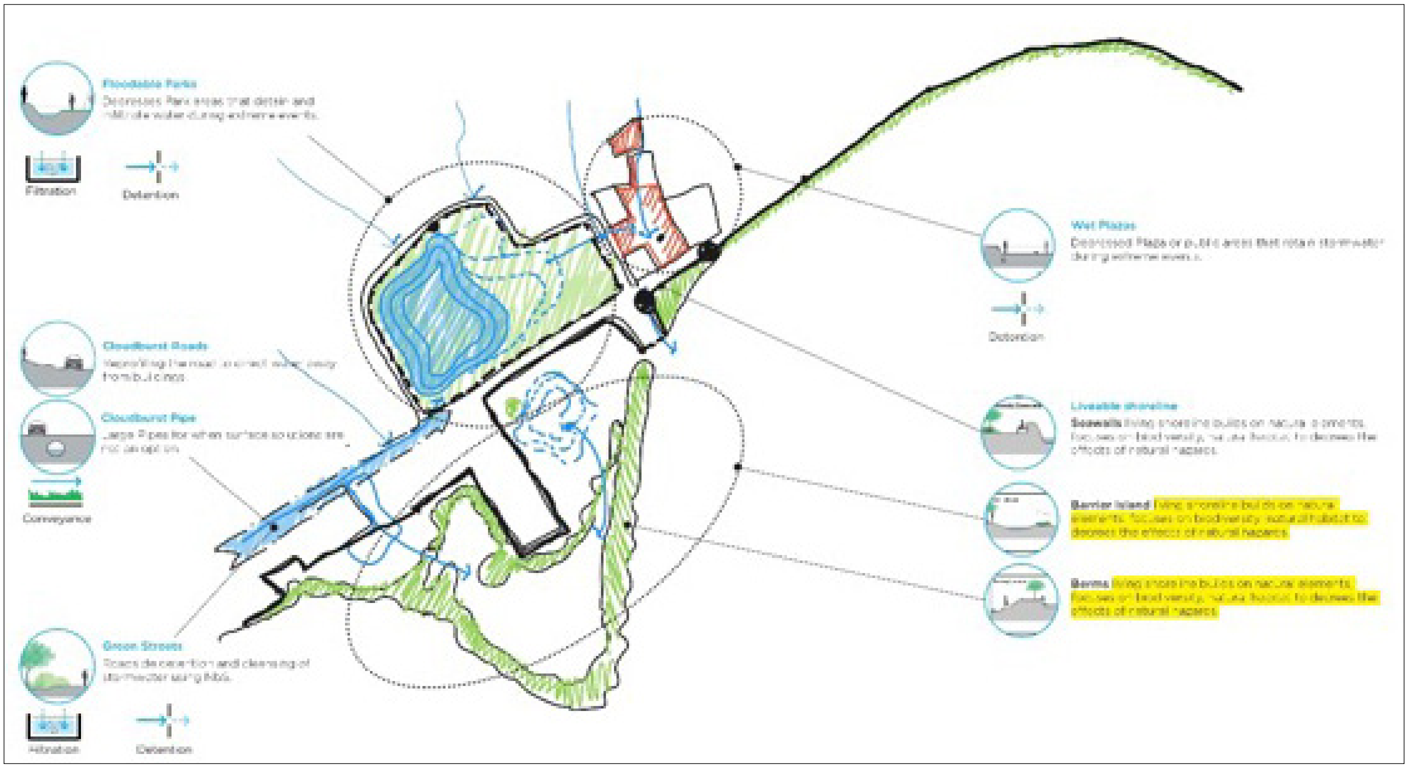
For example, a specific short term intervention for the St Inez Road would be to build a parallel relief drain from the junction near St Inez Church to St Inez Creek for evacuation of the water that inundates at this location during heavy rainfalls.

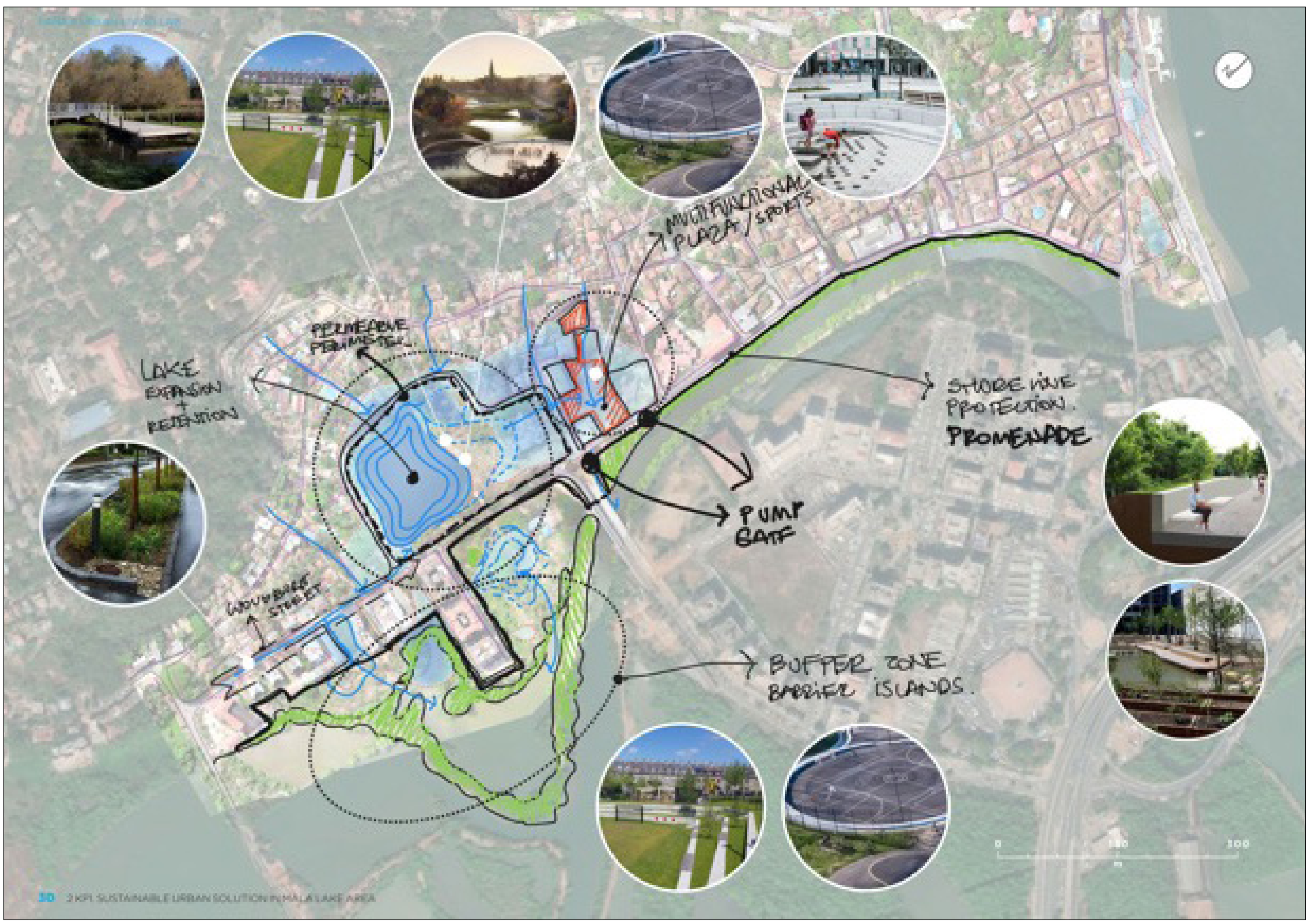
Green Streets

The green streets should be established with a combination of small-scale channels and stormwater planters or permeable paving. Stormwater should be collected, delayed and then channeled toward the cloudburst roads.
1) New drains to convey flows to St Inez Creek. Existing drain needs rehabilitation and capacity augmentation to convey the flow accumulating at the junction near St Inez Church.
2) Create green streets and rain gardens to slow down the runoff

Planning is underway by Goa State Urban Development Authority to improve the St Inez Road from Vivanta Junction to Adarsh Colony Junction as a Smart Road under India's national Smart City Mission. The streetscaping and rain garden toolkits can be included into the design as part of the improvements to have multiple functions and co-benefits of street improvements, urban flood management and improve the livability of the neighborhood.

Typologies for Mala Lake Area Flood Mitigation





How to mitigate flooding in Mala Areas

To limit damages from flooding, the naturally low-lying areas may be utilised to temporarily store stormwater during times when gravitational drainage is restricted due to high water levels in the recipient river. Such a system may be design using a combination of Nature Based Solutions (NBS), multifunctional spaces and traditional drainage infrastructure to ensure optimal utilisation of the land and provide co-benefits in the form of recreational space and improved microclimate conditions in the face of increasing frequency and intensity of heat waves.

Floodable Parks

Floodable Parks and recreation spaces present the greatest opportunity for large retention spaces within urban areas. They can be located throughout the watershed and receive stormwater conveyance systems or adjacent water bodies. They can provide a combination of hydrological services including, water quality improvements via filtration, retention, detention and infiltration.

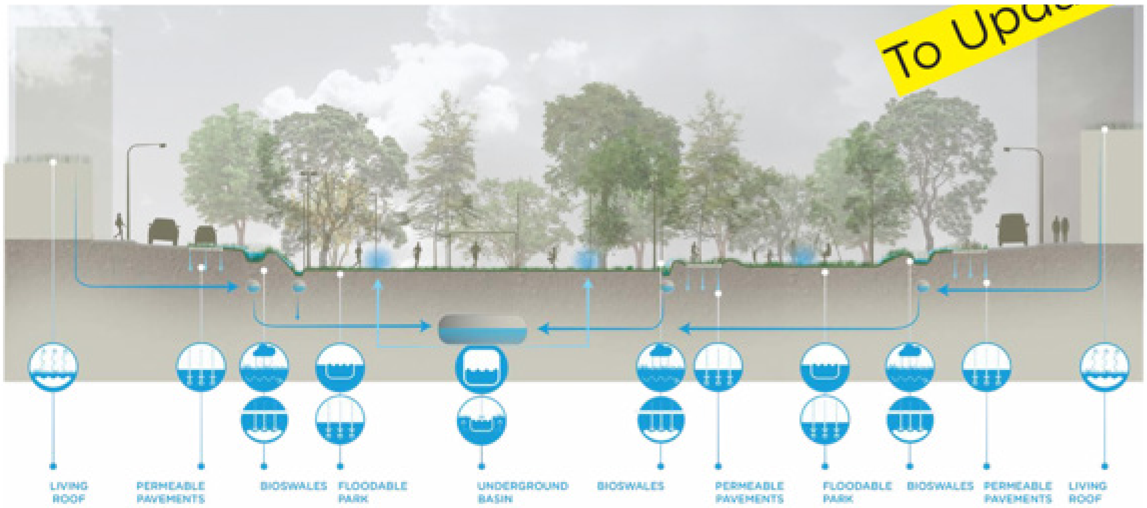
The Mala area is completely developed with few public places which can be redeveloped to accommodate such a park. There are institutional spaces, which institutions such as the Institute of Public Assistance, which has a large compound, have the potential to be redeveloped as a multi-functional and floodable park.

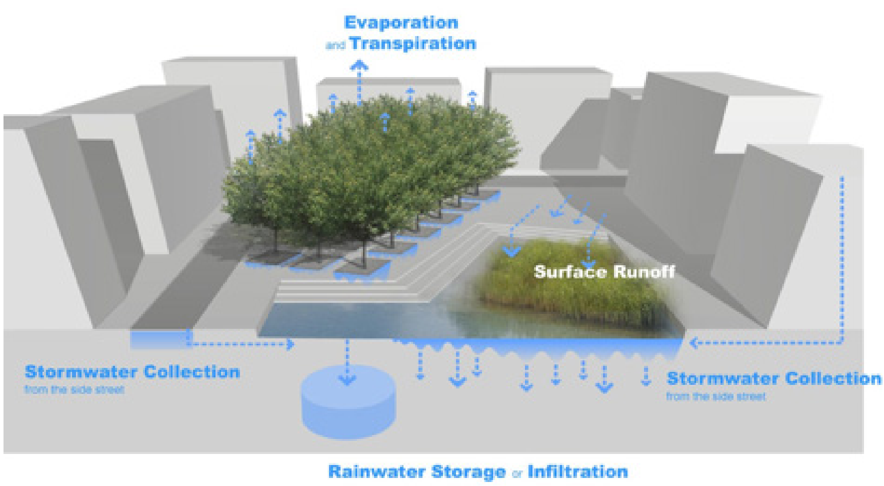
Wet Plazas

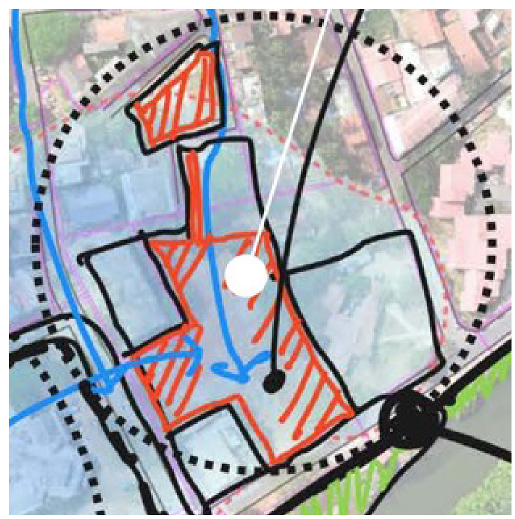
Wet plazas or floodable public spaces are another great opportunity for large retention capacity within dense urban environments. Typically hardscapes with some potential vegetation, these spaces collect, detain and retain stormwater to reduce flooding downstream. Additionally, they can incorporate drainage connections to allow the plaza, courtyard, etc. spaces to return to normal use quickly.

The area around Mala Lake is suitable for development of wet plazas. There exists the market building which is currently not used. The Water Resources Department is implementing Flood Mitigation Measures and Construction of Flood Water Pumping Station at Mala, Panaji under the Smart City Mission. The proposed pump station is planned at the land area belonging to Greater Panaji Development Authority adjacent to the Mala Lake. Along with this development, the remaining area surrounding Mala Lake can be improved as planning wet plazas to increase public access, act as detention area for flood waters and improve the liveability of the residential neighbourhoods of Mala and Fontainhas.

Typical Rendering of Floodable Park







Green Streets

Green Streets are proposed as upstream connections to all cloudburst roads or retention areas. The green streets should be established with a combination of small-scale channels and stormwater planters or permeable paving. Stormwater should be collected, delayed and then channelled toward cloudburst roads.

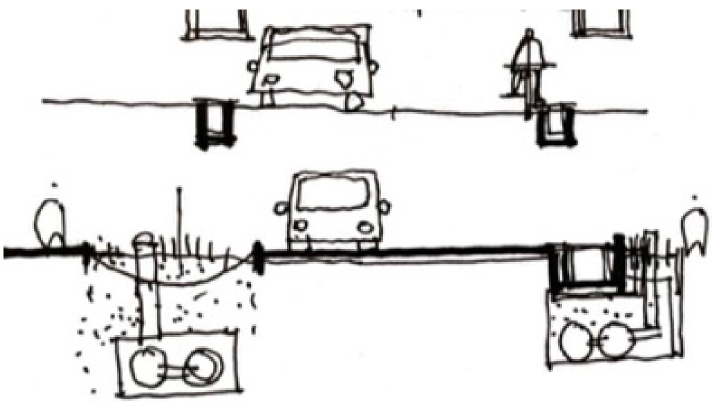
Cloudburst Roads

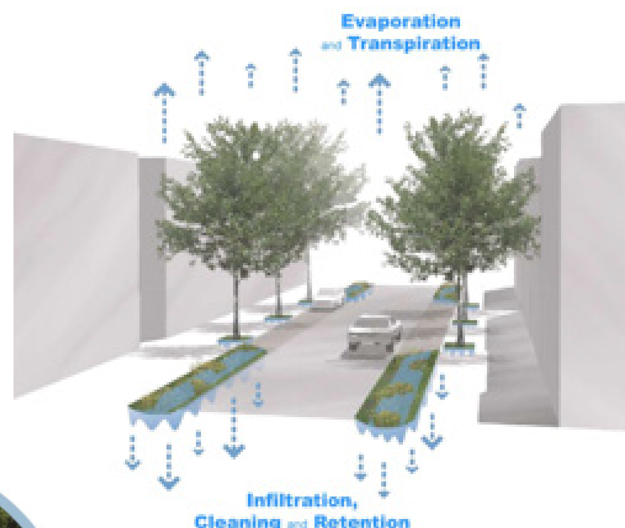
Cloudburst roads are used to channel and direct cloudburst water. These streets can be formed with a V-shaped profile and raised curbs to ensure water will flow in the middle of the road, away from the buildings. In addition, channels and swales can be established at the side of the road so that the water runs in urban rivers or green strips.

Cloudburst Pipes

A cloudburst pipe handles rainwater in the same way as cloudburst roads. This is placed just below street level to ensure connection to other surface solutions. This solution is used if there is limited space for above ground conveyance

Planning is underway by Goa State Urban Development Authority to improve the Rua de Ourem Road from Four Pillars Junction until Old Patto Bridge as a Smart Road under Smart City Mission. The NBS concepts streetscaping and rain garden toolkits can be included into the design of Smart Street plans, as part of the improvements to have multiple functions and co-benefits of street improvements, urban flood management and improve the livability of the neighbourhood.





Bioswales

Identification of Street Stretch / area under re-development	Existing Situation Analysis	Concept Plan (Proposed section, basic line drawing)	Procurement	Construction & Supervision	Maintenance
NbS / Toolkit Development stages	Topo Survey, study drainage system, flooding issues, influence of neighboring catchments, road hierarchy, adjacent landuse, stakeholders, etc.	Planning and design of NbS elements based on drainage, road hierarchy, climate, other basin influence. Location on road, functional spaces etc.	Implementing Agency to Prepare & get approval of Bill of Quantities, estimates etc. Maintenance Budget, manpower etc. Procurement of agency to build	Construction of NbS elements, along with other improvements. Plantation on ground, irrigation, etc.	Budget for Maintenance. Single agency for uniform maintenance Irrigation, control of growth, pruning, weeding, manuring, replacing & replanting, cleaning of drains etc.

Stormwater Management Planning

Strategies for stormwater management have expanded in recent years, with an emphasised focus on capturing rainwater where it falls rather than moving it away as quickly as possible. Now is time to let go of the out of sight, out of mind mentality of yesteryears and move forward with rethinking stormwater as a valuable resource rather than a waste product. In this context the infrastructure for stormwater management has to be viewed through a fresh lens in order to optimise infrastructure spending, evaluate benefits to the community and be sustainable to the environment.

The key steps in planning for implementation of these sustainable infrastructure elements are:
1. Understand the Site: Every site requires a unique set of interventions and toolkits. The overview of the site and identification of issues are key outputs from this step.

2. Define objectives: The management and development of interventions should seek to achieve a range of outcomes relating to water quality, hydrology, conservation, biodiversity and amenity. Each of these outcomes can be met by ensuring development complies with the appropriate objectives and targets identified for the site.

3. Identify Suitable Measure: This is the concept plan development stage where the best interventions from the toolkits are selected based on site, objectives and are evaluated for site suitability
4. Stakeholder consultation: The buy-in from the stakeholders and community is sought so as to have participatory decision making, create a sense of ownership and to achieve success during the implementation.

5. Model Study: Prior to implementation of proposed interventions, mathematical modelling provides a relatively fast and easy method to evaluate the outcomes of the intervention. Creating a base case of the existing site (i.e. pre-development) and that of systems proposed for the development are carried out in this stage. Visualisation tools provide the additional benefit to have rendering of the outcomes and tuning of the designs to best fit the site.

6. Finalise measures: Once the concepts are developed, model studies carried out and stakeholder inputs are obtained, the designs can be finalised and the interventions can be implemented. The institutional framework for implementation and monitoring of the outcomes are other decision points to be taken in this stage.

7. Maintenance: Maintenance of interventions is a very critical component for the success of sustainable management. Often the maintenance of stormwater infrastructure does not get its due weightage in urban planning or budgets. This oversight must be corrected and an active maintenance programme has to be in place with adequate resources allocated for it.

Management & Maintenance of Stormwater Systems

During discussions with City Corporation of Panaji officers, it is understood that CCP is primarily responsible for the maintenance of the stormwater drains in the City. CCP also manages the solid waste collection and disposal in Panaji. The waterways are maintained by the Water Resources Department, which also operates and maintains the flood water controls, stormwater pump station etc.

The CCP has a programme to desilt the drains pre-monsoon and during the monsoon periods, which is outsourced on a contract due to resource constraints. However, there are constraints and shortfalls in the implementation of this seasonal maintenance programme. During site visit, it was observed that in many places the drains are filled with silt and other solid waste, including plastic waste, thus reducing the effectiveness of the drains. A comprehensive maintenance programme to remove the silt and other solid wastes from getting into the drains is required to be put in place. Regular sweeping of the streets, removal of road side silt and fine particles using vacuum sweeping, improving awareness of the public and business communities to properly dispose off their waste are also necessary steps towards achieving a cleaner drainage system.

Along with cleaning of the drains, it is important that the inside surface of the drains are repaired and maintained in a hydraulically smooth manner. This improves the carrying capacity of the drains and helps in easier evacuation of water. This must include removing and replacing any utility pipes that are hindrance to the flow of water in the drain or can cause clogging by way of capturing floating debris.

The Water Resources Department does not currently have any routine maintenance programme for the creeks and waterways within the City.

With the introduction of Nature based Solution, the interventions will require a proactive maintenance routine to keep them functional and to maintain the aesthetics. The streetscapes and plants require the most care during the initial years in order to get established, and thus will require regular care, weeding, replacement, watering and periodic pruning to check the growth. Once the vegetation is established, the maintenance activities are routine and will be less frequent. Based on the toolkit and the extent of adoption of the NbS in the City, the maintenance programme and resource requirements have to be adequately provisioned for in the City budgets.

Summary and Way forward

In the previous subsections of the Flood Mitigation Plan Section, application of Nature Bbased Solutions and Blue Green Infrastructure has been presented as the main approach to be used, when developing the Flood Mitigation Plan and outlining Stormwater Management Planning. Specific measures to be applied have been outlined for the three most vulnerable areas including the 18th June Road, St Inez Road and the Mala Area.

There is no single solution and no 'quick fix' to all the flooding problems and challenges faced by the city Panaji. Some solutions could be applied to several different locations across Panaji while some locations will need more than just one solution. As well, in some cases, NBS and BGI measures and tools should be combined with and supported by traditional grey infrastructure solutions.

Some solutions are relevant for the short-term in order to start mitigating the flooding right away and would later need to be supplemented and/or replaced by more comprehensive solutions in a longer-term perspective. Therefore, short, medium and long term solutions should all be considered, be interconnected and can be combined, depending on assessments of the extent to which the previous solutions actually solved the problem, budget and time scale.

A summary of the proposed Flood Mitigation Plan with an overview of recommended solutions for specific locations in the most vulnerable areas in Panaji is presented below. The listed solutions are shown in a timing order with short-term solutions first, then medium-term and lastly long-term.

Broadly indicated, short-term solutions are to be understood as interventions, which can be accomplished in the first 1-2 years. Medium-term solutions are more comprehensive interventions, which may be accomplished within the following 2-4 years, while long-term solutions may require even more time to accomplish and should not be implemented until the effect of all short- and medium-term solutions have been observed and evaluated.

Overview of recommended soluti		
Sl. no.	Location	Identified problem
Short-term		
1	Major stretches of 18th June Road, particularly between: (a) Swami Vivekanand Road to Dr. Pandurang Pissurlekar Road (b) Along Dr. Pandurang Pissurlekar Road	Existing drains have not been re-configured to carry the increase in surface runoff water
2	The crosses of 18th June road at Swami Vivekanand Road and Dr. Pandurang Pissurlekar Road.	Surface runoff and storm water creates flooding, particularly during the monsoons and/or high tide in the Mandovi river.
3	The Swami Vivekanand Road from near the Geetha Bakery junction to the military point at Mandovi River	Surface run-off water at this stretch of Swami Vivekanand Road limits the capacity to evacuate water from the 18th June road.
4	Church Square (Praca de Igreja street) to the designated parking area near Garcia de Orta Garden.	Limited capacity of diverting surface run-off water.
5	Various locations among the above-mentioned areas of the 18th June Road	Accumulated flooding water in the above areas of the 18th June Road
6	Rua de Ourem Street from old highway to flood pump station	Accumulation of flood water along Rua de Ourem street
7	Rua de Ourem from new patto bridge to old patto bridge	Management of run-off from drains connecting from Mala and Fontainhas areas
8	Ria de Ourem creek between New Patto bridge to old highway junction	Ingress of high flood water during high tide to the Rua de Ourem street and causing flooding
9	Mala Lake surroundings	Flooding of the area around Mala lake due to ingress of flood water and limited capacity to drain out during tidal influence periods
10	Pan city Storm Water Management	To develop scientific method of managing storm water from run-off, infiltrate, store and discharge

ons for specific locations in Panaji

Recommended solution
The carrying capacity of kerb drains can be improved by re-lining the drains, removing utility hindrances and putting in place a robust O&M plan to address siltation and debris removal. The O&M plan will need to be adhered to continuously, and works be undertaken regularly at defined time-intervals.
Connecting the surface drain to the deep drains in this location. The connection to these drains should also be equipped with flap valves or other devices, which can be operated to prevent reverse flow during adverse events combined with high tide situation in the Mandovi river.
Enabling surface run-off to flow along the road by the side of Swami Vivekanand Road towards Mandovi River by correction of road profile slopes.
Diversion of the surface runoff towards the Parking area, developing this garden as a temporary detention basin to hold the surface runoff during high tide events to minimize impact to the citizens. Overflow to be drained into the drain along Cunha Rivera Road towards Fisheries Jetty
As an acute short-term measure, having portable diesel-powered pumps could be used to remove inundated water. The CCP could have couple of diesel-powered pump sets as standby equipment for mitigation of localized flooding issues
Enabling surface run-off by re-profiling of the street to increase carrying capacity along and sheet flow on the street during heavy flows. Addition of stormwater pipe along the central trough for increased carrying capacity
The carrying capacity of kerb drains can be improved by re-lining the drains, removing utility hindrances and putting in place a robust O&M plan to address siltation and debris removal. Green streets along the Rua de Ourem to enable infiltration and urban scaping of the promenade.
Improve operation, maintenance and monitoring of the khazan gates.
Improvement of drains leading to Mala lake from upstream residential neighbourhoods. Flood water pump station to augment capacity of flood water discharge
Initiate modeling studies and storm water master plan to integrate blue-green solutions along with conventional infrastructure to manage storm water

Overview of recommended soluti

Sl. no.	Location	Identified problem
Medium-term		
1	Various locations among the above-mentioned areas of the 18th June Road	Accumulated flooding water in the above areas of the 18th June Road
2	Inundation of 18th June Road near Gujarat Lodge (Swami Viveka-nand Road junction)	Accumulation of flood water due to local depression in to-pography
3	Mala Lake surroundings	Flooding of the area around Mala lake due to ingress of flood water and limited capacity to drain out during tidal influence periods
4	Along St Inez Road	Frequent flooding due to storm water, particularly during the monsoons.
Long-term		
1	Ria de Ourem creek between New Patto bridge to old highway junction	Ingress of high flood water during high tide to the Rua de Ourem street and causing flooding
2	Mala Lake surroundings	Flooding of the area around Mala lake due to ingress of flood water and limited capacity to drain out during tidal influence periods
3	Storm Water Management – Pan city	Reduce run-off from impervious surfaces and increase infil-tration where rain falls

ons for specific locations in Panaji

Recommended solution
A medium-term solution for removing flood waters by pumping it out, replacing the use of diesel-powered pump sets, could be construction of stormwater pumping stations. However, stormwater pumping stations need adequate public space as well as it takes time to install and commission the necessary infrastructure, including the drains to pump out the water. The site selection and capacity of the storm water pump station has to be technically evaluated based on hydraulic modelling, level of protection required and so on.
Re-define the drainage of this area to drain towards St. Inez creek though cloud burst pipes and re-profiling of 18th June road to be a cloud burst street with depressed crown on the street. Connecting to the deep drain to drain connecting from Boca de Vacca near Goa Sahakar Bandar. This allows for drainage of this area irrespective of tidal influence on Mandovi River.
Floodable park adjacent to Mala lake – near the old market building, along with development of new pump house by WRD.
As BGI measure, green streets should be established with a combination of small-scale channels and stormwater planters or permeable paving. Stormwater should be collected, delayed, and then channelled toward the cloudburst roads.
Reinforcement of the tidal bund with berms, barrier islands and seawalls. Improve operation, maintenance and monitoring of the khazan gates.
Expansion of Mala Lake perimeter and capacity for increased retention Re-development institutional spaces as multi-functional plaza/sports facility. Eg. Open area Institute of Public Assistance is a potential candidate for re-development to improve access to public.
Widespread adoption of nature based solutions, green streets, swales, pervious pavements etc., across the city.

Way forward

This Plan has formulated strategies for the management of stormwater for Panaji in a sustainable manner. It is for the stakeholders of the City to action these strategies into various projects in order to achieve the goals and vision set out.
The change management from the mindset of using traditional infrastructure solutions to mitigate urban flooding to use of Nature Based Solutions and Blue Green Infrastructure elements can be possible only when all the stakeholders are aligned. The interdepartmental committee formed can spearhead this transition to onboard all the stakeholders.

Panaji as an urban city lacks a robust stormwater master plan. The drainage system of Panaji has to be upgraded through rehabilitation and augmentation commensurate with the urban growth and climatic changes. IPSCDL as the nodal agency should initiate a stormwater master plan exercise involving all the stakeholders. The planning should be carried by consultants with knowledge of global best practices in sustainable stormwater management practices.
While the planning for stormwater management evolves, there exists ample opportunities to implement pilot scale and medium scale Nature Based Solutions in ongoing Smart City Mission Projects. Though some efforts of planning have already been completed in some of the projects, the time is right to make incremental changes and accommodate as many of the BGI toolkits into these projects.

The guideline document – Manual on Stormwater Drainage Systems, 2019 – prepared by Central Public Health Environmental Engineering Organisation under Ministry of Housing and Urban Development, Government of India, provides adequate details on many of the sustainable toolkits discussed in this plan. Further, Indian Road Congress has brought out a Special Publication series 119-2018 titled Manual of Planting and Landscaping of Urban Roads. These two documents provide adequate guidance for design and inclusion of the sustainable BGI toolkits into the present design of Smart Roads in Panaji.

The NbS is a decentralised tool in sustainable development. The impact of NbS can be measured only when wide-spread implemented and cannot be measured by isolated installations. Most of the BGI tools can be co-implemented with other projects, while some of them are projects by themselves. The interdepartmental committee set up for rejuvenation of urban creek and other projects in Panaji should deliberate on the policy framework for adoption of NbS and recommend to the Government to issue specific orders to mandate the use of NbS wherever they are applicable in urban projects in Panaji and in the larger extent of Goa.

Bibliography

1. A.K.Gosain, P.K.Khandelwal and S.Kulshrestha. 2009. "Urban Floods: Case Study of Delhi." Disaster & Development, April: 15-45.
2. Chakrabarti, Anil K.Gupta and P.G.Dhar. 2009. "Urban Floods and Case Studies Project: An Overview." Disaster & Development Vol. 3 No. 1 April 2009, 1-14, April: 1-14.
3. Correia, F.N., Da graça saraiva, M., Da Silva, F.N. et al. 1999. "Floodplain Management in Urban Developing Areas. Part I. Urban Growth Scenarios and Land-Use Controls." Water Resources Management 13 1-21. doi:https://doi.org/10.1023/A:1008097403587.
4. CPHEEO. 2019. Manual on Stormwater Drainage Systems Volume-1, Part A: Engineering Design, First Edition. Ministry of Housing and Urban Affairs, Govt. of India, Central Public Health Environmental Engineering Organisation. http://cpheeo.gov.in.
5. CRISIL Risk and Infrastructure Solutions Limited. 2015. Revised City Development Plan for Panaji, 2041. Panaji: Corporation of the City of Panaji.
6. CSE. 2020. Roadmap for Implementation of Water-Sensitive Urban Design and Planning in Odisha, Rainwater Harvesting in Public Parks and Open Spaces. New Delhi: Centre for Science and Environment.
7. —. n.d. Water and Wastewater Management, Story, Case Studies for Water Sensitive Design and Planning (WSDP). Accessed April 15, 2020. https://www.cseindia.org/case-studies-for-water-sensitive-design-and-planning-wsdp-6396.
8. Farhat Rafiq, Sirajuddin Ahmed, Shamshad Ahmad, Amir Ali Khan. 2016. "Urban Floods in India." International Journal of Scientific & Engineering Research 7 (1): 721-734.
9. Gupta, Kapil. 2019. "Challenges in Developing Urban Flood Resilience in India. 378:20190211. http://dx.doi.org/10.1098/rsta.2019.0211." Philosophical Transactions of the Royal Society A (The Royal Society Publishing) 378 (2168). doi:http://dx.doi.org/10.1098/rsta.2019.0211.
10. KC Green. 2018. "Green Stormwater Infrastructure Manual." City of Kansas City, Missouri.
11. LKS INGENIERIA, S.COOP. 2017. Detailed Project Report Hydraulic and Environmental Regeneration of Santa Inez Creek. Panaji: Goa State Infrastructure Development Corporation.
12. Maria Pregnolato, Alistair Ford , Craig Robson , Vassilis Glenis , Stuart Barr and Richard Dawson. 2016. "Assessing urban strategies for reducing the impacts of extreme weather on infrastructure networks." Royal Society Open Science 3 (5). doi:https://doi.org/10.1098/rsos.160023.
13. Ministry of Urban Development, GoI. 2017. Urban Flooding, Standard Operating Procedure. New Delhi: Town and Country Planning Organisation, MoUD, GoI.
14. Prof. AG Chachadi, Dr. Kotha Mahender. 2104. Urban Rainwater Harvesting, Rainwater Harvesting in very High Rainfall Area. New Delhi: Centre for Science and Environment, 18-27.
15. Ramboll and Ramboll Studio Dreiseitl. n.d. The Copenhagen Cloudburst Formula: A Strategic Process for Planning and Designing Blue-Green Interventions. Copenhagen, Denmark: Municipality of Copenhagen.
16. SEEDS and CRED. January 2018. Decoding the Monsoon Floods. New Delhi: SEEDS and CRED.
17. T.Sundarmoorthy, Lalitha Ramadurai and N.G.Anuthaman. 2009. "Urban Floods: Case Study of Chennai." Disaster & Development Vol. 3 No. 1 April 2009 105-181, April: 105-181.
18. WAPCOS. 2014. Final Detailed Project Report for Development of Santa Inez Creek. Gurgaon: Corporation of the City of Panaji.

IMAGINE panaji
SMART CITY DEVELOPMENT LTD.

TRANSITIONS RESEARCH | teri THE ENERGY AND RESOURCES INSTITUTE | Oxford Policy Management | ROYAL DANISH EMBASSY New Delhi | MINISTRY OF FOREIGN AFFAIRS OF DENMARK