PUNE CITY FLOODS

CAUSES, ANALYSIS AND MITIGATION MEASURES

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Rationale and Scope of the report

Rationale

On 12th July, 1961 Pune city faced devastating floods due to collapse of the newly constructed Panshet dam and breach of Khadakwasla dam. The dams that would have supplied water to Pune city all year along, emptied within a few hours that day.

A catastrophe such as dam collapse is a rare phenomenon. However, there are actions, small and big, separated over space and time that could have a cumulative impact like Panshet floods, in near future.

It will not be an exaggeration to say that we got a glimpse of it, in the form of floods of 2019. Floods in the Ambil odha, a major feeder stream to Mutha and in the Bhairoba nalla, a major feeder stream to Mula-Mutha caused loss of life and property.
Once we identify the impact of our actions, we can devise solutions to make corrections in the existing situation and take measures to prevent occurrence of the similar one, in future.
In the report, we make a detailed narrative of the causes and suggest solutions for controlling floods in Pune city and region around Pune.

Scope of the report

Given timeline for preparation of the report does not allow time for survey of the entire stretch of Mutha, Mula and Mula-Mutha in Pune city. However, the recommendations provided in this report are based on various scientific investigations done over various periods, on various subjects in the area and region. We have elaborated on a "cause", providing a detailed narrative, its contribution to floods. We have suggested a solution for this cause.

The discussions in the report are representative of the entire river stretches. All possible causes that contribute to flooding in an urban landscape are covered in the report. The scope of the report is limited to:

1. The rivers Mula, Mutha & their confluence. Pawana and her watershed is not included.
2. Sub watersheds of Mula & Mutha
3. Aquifers of Pune city

Causes and solutions can be considered as a template. All instances of the causes cannot be covered in the report. It is beyond the scope of this current report. An extensive survey and ground-truthing will be required to achieve that. We would be interested to create an exhaustive report if the committee decides to take it ahead as a full-fledged project, in the future.

Executive Summary

Floods devastate settlements, bring misery to human lives, disrupt cities, and incurs financial losses to the nation. All of these were evident in Pune in the months of August and September 2019, when the city experienced unprecedented flooding in its rivers. A preliminary analysis of the floods reveals that it was not just the fury of nature that wreaked the havoc, but a significant part of the problem was due to human interventions in the Riverine and stream ecosystems. This report intends to analyse the floods in a holistic manner, considering the river as a continuum and a living ecosystem. In the first section we analyse the causes of the floods, which are depicted here diagrammatically (see Figure 1).

Figure 1: Causes of Flood

We present three case studies and offer recommendations on the problems. In the second section, we discuss the natural approach to flood management and make policy recommendations to mitigate the risks.

Integrated flood risk management recognises that flood risk can never be eliminated and that resilience to flood risk can include enhancing the capacity of people and communities to adapt to and cope with flooding. It includes ecological restoration and rejuvenation of the rivers, policy interventions and measures in governance.

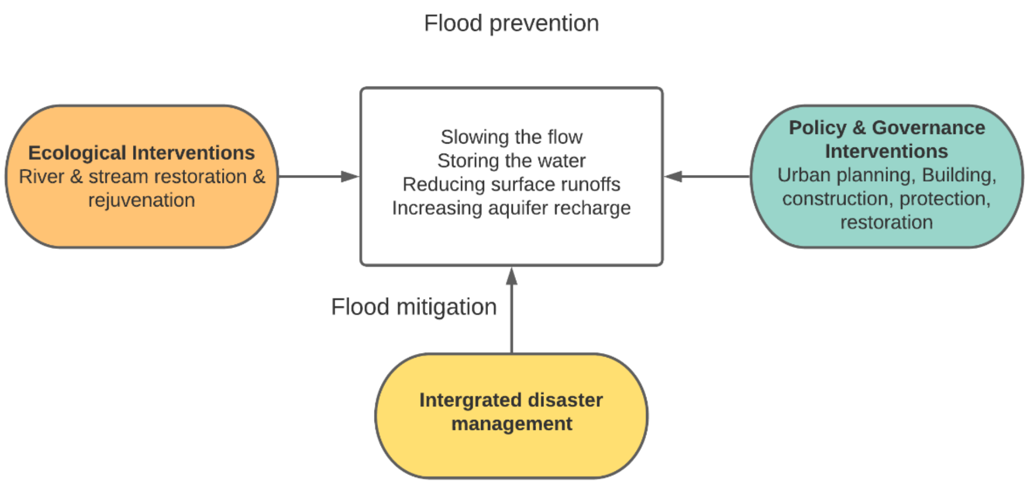


Figure 2: Integrated Flood Risk Management

Flood fury in Pune

River flooding is classified into three types (Figure 3)

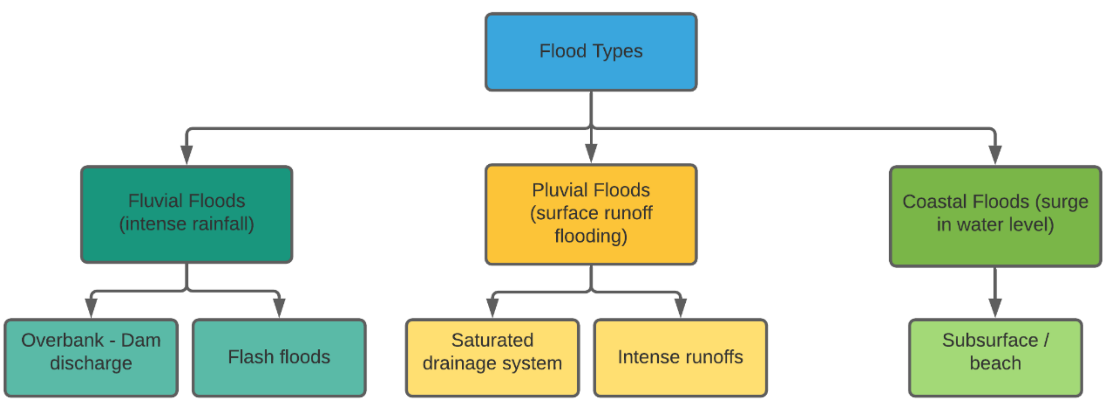


Figure 3: Types of Flood

Fluvial flooding is caused by intense rainfall in a short duration. Overbank flooding occurs when water overflows the banks of a river or stream. Flash flooding is characterized by an intense, rapid gush of water that occurs sporadically. This poses threats to urban settlements.

Pluvial, or surface water flood, is caused when heavy rainfall creates a flooding in an urban settlement. This is not related to an overflowing river. This typically happens when the urban area is saucer shaped. Rainwater saturates an urban drainage system and water flows out into streets. This is the situation which Pune city was put into. The important lesson here was that pluvial flooding was not just on the riverbanks, but was scattered across the city (Figure 4)

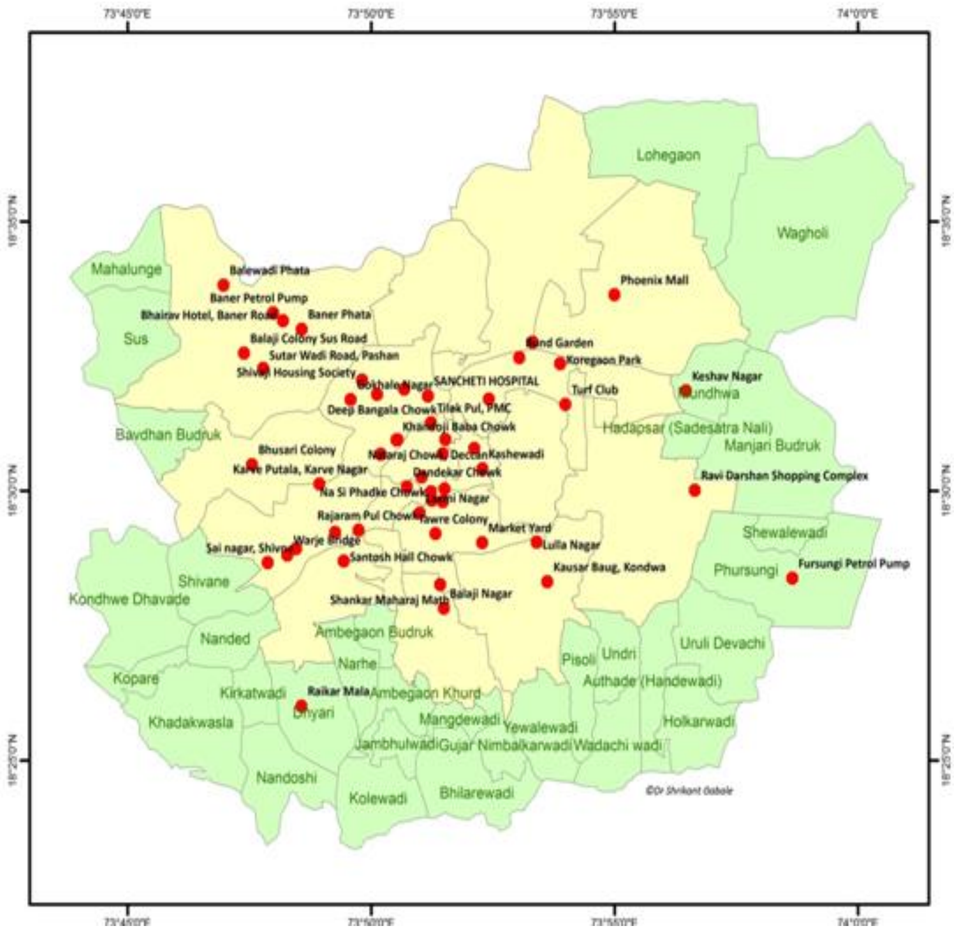


Figure 4: Flash Flood Locations in Pune City (Map: Dr. Shrikant Gabale)

Section 1

Chapter 1 - Understanding Pune Urban Floods

Introduction

In the last few years, urban flooding has become a frequent phenomenon. Nearly every city is vulnerable to urban flooding in some way, and the residents are at high risk. In cities, farmland, vegetation cover, and bare soil have been converted into built up areas, leaving little space for water to percolate. As a result, most of the rainwater runs off the hardscapes, resulting in pluvial flooding or urban flooding. With the rapid increase in impermeable surfaces and increasing urban sprawl, the risk of flooding increases significantly. Furthermore, the urban floods are more lethal with the intensification of rainfall. The risks of urban flooding are expected to increase with changing climate.

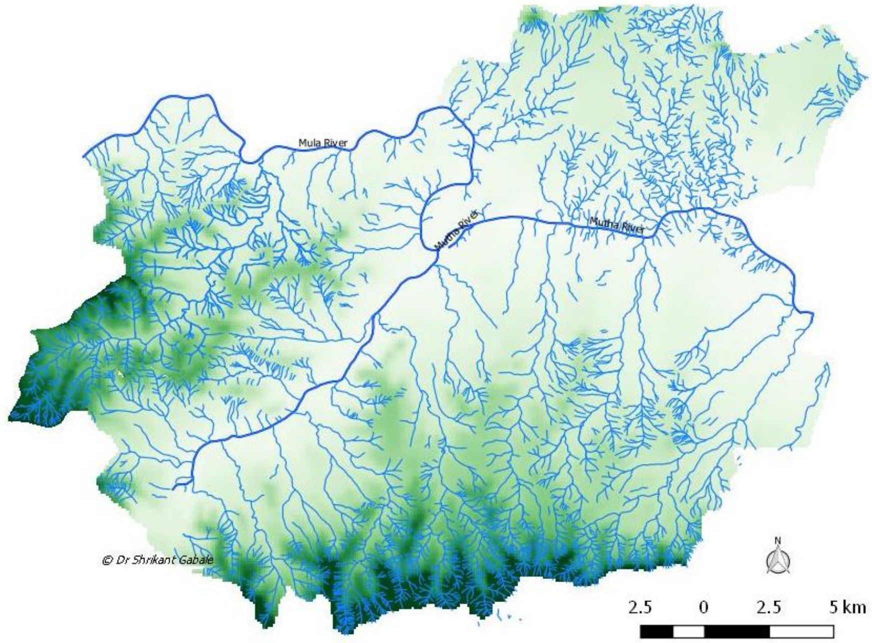
Such urban floods are amplified by man-made interventions. By proper urban planning, these floods are controllable, and intensity can be minimized.

Naturally occurring floods in a river ecosystem involve an area or land along the river that is seasonally submerged. But as rains subside, the water level in the river returns to its normal capacity, often creating a buffer on the flanks called the river flood plain. Though these flood lines are well marked, based on the historical floods that occurred, the development inside these flood lines should be restricted adhering to principles, guidelines and norms that are made from time to time. Moreover, floods are an overflow of large quantities of water onto a normally dry land. The reasons of natural flooding differ from one city to another depending on precipitation patterns, morphological characters, winds, climate change etc, however, very few instances of natural flooding are recorded in the Pune city over the past few decades.

Physical Setting of Pune

Pune is situated on the Deccan plateau and lies on the leeward side of the Western Ghats with an average altitude of 560 m from the mean sea level. It is located at the confluence of the Mula and Mutha rivers and lies between latitudes 18°25' N and 18°37' N and longitudes 73°44' E and 73°57' E. River Mutha passes through the city and has an asymmetrical valley. Pavna and Indrayani traverse the North-Western outskirts of the urban area. The highest point in the city is Vetal Hill (800m above mean sea level-(MSL)) whereas the highest point just outside the urban area is the Sinhagad Fort (1300 m above MSL). The general drainage pattern formed in this area is of dendritic type. Ramnadi and Devnadi are tributaries of Mula river meeting her at right bank in Baner area. Pawana river, travelling through Pimpri Chinchwad Municipal Corporation area meets Mula river at the left bank in Dapodi. The Mula and Mutha rivers further merge with each other near College of Engineering, Pune forming Mula-Mutha river, which further meets Bhima river at Ranjangaon

Saandas in Shirur Tehsil. Bhima river meets Krishna river in the state of Karnataka, which ultimately drains into Bay of Bengal in Andhra Pradesh.



Map showing rivers in Pune city

The Mula and Mutha rivers have dams in their source regions, upstream of Pune city. Mutha River has four dams Khadakwasala, Panshet, Warasgaon and Temghar. Water is discharged into river / supplied to Pune city and rural areas through Khadakwasla dam. Mulshi Dam is on the Mula river which is a hydro power dam by Tata's. Pawana dam spans the Pawana river. These dams play a significant role in the water levels in these rivers. Each river also has its sub-watershed within city, with network of feeder streams.

Pune city falls within flood plain area of rivers, the very basis of establishment of Pune city. In the floodplain region the rivers deposit fertile silt and sediments along its banks. These fertile banks are ideal for agriculture and thus attract a settlement.

Changes in the environment are the unavoidable consequences of development. The expansion of Pune city over the years and rising construction activities have altered the topography, drainage, and geomorphic environment of the region. Various negative impacts on the physical environment such as loss of agricultural land, surface and groundwater depletion, changes in geomorphic features, flooding, and others, have increased as the city expanded.

Pune Floods & City Development

Pune's geographic conditions are conducive for development and expansion and this has led to conversion of agricultural lands along streams and transportation. Soon, settlements started creeping up along the slope of hills, and the cutting and filling disturbed the natural flow of streams. Debris dumping has caused cementing of stream and river bases, which prevents percolation of water and broke stream links which triggered water logging. This has led to flash floods in the rainy season.

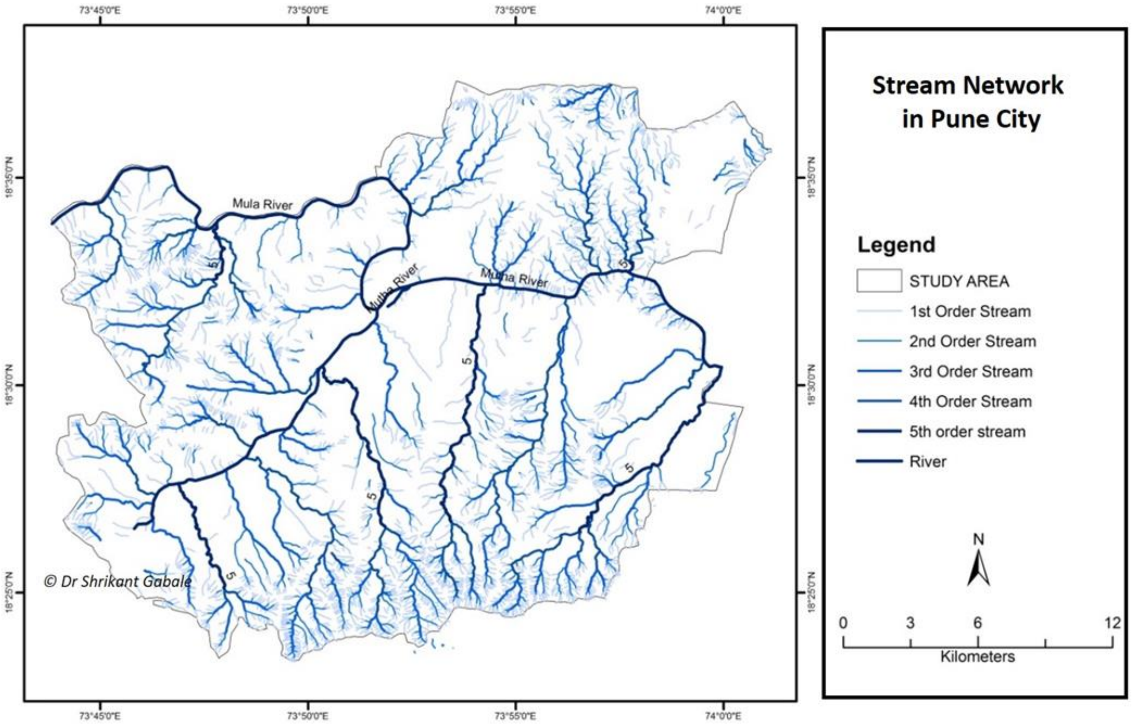
Due to building and construction, streams connecting with Mula and Mutha rivers in central Pune are getting blocked or choked causing hazardous conditions in many areas. This has disturbed Pune's water table and ecology around it causing streams to disappear over the period. Increase in impermeable surfaces is one of the many human fabrications that dislodge hydrological processes. Impervious surfaces are materials that stop the penetration of water into the soil. The result of this barrier is increased runoff, higher stream channel velocities and greater flooding.

Healthy urban streams have been recognized as a fundamental prerequisite to achieve sustainable management of our cities and fulfilling our imperative to maintain healthy aquatic ecosystems for future generations (United Nations General Assembly 1987). There are several excellent summaries on the effects of urbanization on stream health (Walsh et al. 2005). Urbanization alters river ecology in and downstream of cities, harming aquatic systems and prompting efforts to protect, rehabilitate, and even fully restore urban streams. Yet these efforts seldom succeed, mostly because of narrowly prescriptive solutions that do not take advantage of interdisciplinary knowledge in the physical, biological, and social sciences or because they do not treat the full range of urban change in streams (Karr and Rossano 2001).

Drainage Network in Pune

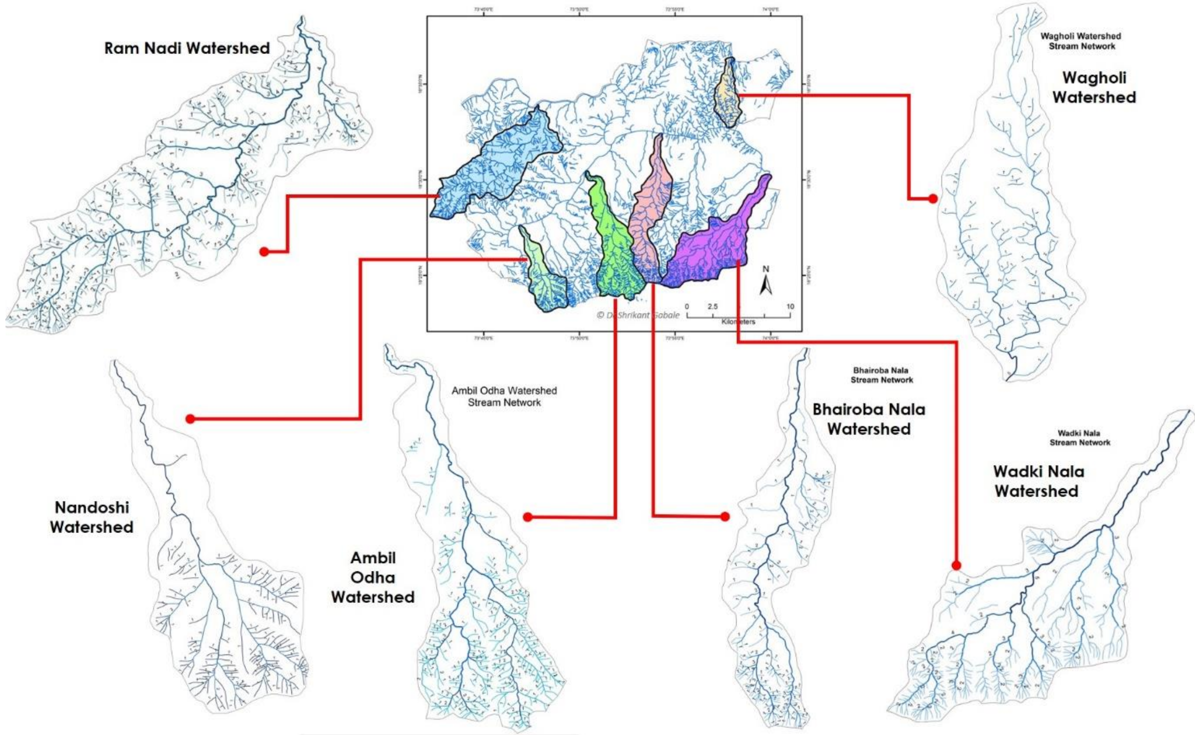
Dendritic or tree shaped drainage pattern is observed in Pune and surrounding area. The network of tributaries of various orders and magnitudes of the trunk or master stream resembles the branches and roots and rootlets of a tree. At city level, a common problem is observed that the management of a single, natural unit, such as a drainage basin, is divided between several administrative divisions, resulting duplication or dispersion of efforts, and perhaps conflict.

Two major drainage basins are developed in this area, the Mula and Mutha river basins. A detailed morphometric analysis of Mula and Mutha river basins by dividing them in major and minor sub basins was carried out by Dr Shrikant Gabale. The toposheets no. 47F/14/2, 47F/14/3, 47F/14/5, 47F/14/6, 47F/15/SE, 47F/15NW, 47F/15/NE, 47J/3/NW, and 47J/2/SW year 1990 to 1980 were used.



Rivers and Stream Network in Pune City (Map: Dr. Shrikant Gabale)

The Mula and Mutha basins have 2246 first order, 483 second order, 128 third order, 28 fourth order and 6 fifth order streams. These two major basins are divided in to six sub basins -Nandoshi, Ramnadi, Ambil Odha, Bhairoba Nala, Wadki Nala and Wagholi. These sub-watershed basins cover about 35% of total area of Pune. These watershed areas are having rapid urbanization since year 1980 till date.



Major Sub-Watersheds in Pune (Map: Dr. Shrikant Gabale)

The development of Pune city can be observed within these sub basin areas. As per the topographical characteristics of Pune city, concentration of first order streams in southern area is more than other area. Around four major watersheds are occupied in southern zone. Nandoshi, Ambil Odha, Bhairoba Nala and Wadki Nala are major watersheds with fifth order streams.

The North-West area is covered with hilly terrain having major hillocks presently situated in this area. Vetal hill range from Kothrud is the water divide for Mula and Mutha rivers. Streams flowing from Aundh, Baner, Sus and Mahalunge area are the part of Mula river system. Ram Nadi plays important role in this area, which covers major part of the area.

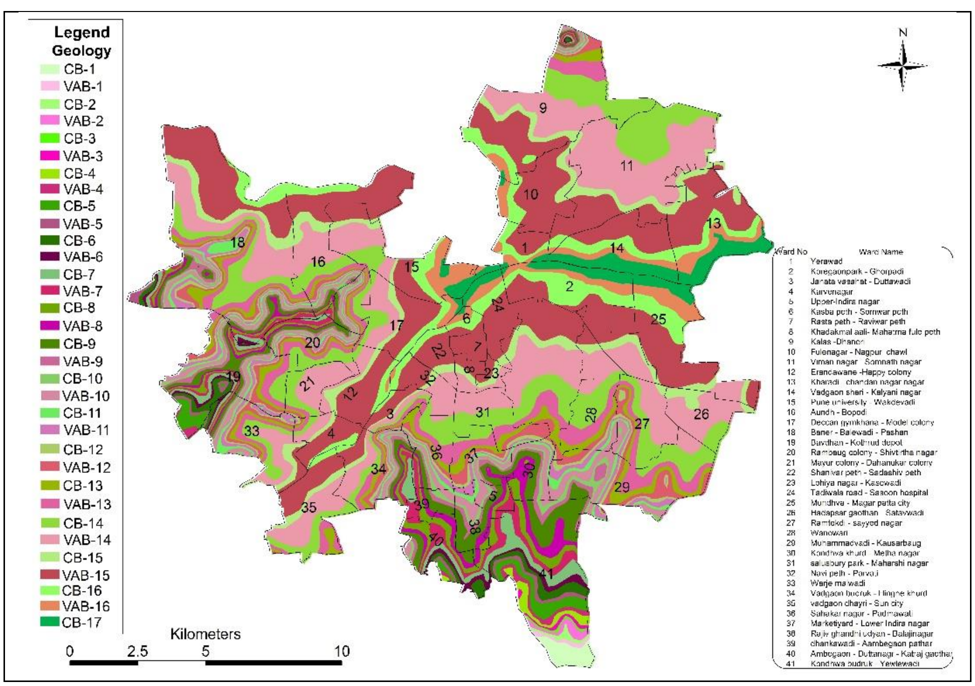
The northern area, especially Dhayari, Viashrantwadi, Lohgaon and Wagholi follow dendritic pattern of stream network. Concentrations of first order streams are highest in this area because of change in geological flow. This area is in Dighi hill range having uneven topography i.e. flat and small hillocks. Most of the streams in this region are non-perennial.

The central part is relatively flat and can be identify as river valley of Mutha and Mula rivers. This area is occupied by 4th and 5th order streams.

Chapter 2 - Geological Framework and Aquifers of Pune city

The geology of the Pune region is dominated by a sequence of basalt (lava) flows. The lavas disposed are horizontal "flows" giving rise to a 'trappean' landscape of a step-like morphology called 'traps'. Each lava flow varies in thickness from 10s to 100s of meters. These basalts were formed from lava erupted on the surface, some 65 million years ago. The lava solidified, weathered, and was fractured subsequently. Based on their nature and geometry, basalts are broadly classified into two major hydrogeological types, namely, the vesicular variety (VAB) which has numerous voids and pores along with horizontal sheet joints and the other is the compact variety (CB) which is massive and compact with fewer openings that are largely vertical in nature. Each lava flow can be divided into such units and sub-units to make a fundamental hydrogeological differentiation, even at scales of river basins.

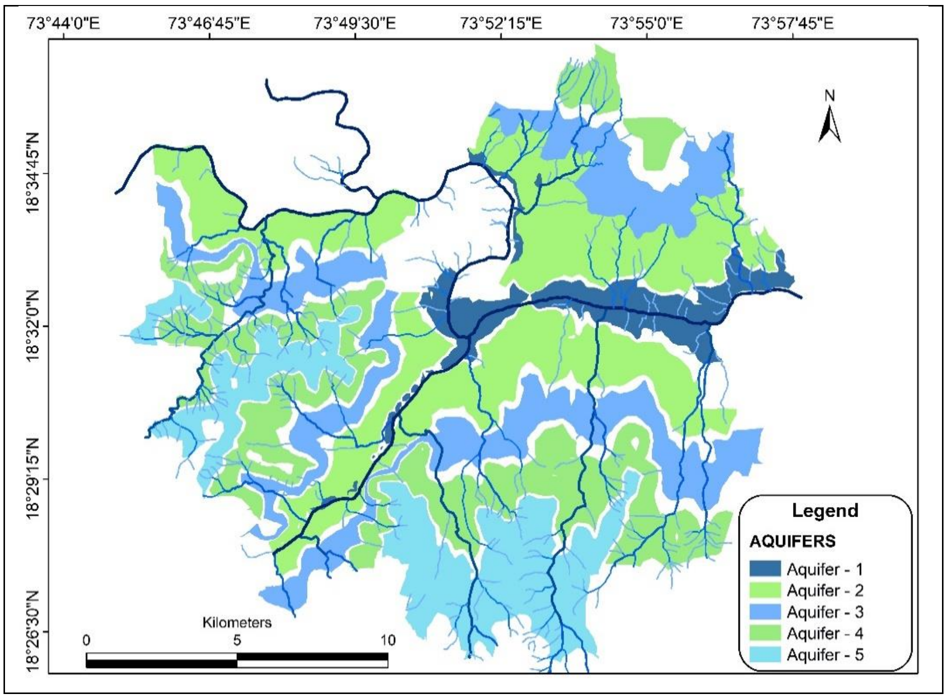
During a study by ACWADAM, twenty-three units of alternating VABs and CBs were identified in Pune city and its environs, based on the mapping conducted in detail between 450 m above msl to the highest elevation of up to about 980 above msl. The geological map has been produced based on this data and overlaid on the Pune's electoral ward boundary (2017) to provide a micro level perspective of the hydrogeological setting of the city. In simple terms, the shades of pink represent VABs and shades of green represent CBs. The geological map for Pune city was used as a foundation for the more detailed hydrogeological mapping of the aquifers in Pune city.



Micro level geological map of Pune city Map (ACWADAM)

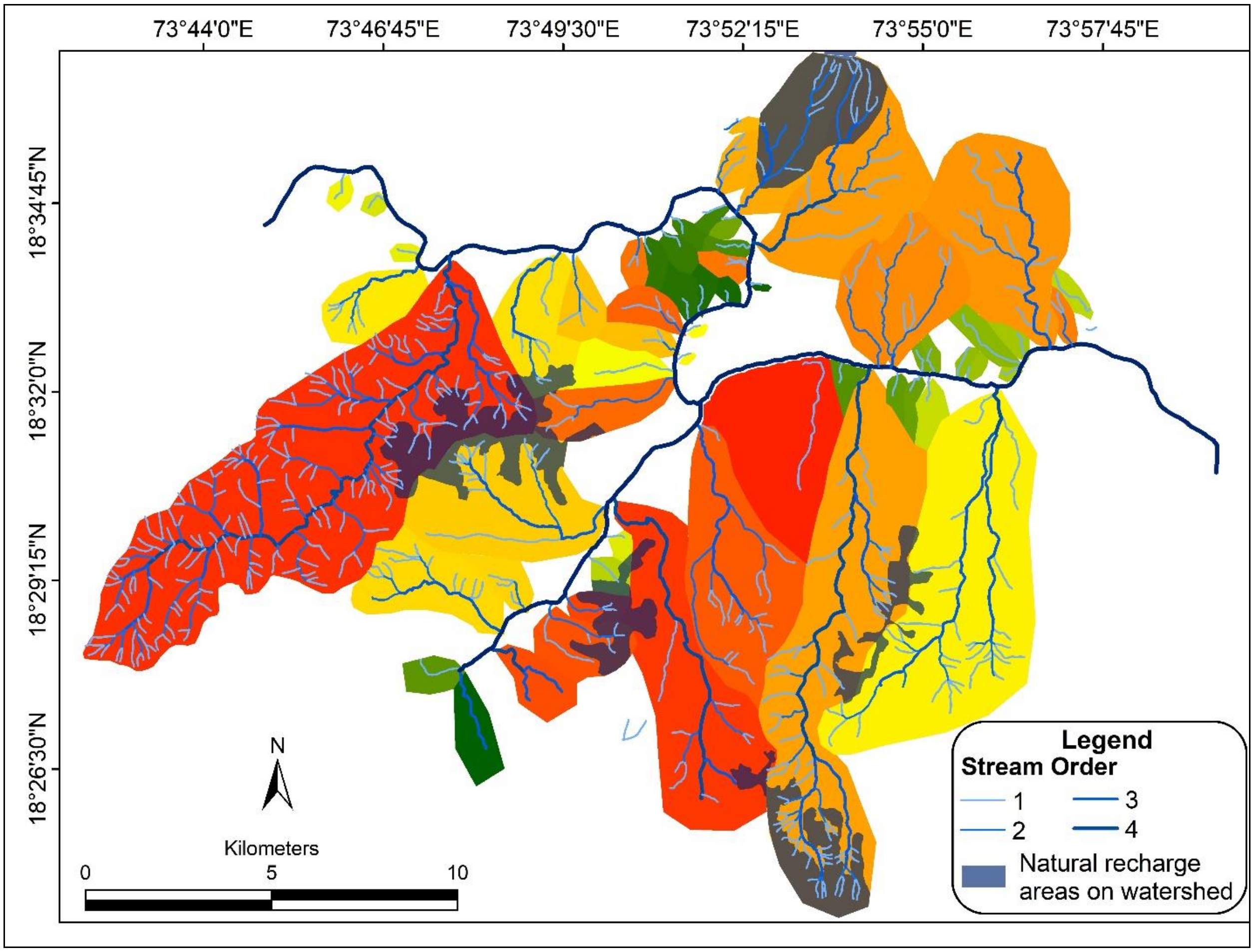
An aquifer map below represents the disposition of the shallow unconfined (phreatic) aquifers for Pune city. Pune city has five aquifers - Aquifer 1, Aquifer 2, Aquifer 3, Aquifer 4, and Aquifer 5 - in increasing order of their elevations (above msl) where they are exposed at the surface. These five aquifers are generally about 10 to 20 m thick.

To mitigate and control the urban flooding situation in the near future, it is imperative to understand the aquifer wise natural recharge areas and their disposition with respect to land use pattern and the geomorphic zones that overlie these aquifers, in order to device any flood mitigation strategy.



Aquifer disposition map of Pune city (Map: ACWADAM)

To overcome the flooding situation and to restore the natural setup of streams and Aquifers, groundwater recharge is an essential component, which can be achieved by application of ''Managed aquifer recharge" (MAR). Based on the exposed locations of the tops of the aquifers in Pune city and based on the groundwater level data for two seasons, were further used to sharpen the location of the zones of natural groundwater recharge along the contours of the land where the tops of the main aquifers were mapped. The recharge zones also coincide with the watershed map of the city. In order to illustrate the correlation between recharge areas and Pune's watersheds a map, an overlay of the key zones where natural recharge conditions exist is provided below, indicating those areas that must constitute the priority zones for recharge and recharge area protection in Pune city.

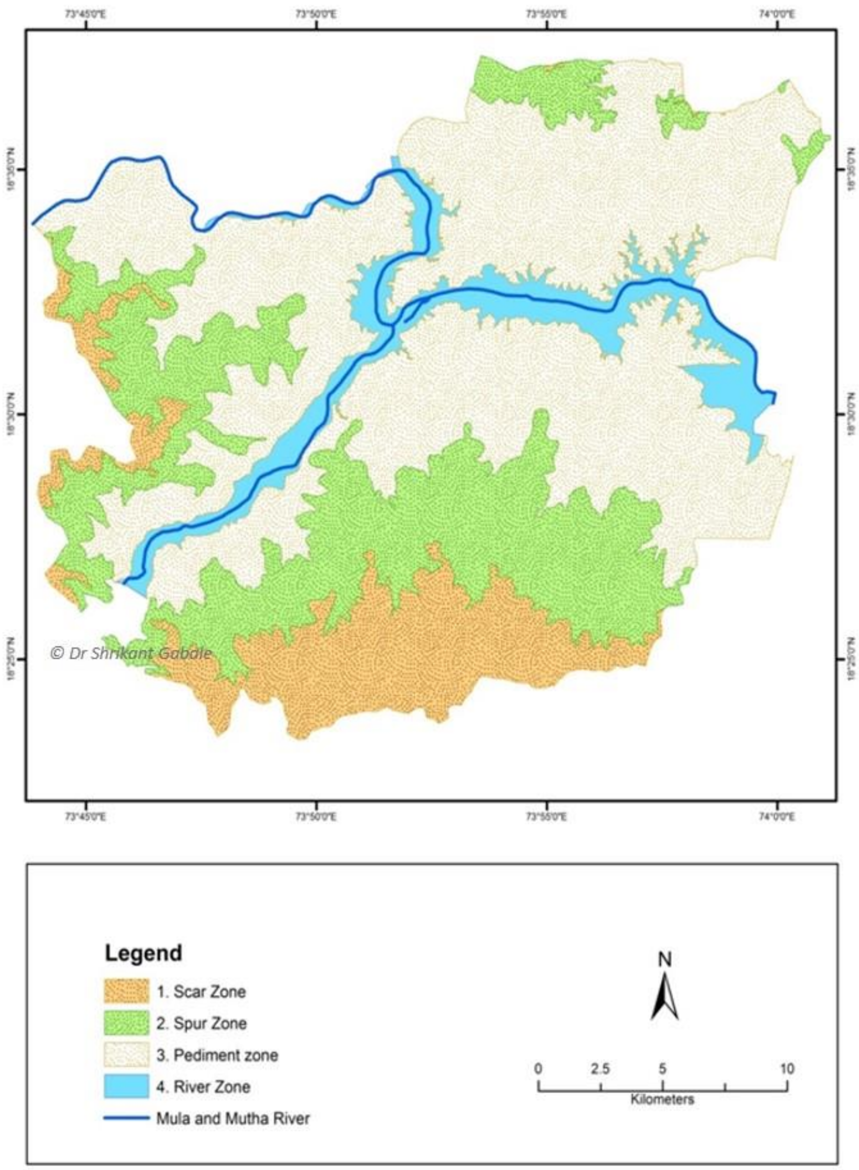


Some crucial aquifer recharge areas overlaid to watersheds within Pune electoral boundary (ACWADAM, 2019)

Geomorphic Zones of Pune city and its surrounding Areas –

Based on geological setup and geomorphology of the region, the Pune City area shows two major geomorphic units:

1. Upper Diagonal region (River plain Area)
2. Lower Diagonal region (Upland Area)



Geomorphic map of Pune City (Dr. Shrikant Gabale)

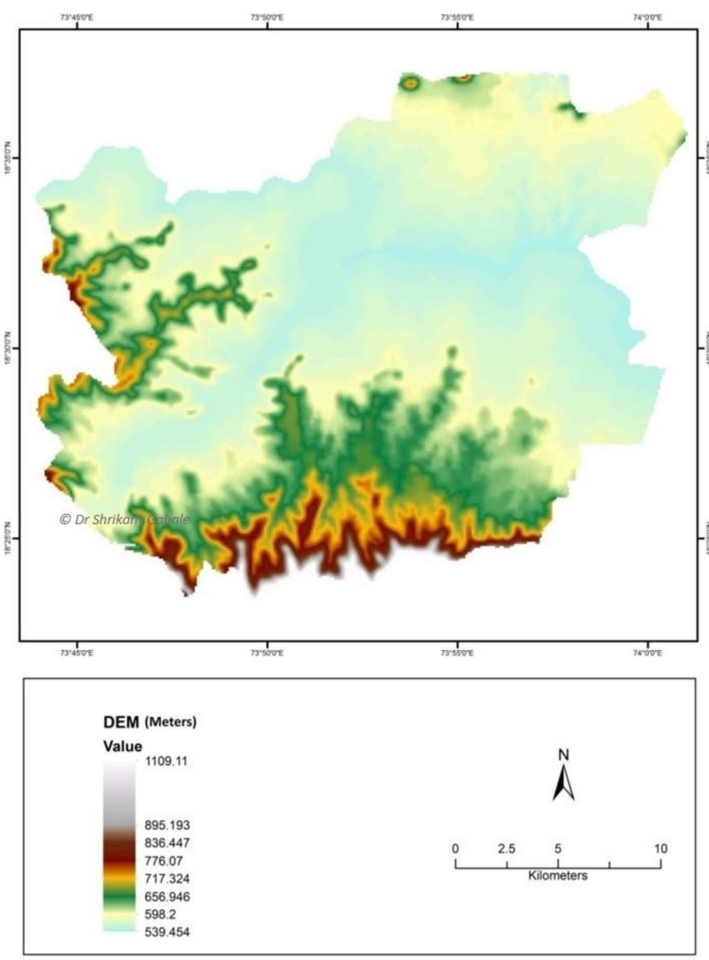
Here, the Upper Diagonal region shows the river plane province of Mula-Mutha River. The Dighi hills act as a water divide between Mula and Indrayani River, which lies to North of Dighi Hills. Confluence of Mula and Mutha River is in the central part of Pune, which flow from West and South-West direction, respectively.

Scarp zone is a cliff or steep slope. A spur is a long, gently-sloping 'tongue' of ground that runs down from a hill to lower ground. A spur is often formed by two roughly parallel streams cutting draws down the side of a ridge.

The spur zone is followed by the **pediment zone** which covers the largest portion in the Pune city, which is 279.25 sq. km. This pediment zone is nothing but a river depositional zone and represents the valley. This is dominated by Mutha River drainage basin area to the eastern side. Pediment zone of Mula River lies to its right bank and the North Western side. The pediment area widens towards east as both the rivers reach their pre-mature stage. Their early mature stage denotes minimum pediment area. The dense population is settled on this pediment zone of Mutha river.

An area which comes under a maximum discharge of river to its normal position afterwards is considered as a **riverbank**. This is the flood plain region of the river. In Pune, river zone covers 46.76 sq. km. As both rivers are flowing in their matured stage, this region is mainly dominated by river's depositional activity. The rivers deposits alluvial materials near confluence, increasing channel widths of both river channels. Near the confluence, a depositional island 'Naik bait' is formed due to heavy sediment depositions over the period. This natural island is also occupied by human settlement.

Following map shows administrative wards situated at different elevation levels in Pune city.

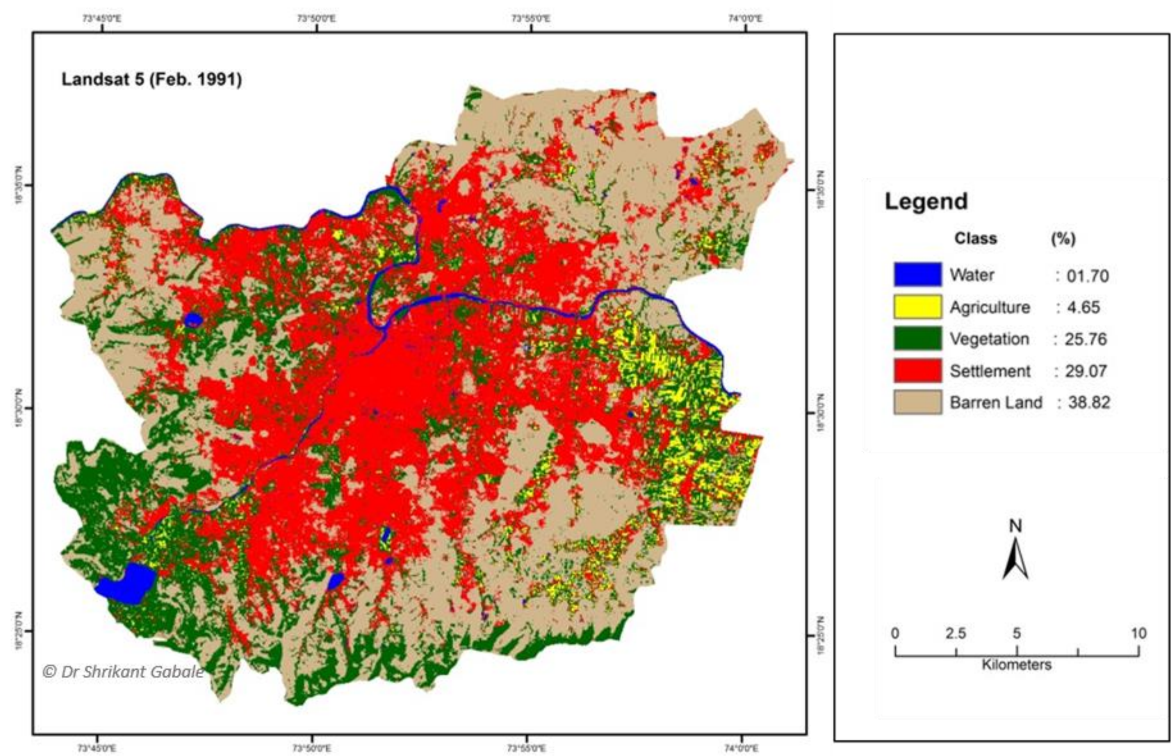


Elevation Class (Mtr.)	Color	Wards (Administrative Division)	Villages
900-1109		-	Kolewadi, Yewalewadi, Bhilarewadi,
770-900		-	Holkarwadi, Yewalewadi, Bhilarewadi, Kolewadi, Handewadi, Kopare, Bavdhan
710-770		Kondhwe, Kopare, Aundh, Karve Rd	Handewadi, Holkarwadi, Wadachiwadi UruliDevachi, Bavdhan Mangalewadi, Yewalewadi Nandoshi, Sus
590-710		Bibwewadi, Dhanakawadi,Ambegaon Bk. and Kh. Dhayari, Kirkatwadi, Kondhwe, Warje, Shivane, Bavdhan, Aundh, Karve Rd, Sahakar Nagar, Hadapsar	Handewadi, Holkarwadi, Wadachiwadi, Undri, Pisoli UruliDevachi
539-590		Tilak Road,Sahakar Nagar,Vishrambaug Wada,Pune Cantonment, Ghole Road, Dhole Patil Road, BhavaniPeth, WarjeKarve Nagar, Karve Rd.,Mhalunge,Aundh, Mundhwa, Yerwada, Sangamwadi, Khadki Cant, wagholi, Lohegaon	Khadakwasla, Nanded, UruliDevachi

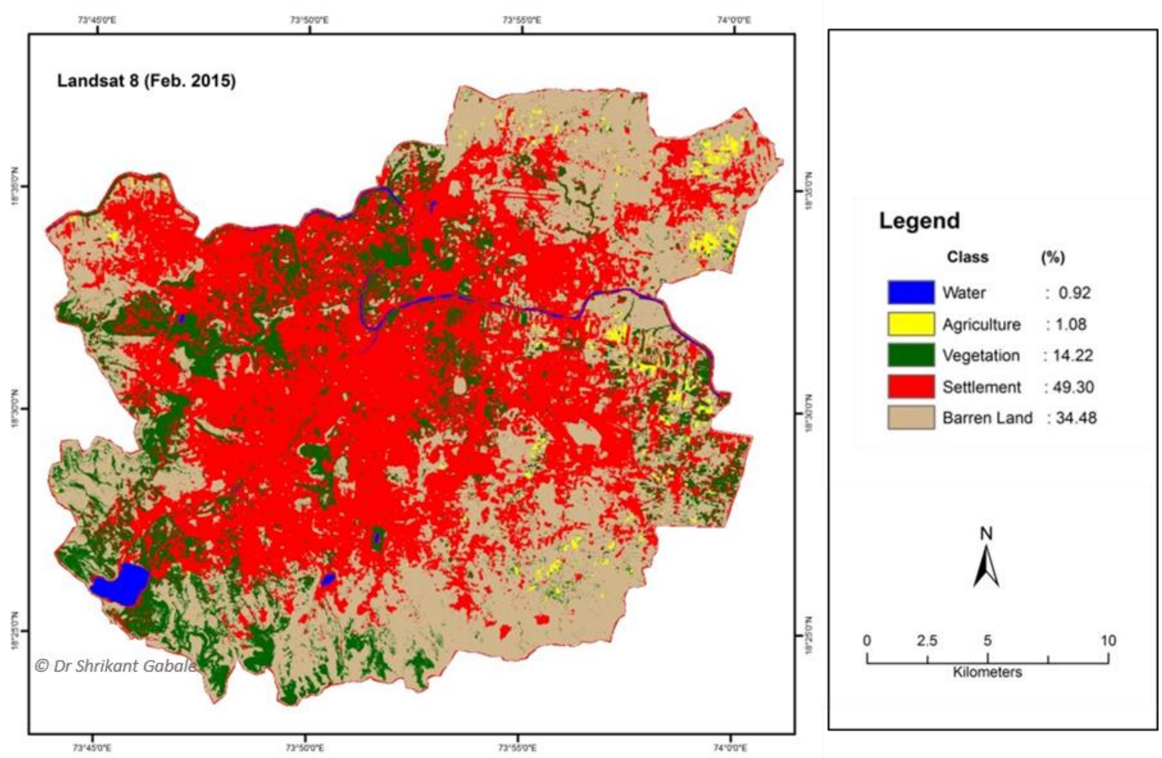
Digital Elevation Model (DEM) of Pune City (Map: Dr. Shrikant Gabale)

Chapter 3 - Land Use and Land Cover change Detection

The study conducted by Dr. Shrikant Gabale, in Pune and its surrounding areas indicates that multi-temporal remote sensing images i.e. Landsat images are useful to detect the changes in land cover quickly and accurately. The study reveals that the major land cover categories in Pune city in which changes over the years were observed are water bodies, vegetation, and settlement area. Overview of changes in Land Cover over the years from 1991 to 2015 is as follow:



Pune 1991: The results of classification suggest that area under Waterbodies accounts to 1.70%, area under Agriculture is 4.65%, Vegetation is 25.76 %, Settlements is 29.07 % and Open/Barren Land is 38.82 % of the total area and thus this total area is divided in above five components or areas. The image shows natural, physical, and human intervention in the study area. Vegetation, Open/Barren Land and Water bodies together occupy 66.28% of the total area. Human settlements and agriculture land occupy 33.72% area. These percentages suggest that the impact of human activities or human interference on nature or physical features were comparatively less during these years.



Pune 2015: Area under water bodies accounts to 0.92%, Agriculture 1.08%, Vegetation 14.22%, Settlements 49.30%, and Open/Barren land occupies 34.48 %. The natural features like Vegetation, Open/Barren Land and waterbodies occupy 49.62% of the total area and human settlements and agricultural land occupy 50.38 % of the total area. Comparing it to physical aspects of the study area in year 2015, an unambiguous difference is observed in area under waterbodies (422.33 Ha.) indicating heavy development along them, and a swift increase in area under settlement (10957.87 Ha.) is observed endangering vegetation cover and conversion of Open/Barren land in and around the city. Hence, heavy urbanization is reason for depletion of good fertile land in Peri-Urban area, heavy development along water bodies and vanishing of non-existing streams.

Sr. No.	Class / Land Cover Type	1991	2015	Difference from year 1991 to 2015		
		(%)	(%)	(%)	(Ha.)	(Sq.km.)
1	Water bodies	1.70	0.92	0.78	422.33	4.22
2	Agricultural Land	4.65	1.08	3.57	1932.97	19.32
3	Vegetation Cover	25.76	14.22	11.54	6248.33	62.48
4	Settlement area	29.07	49.30	20.23	10953.53	109.53
5	Open / Barren Land	38.82	34.48	4.34	2349.89	23.49

Source: Dr Shrikant Gabale Report

Chapter 4 - Pune floods

Pune is experiencing frequent episodes of urban flooding every monsoon. These floods happen in a relatively short period of time and can inundate an area with several feet of water.
Urban flooding occurs when water builds up into a city or town through precipitation that generates flow and stocks, the result of incoming flows from outside. Such a build-up is faster than the rate of drainage, infiltration to soil and groundwater and augmentation to storages – both natural and man-made (ponds, tanks, lakes, reservoirs. The chain of dams upstream of Pune make the city vulnerable to flooding from dam releases too.

Urban floods can cause loss of lives, built capital and are a disturbance in city life. Even though casualties are typically low, the economic damages are high. The 2019 floods in Pune were devastating. They claimed 21 human lives and left many homeless. This flood exposed the impacts of encroaching upon rivers and the network of their streams. Furthermore, dam water released caused high water levels compared to earlier years.

Pune city is more vulnerable to floods due to its saucer shape with hills on the edge, and a chain of dams just a few kilometres from the city, in the upstream region of its rivers.

Water Level rise and flood alert

Chapter 5 - Photographs of 2019 Pune Floods

Ramnadi Flood

Vitthal Mandir at Vitthalwadi, Mutha river

Flood affected area at Mutha river

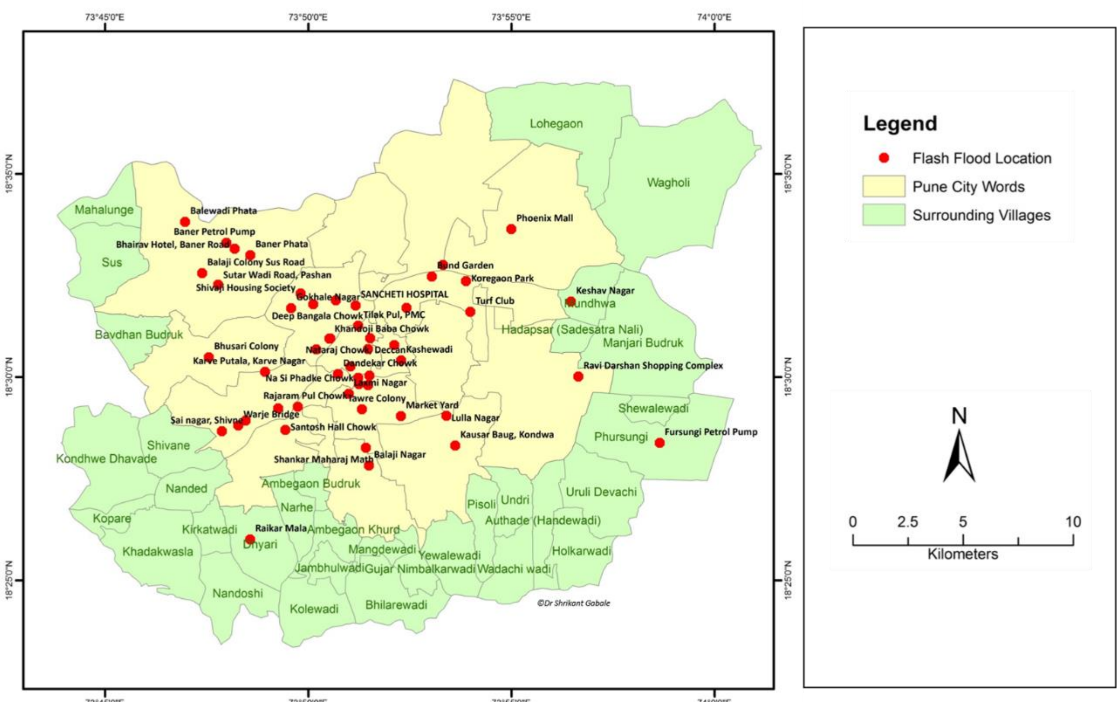
Flood Affected People at Mula River

Flash floods in Pune-

Urban flooding is mainly due to a disturbed drainage in an urban area. As there is little open soil that can be used for water storage nearly all the precipitation needs to be transported to surface water or the sewage system. High-intensity rainfall can cause flooding when the city sewage system and draining canals do not have the necessary capacity to drain away from the amounts of rain that are falling. Water may even enter the sewage system in one place and then get deposited somewhere else in the city on the streets.

In Pune, during monsoon in the last couple of years, roads turned into rivers and nullahs overflowed washing away culverts and small bridges. The city's drainage system seemed non-functional as gushing water on the roads swept away scores of cars, motorcycles, and scooters, ripped out paver blocks from pavements and eroded the road surface in several places.

Flash Flood Location in Pune city and Surrounding



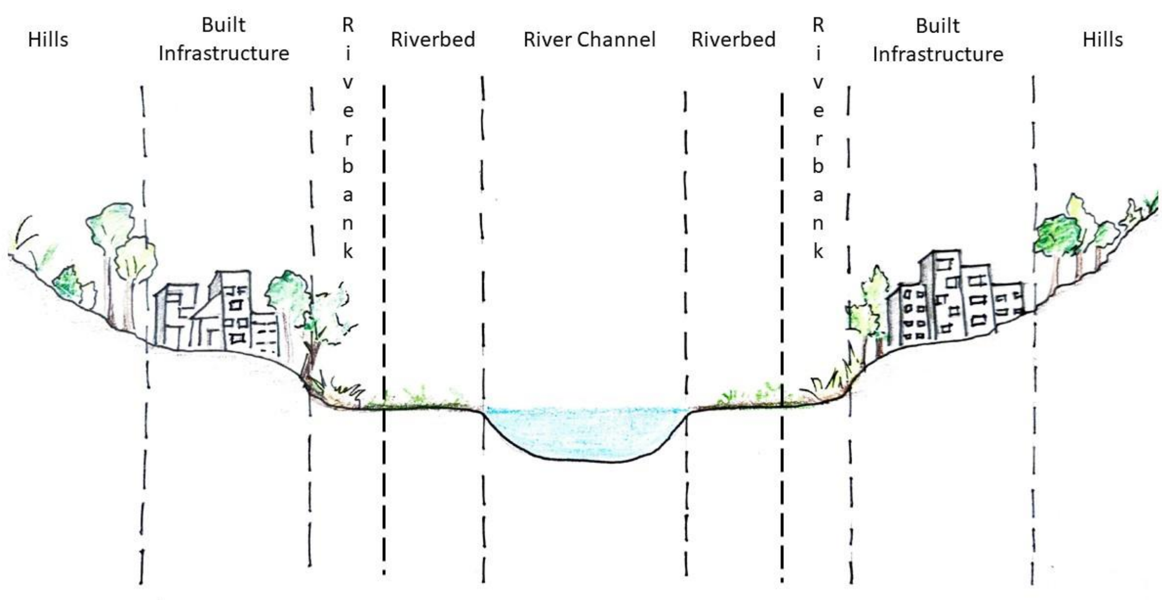
Map by Dr. Shrikant Gabale

As per the site survey, Dr Gabale has identified 66 flash flood locations in Pune city. Most of the locations are in major chowks and near to crowded spaces. No proper sewage system and waste being pumped into water bodies, increased runoff owing to cement and concrete roads, Diversion of streams, Deposition of construction debris in streams are the reason behind the flash floods in urban area.

Causes of Urban Flooding

As described in earlier chapters, in urban areas the drainage pattern of rivers and its feeder streams get affected to large extent due to development and encroachment. This is the main reason for flooding in urban areas. Few other factors also contribute significantly to this man-made catastrophe. Major factors are as follows:

1. Flash floods occurring due to topographical changes in source regions, flood plains and confluences of rivers
2. Accumulation of local Rainfall runoffs due to insufficient drainage ways.
3. Lack of sufficient structured and unstructured drainage for flood waters
4. Overflowing rivers due to insufficient capacity of rivers to discharge the waters on bank due to encroachments
5. Reduction in aquifer volumes, especially the porous and permeable shallow unconfined aquifers due to foundation excavations
6. Reduction in natural recharge areas owing to building and infrastructure
7. Inadequate and insufficient flood risk assessment and management
8. Natural functioning of rivers and streams in urban areas is affected due to number of reasons. These causative factors exist at various levels in the landscape. Following illustration shows the cross section of river and surrounding city landscape. The flood causing factors exist at each of the landscape feature shown here.



Cross-section of river and its catchment in urban area (Sketch: Aditi Deodhar)

The factors responsible for urban flooding are enlisted and described in detail below. The factors are listed in a sequence of their occurrence, starting from the river channel towards the hills.
Causes of urban flooding:

Landscape Feature	**Causes of Urban Flooding**
River Channel & Riverbed	• Channelization of river • Encroachment / Construction in riverbed • Major infrastructure project in riverbed (Metro) • Redundant structures in riverbed • Unplanned structures – New bridges, Weirs, bunds • Existing debris from old constructions in riverbed • Privately owned structures Samadhis, Hauds (e.g. Someshwar haud on Ramnadi) • Choking off the natural groundwater discharge zones – seeps and springs that bring water from aquifers into the river channel
Riverbank / Riparian zones	• Heavy debris dumping on riverbanks • Development within blue line • Developmental projects along riverbanks • Encroachment along riverbanks (illegal settlements) • Increase in hardscape area
Built infrastructure	• Disturbed feeder stream network • Lack of sufficient structured & unstructured drainage of flood waters • Increase in hardscape area • Underground interventions, especially foundations, basements etc. that lead to loss of valuable shallow aquifer storage
Hills	• Disturbed feeder stream network • Increase in hardscape area • Construction projects • Sub-watersheds of rivers getting affected due to unplanned development, improper EIA studies • Disturbance in natural aquifer recharge areas and springs

Chapter 6 – Root cause analysis and proposed Solutions

Channelization of rivers

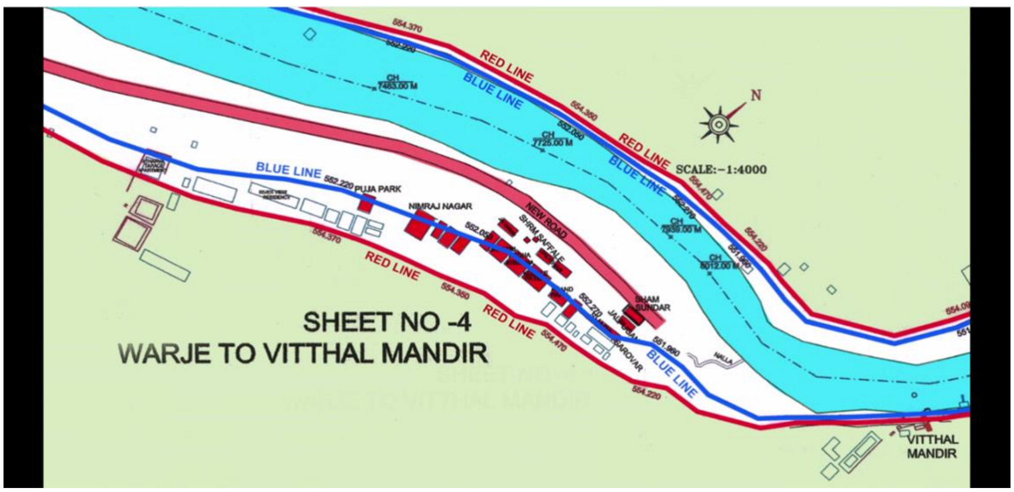
Mutha river is extensively channelised within Pune city. Such concretized riverbanks alter the natural functioning of river. Natural river channel has its own course carved through millions of years of action. The river flow carries out function of exchange of sediment, silt. There is exchange of surface and sub-surface water between river and riverbank, riverside wetlands.
Due to concretized bank, the connection of river with its bank, its water spread area is broken. This affects various natural habitats created along river, stagnant pools of water are formed in depressions along river, springs meeting river are also affected.
The riverbed area outside the constructed channel becomes easy place for dumping of garbage and debris, construction, illegal structures etc. All these factors cause obstruction to flood water spread.

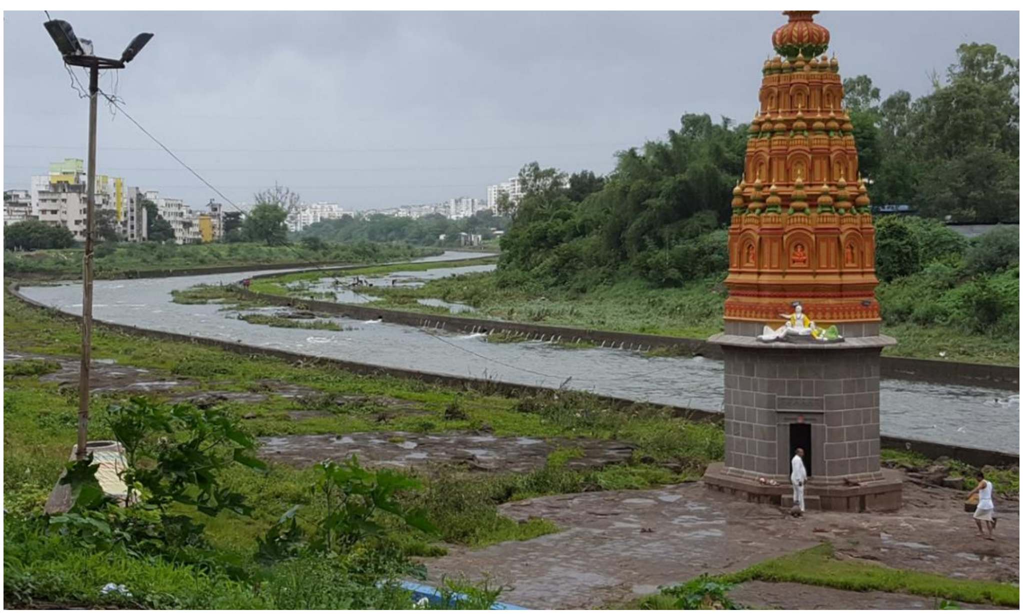
Action / Solution Removal of concretized banks and restoring the riverbank, riparian zone through ecological measures and protection of springs along riverbed and in source region.

Encroachment / Construction in riverbed

Construction and illegal encroachment are seen within the riverbed. Roads are also planned within riverbed e.g. The 3.5 km road was planned by Pune Municipal Corporation (PMC) from Warje to Vitthalwadi, along Mutha river. This road was inside blue flood line. Petition was filed by Ar. Sarang Yadwadkar against this encroachment. 65% of the road construction was complete by then. National Green Tribunal (NGT) ordered the road to be removed. Supreme Court also continued the order by NGT.

Road was removed by PMC following order from NGT. However, the debris was left as it is in the riverbed. Deadline for removal of debris was extended thrice. Rs. 15 crores were spent in construction of the road, and Rs. 4.5 crores were spent in removal of the same.





Action / Solution:

Removal / relocation of these structures and establishing natural riverbank using ecological measures, restoring original topology altered by these structures.

Major infrastructure project in riverbed

Government infrastructure projects like Metro, Ring road covers a large portion of riverbank and riverbed. Such heavy concrete structure not only affect river ecosystem but also the groundwater recharge in this zone. Such structures also cause an obstruction to flood water and displace water towards the riverside residential areas.

Solution: Alternate routes for such transportation projects should be designed with help of ecology and hydrogeology experts.

Structures and Redundant structures in riverbed

In riverbed redundant objects are seen lying like defunct big pipelines, scrap cars etc. Scrap cars are regularly dumped in the riverbed towards the right bank of Mutha, near Chhatrapati Sambhaji Bridge.

Sewage pipeline lying idle in the Mutha riverbed, which is not connected anywhere. It was probably brought for some work and is left as it right in the riverbed.

Redundant Pipeline in Mutha Riverbed at Vitthalwadi

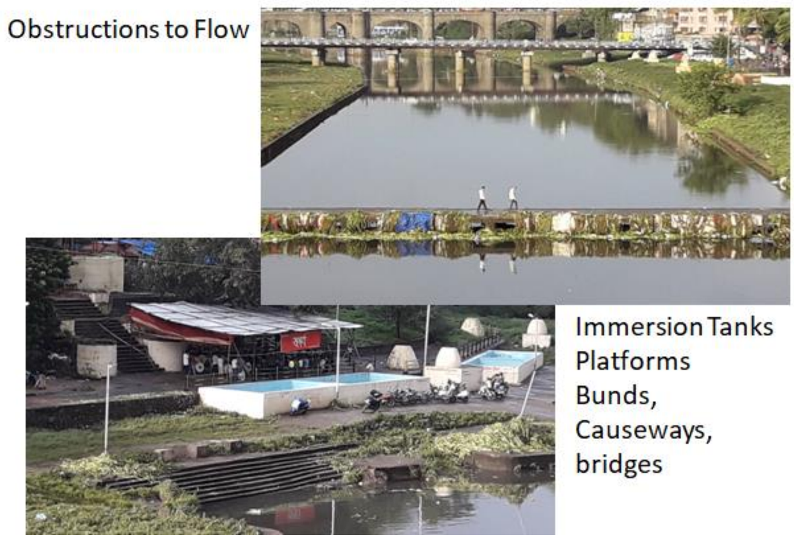
Structures in Mutha Riverbed at Vitthalwadi

Sewage chambers, Ganesh Immersion tanks are constructed in the riverbed. All these objects are obstruction to flood water flow.

Structures in Mula, Ramnadi, Devnadi -

Solution/ Action:

Immediate removal of the defunct objects / structures and relocation of other structures.



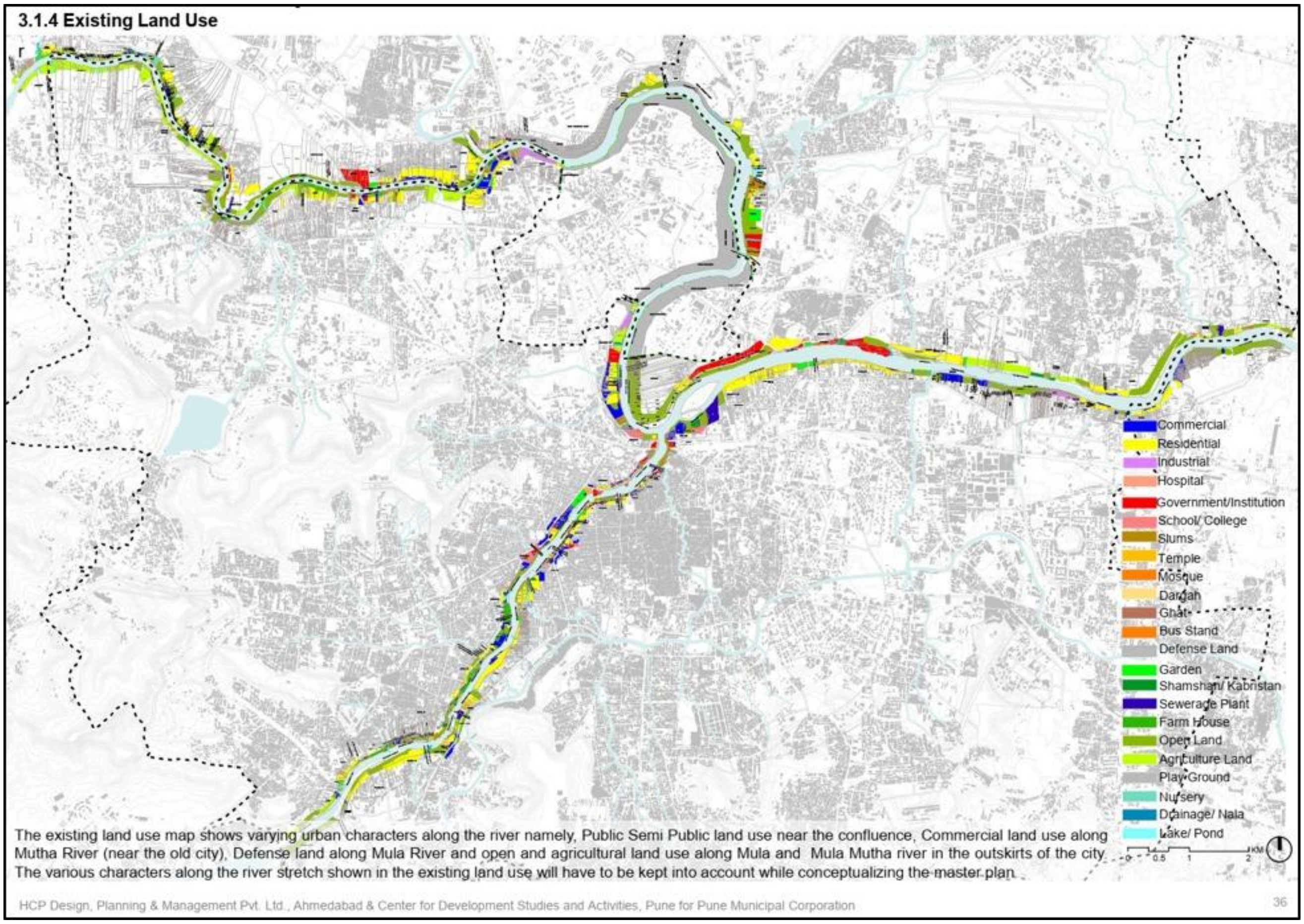
Debris dumping on riverbanks

Construction debris is heavily dumped along riverbanks. Sometimes it is used for levelling of riverside land for protection of farms / property from flood waters. This hampers the riverbank and its riparian zone, affects ground water recharge, and most importantly obstructs and alters the flow of flood water. It causes breaking of stream links which triggered water logging on sites and flash floods in rainy season.

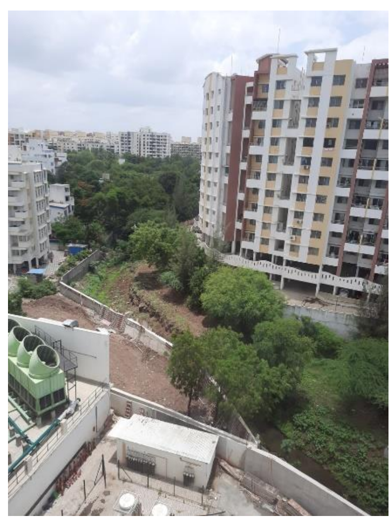
Action / Solution: Strict action by Municipal authorities and separate team of 'river watch guards' to be formed for prompt action.
Removal of all existing debris along riverbank and restoring the area by ecological measures.

Development within blue line

At many places' development is seen within blue line, some structures are illegal, and some are legally constructed with permission of local authorities. This violation of development plan rules encourages others to follow the same and during flooding such areas are highly at risk and are major obstruction to flood water flow.



Land use within red flood line (source: draft DMP Pune Rive rejuvenation project)



Flood Line Violation: Construction in Mula Flood Plain, Diverting Storm drain, reducing stream size, & Heavy dumping, Jupiter Hospital flooded in 2019

Action / Solution: Strict action against such violations and removal of the structures. Some policy to be devised for compensation in case construction is prior to establishment of rules.

Developmental projects along riverbanks

Agriculture lands along rivers are rapidly getting converted into non-Agricultural (NA) status and going under developmental projects (building construction and township development). Builder bye huge riverside lands from farmers and do construction activity. In such cases even though basic rules of EIA and green building development are followed, such major land use changes all over along river are harmful for river ecosystem functioning. In case of flooding scenario, there is no space left for the flood water to spread, ultimately it causes more harm to human life and to the construction itself. Such large-scale hardscape along river also affects ground water recharge. **Examples**: Nanded city along Mutha river, Godrej Properties at Mundhawa, MIT boat club structure etc.

Google map showing location of Nanded City

Solution:

Declaring the riverside area as green zone and giving some incentives to farmers for not converting the land to NA status. Green zone area along both the riverbanks to be decided with the help of geology & ecology experts.

Encroachment along riverbanks (illegal settlements)

Riverbanks are easy sites for temporary settlements of workers or formation of slum. Such settlements spread rapidly, destroying the riverbank habitat, and encroaching upon an area where flood water could spread, recede, and recharge ground water or the hyporheic zone. People living here are most vulnerable during floods.

Flood affected people along Mula River, Flood 2019

Action / Solution: Removal of the illegal settlements from the riverside and provide rehabilitation with the help of NGOS

Disturbed feeder stream network

Feeder streams of the rivers are heavily encroached upon, their banks are cemented/ channelized, sewage discharged into them converting the feeder streams into a gutter. During rainy season, these streams with heavily altered storm water carrying capacity, add up in flooding the bankside residential areas.

At some places ground floor of adjacent societies is under water for successive days during high rains, even if flood situation is not there along river.

As development expanded settlement started creeping on foot hill slopes. Cutting and filling of hill slops cause disturbance in natural flow of streams and blocking it due to dumping of construction debris/waste which indirectly were responsible for non-existence of streams.

Ambil odha, one of the major feeder streams of Mutha river is heavily encroached with considerable decrease in its channel width. Ambil odha watershed study shows that a large percentage of its first order streams are non-existing now. Details of the stresses on Ambil Odha are explained in Case Study 3.

Action / Solution: Making action plan for stepwise removal of encroachment along feeder streams. Removal of concretized banks and stabilization of banks by ecological measures.

Stream Buffers

Lack of sufficient structured and unstructured drainage of flood waters

Structured Drainage is a system of management of urban water and surface water runoff in a more holistic manner.

Current Pune Drainage system is incredibly old, technologically, and scientifically. Existing drainage systems are insufficient in face of flooding.

Action / Solution: Incorporate Sustainable Urban Drainage Systems (SuDS) to deliver a more holistic approach to managing surface water and wherever possible mimic natural drainage. Sustainable drainage is a concept that includes long term environmental and social factors about drainage. It considers quantity and quality of runoff, and the amenity and aesthetic value of surface water in the urban environment.

SuDS manages rainfall close to where it falls. Sustainable Drainage system can be designed to transport surface water, slow runoff down before it enters watercourses. They provide areas to store water in natural contours and can be used to soak (infiltrate) into the ground or evaporated from surface water or transpired from vegetation (evapotranspiration).

Sponge City- Smart City

Underground interventions

Metro pillars in the riverbed reach deep underground. As per aquifer disposition map of Pune city by ACWADAM, the shallow aquifers along Mutha river fall in category of aquifer type 1. Concrete pillars might have hampered the aquifer system.

Action / Solution: – MAR in consultation with ACWADAM

Increase in hardscape area along river and within city

Ratio of softscape to hardscape is not maintained in green zones of development plans e.g. gardens and other open spaces. In all these areas increased use of paver blocks, playground mats are there which reduces groundwater recharge considerably. Due to these structures, there is increase in run-off contributing to flooding. This adds up to pluvial flooding.

Action / Solution: Water sensitive urban designs

Sub-watersheds of rivers getting affected due to unplanned development

Large number of new construction projects are coming up in hilly areas in outskirts of Pune, which are sub-watershed areas of the feeder streams of rivers. Such projects alter the sub-watershed character to large extent.

Secondly, EIA studies for such new developmental projects lacks detailed study of seasonal streams and the morphometric analysis of drainage pattern. Seasonal streams are encroached upon during such projects.

Action / Solution: Improving quality of EIA studies.

Detailed mapping (morphometric analysis) of all such sub-watershed streams in the development plan of Pune, which will assist in not altering the land-use in such cases.

Lack of flood studies

Blue and red line need to be defined after every 20 years and revised maps to be prepared by concerned authorities. This does not seem to be happening.

Lack of flood analysis at local level, lack of creating awareness among public is adding up to more challenges during flood situation.

Need of superimposing PMC storm water management maps and flash flood maps, which will help in clarity of on-groundwork.

Lack of understanding of -

1. Types of flows which need to be managed during floods.
2. Study of type of sediments and amount of deposits in every zone by every stream
3. Mapping of Velocity and hydrograph of every stream as per morphological characters comparing with changed hydrograph of every concretized and channelized stream meeting the rivers.
4. Stages of every river flowing in Pune region. E.g. Young, matured, or premature stage
5. Cross profiles of every stream and tributary.

Section 2

Chapter 7 - Integrated Approach for Flood Mitigation

Fewer tress and compacted soils on bank, and straightened river channels which funnel water towards the city as fast as possible are some common problems all over the world. Obviously, there is not enough room especially in areas of flood plain where the cities settle. Water gets squeezed through bridges, between embanked walls putting people and property at risk.

Traditionally, flood defences have included large-scale, hard engineering in and around towns; flood banks and small-scale engineering for rural communities and farmland; and coastal engineering. However instead of reducing the risk, it has increased the risk of flooding.

In countries like Australia, Netherland, UK, US or Norway there is an increasing interest nationally in how the management of the wider landscape can reduce the risk of flooding to cities, towns and villages by slowing the speed of water coming off the hills and temporarily storing water in areas where it will not cause damage. These techniques can be used alongside more traditional methods to reduce reliance on engineered defences and make our catchments more resilient. This could have a significant effect on reducing flood risk without sacrificing production levels or greatly altering land management practices. These measures can also be beneficial to agricultural businesses by reducing the damaging effects of high rainfall events to farms such as soil loss, track erosion or inundation of buildings.

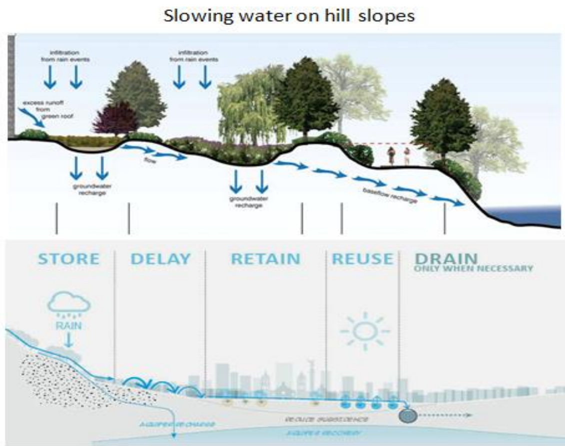
For addressing Urban flooding, a right balance of Natural Flood Management and Structured Flood Management would be a key to manage the floods well and minimize the losses.

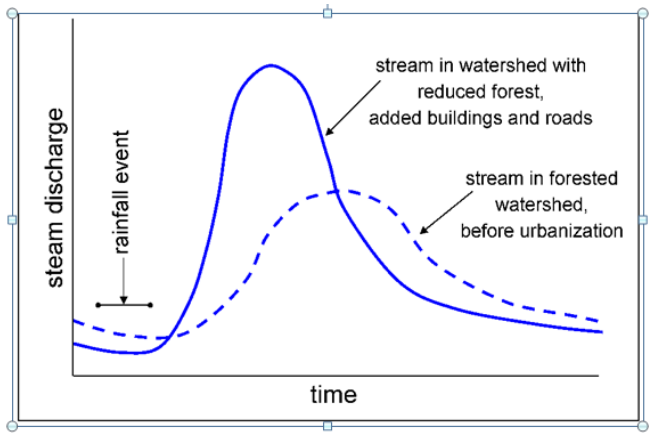
Natural Flood Management:

Natural flood management (NFM) involves implementing measures to restore or mimic natural functions of rivers, floodplains, and the wider catchment, to store water in the landscape and slow the rate at which water runs off the landscape into rivers. Natural flood management takes many different forms and different terminology such as 'working with natural processes', green engineering, sustainable land management or runoff attenuation etc are also used to describe the techniques.

Guiding principles of Natural flood Management:

1. Slowing water: Reducing velocity and allowing water entering subsurface in source regions
2. Creating close canopy of trees, shrubs, grasses, herbs which will hold soil and reduce flow. planting hedgerows and trees,
3. Blocking grips on slopes to reduce velocity
4. Creating buffer strips or zones to percolate water
5. Erosion control measures to reduce sedimentation





Storing water in flood plains by creating and maintaining carrying capacity of streams, tributaries, bunds, ponds, ditches, swales, or floodplains of river so they fill during rainfall events and empty slowly over 12 to 24 hours.

Reducing surface run offs and Increasing subsurface infiltration by reducing soil erosion: Improving soil structure can increase the depth that water is absorbed to, significantly increasing the volume of water that can be stored in the soil. This will make saturation less likely. The root masses will hold the soil and allow seeping in ground.

Intercepting rainfall: Vegetation, especially tree leaves; intercept rainfall so it does not reach the ground. Water is then evaporated from the leaves, reducing the volume of flood water. Trees can reduce the amount of water reaching the ground.

Structured Flood Management:

Conventionally urban storm water runoffs were considered as nuisance and liability. New water – sensitive Urban designs (WSUD) take this as a resource rather than a nuisance or liability. This represents a paradigm shift in the way environmental resources and water infrastructure is dealt with in the planning and design of towns and cities. WSUD principles regard all streams of water as a resource with diverse impacts on biodiversity, water, land, and the community's recreational and aesthetic enjoyment of waterways.

Guiding Principles of Structured Flood Management:

1. Protecting and rejuvenating Rivers, Streams, Lakes, tributaries.
2. Protecting and improving the water quality of water draining from urban environments into rivers, streams, seasonal streams, lakes etc
3. Restoring the urban water balance by maximizing the reuse and infiltration of storm water, and recycling sewage water entering directly in water resources.
4. Conserving our natural water resources through reuse, recycle and system efficiency.
5. Integrating storm water treatment into the landscape so that it offers multiple beneficial uses such as water quality treatment, wildlife habitat, recreation, and open public space.

6. Reducing peak flows and runoffs from the urban environment simultaneously providing for percolation, filtration, infiltration and groundwater recharge.
7. Integrating water into the landscape to enhance urban design as well as social, visual, cultural, and ecological values.

Creating Easy and cost-effective methods of WSUD which could be replicable in other cities for increasing resilience towards floods and climate change. Water-sensitive urban design (WSUD) is a land planning and engineering design approach which integrates the urban water cycle, including storm water, groundwater and wastewater management and water supply, into urban design to minimize environmental degradation and improve aesthetic and recreational appeal.

Guiding Principles for Policy & Governance

1. **Mitigation Matters:** Policy solutions to reduce local flood risks: Budget to be distributed under flood Management of Upper Bhima basin. Central, State, and local Government – Corporations, Gram panchayats etc together must make long term commitments to support flood mitigation efforts by establishing programs that draw from annual budgets for discounts and rebates, or tax rebates for adopting water sensitive designs. Jal Shakti, Water resource Dept, Environment Department, Dept of Drinking water and Sanitation, Jal Sampada, MWRRA along with PMC, PCMC, PMRDA, MPCB, Disaster Management, Agriculture Dept and most importantly Revenue Dept etc must draw the plan together.
    i. Introduce Bonds for City's Natural assets and flood ready infrastructure.
    ii. Tax benefits/ discounts/ Rebates for conserving streams, wetlands, lake in their areas
    iii. Create provision of funds to help communities to become flood ready with help of NGO's
    iv. Foster partnerships/ Collaborations or for flood plain restoration particularly rivers, streams & Lakes
    v. Creating revenue sources for mitigation
    vi. Introduce adaptive farming practices – upstream and downstream areas of Urban
    vii. Policy for opting for Water sensitive designs: stopping all concretized structures in source regions, flood plains and in buffer zones. Replacing them with Water sensitive designs.
    viii. Make policy for urban and rural area rivers in upper Bhima basin

2. **Establishing smarter regulations to reduce flood risks**: Use regulatory strategies to help guiding less risky development to reduce impact of flooding. They should include
    a. updating city zoning ordinances to account for Climate change, Change in rainfall patterns.
    b. Transparency in zoning, mapping, and land use etc to be brought in Public domain

i. Bringing flood zone maps, flood line data, regular updates on floods, flash flood locations etc in public domain
ii. Bringing data of flood preparations by Corporations, Gram panchayats, WRD, State, Revenue Department, PWD etc in public domain.
iii. Bringing NOC's and Building permission details for large Development Projects in Public domain.
iv. Land use change- rules, NOC's in public domain
v. Farming regulations in flood plains and flood zones etc in Public domain in easy to use formats.

c. Encouraging landowners to opt for natural solutions to prevent erosion and run offs wherever possible
d. Existing development to retrofit with water sensitive design regulations – e.g. Stand alone or Large development projects along the banks must be with amount and type of development co relating with proportion of softscape & flood resistant designs.
e. Adopting stringent standards for new developments in flood plains- e.g. For new and large Developments or redevelopments of residential or non-residential structure in the 100-year flood plain, the structure's lowest floor (including the basement and Gas piping, ventilating, air conditioning, and electrical work etc) must be elevated 2 feet above projected flood levels or be flood proofed.
f. Formation of a Hazard Mitigation Committee – Must include WRD, CGWB, Jalshakti, Environment dept, Experts in Ecology, Ground water, Hydrologists, Hydro geologists, Urban Planners, Landscape Architect, Geography experts, NGO's working in water sector, Local citizen groups and all related Govt departments etc.
g. For Large Development Projects- NOC will be required from -Jalshakti, Environment Department, CGWB along with local governing bodies and Collectors & Revenue dept.
h. Bringing all developmental projects along river under one umbrella – This should include projects like RFD, Metro lines, building constructions.

3. **Need of Dam Safety Act:** This will help in keeping account of probable maximum precipitation (PMP) and probable maximum floods (PMF). Currently these are not monitored correctly and unavailable in public domain.

Chapter 8 – River Confluences: eco-sensitive zones

Flood Plain of a river:
Geomorphologically, a flood plain is among the most dynamic of topographic surfaces. This dynamic quality is due to its interrelatedness to the dynamics of a whole system of processes that constitute a stream system and the adjustments such a system makes to the variable flows and loads derived from its drainage basin. Thus, the flood plain can be properly thought of as both a product and a functional part of the whole stream environment and it plays a necessary role in maintaining the overall adjustment that a stream system makes to the variable quantities of water, soluble, and solid particles imposed on it. The complexity of the process relationships between flood plain and stream system has only recently been appreciated and is very sketchily understood.
Confluences of Main stem to tributaries, Natural drains and Rivers in Urban rivers are very crucial areas. Urban settlements grow in pediment zones and flourish in flood zones where confluences get impacted largely resulting in flood risks.

Effects of Confluences in rivers are complex and are studied little until now. However they occur majorly due to Interactions of basin scale, basin shape, network geometry, and disturbance in flood and flow regimes etc.

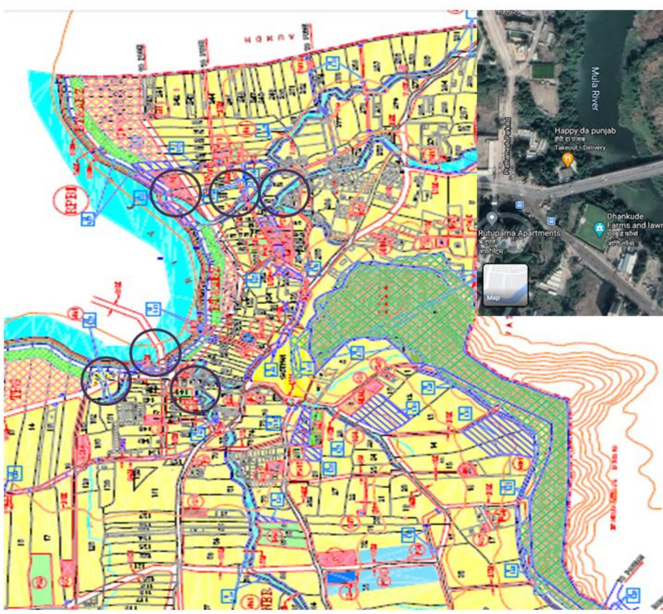
Effects of phases of River at Confluences: Every river and tributary also is in different phase of maturity. All this put together, there is a need to create a policy on Urban Rivers about confluences and flood zones which will enable urban areas to mitigate floods and climate change to an extent. (http://www.netmaptools.org/Pages/NetMapHelp/tributary_confluence_effects.htm

Effects of Morphology: Morphological effects at confluences also reflect the occurrence of storms, floods that trigger transient increases in sediment supply. More frequently occurring floods and associated sediment transport create stratified deposits at confluences [Harvey, 1997]. Flash floods are generated by intense precipitation events, and carry extremely high sediment loads creating deposits intermediate between debris flows and transport of sediments [Costa, 1988]. The frequency and magnitude of erosional and flood events that resupply confluence-specific fluvial landforms (i.e., fans bars, terraces, etc.) are predicted to scale with basin area [Benda and Dunne, 1997; Church, 1998], thereby influencing the age distribution of confluence-related landforms and their associated effects on channel morphology.
Effects of Tributary channel: A tributary channel will locally alter main stem morphology scales with the size of the tributary relative to the main stem. The abrupt meeting of two channels each having independent flow and sediment discharge regimes creates unique erosional and depositional environments with consequent changes in abrupt introduction of sediment and organic material at tributaries trigger numerous types of changes in morphology in the vicinity of confluences.
Effects of Size and magnitude of the debris entering the river: Confluence effects could change drastically depending on magnitudes of debris flow, flash flood, and flood flow events.

All these above effects have been observed by Jeevitnadi volunteers since last 4 years on ground at the confluence of Mula and Ramnadi near Baner.

About Ram River and Mula River confluence:
Ramnadi is an important tributary of Mula River. Urban rivers play major role in an ecosystem of river. The impacts on Urban Rivers are multi level and multi dimensional. Here Mula river is in premature stage and Ramnadi is in matured stage. Confluence of Mula and Ramnadi have resulted in creating multiple ecological processes of channel braiding, Island formation, debris deposition, eroding banks etc. Ramnadi has been experiencing repeated flood events more frequently since 2004.

Floods of 2019 had had proved that intensity of floods near confluence was much under control due to the buffer zone. However recent illegal sand mining has changed the river morphology at the confluence completely posing a great risk of floods.



Multiple confluences and Contours indicating the flood prone regions without any buffer zone

Before Sand mining -
Island of Mula & Ramnadi
and
Ramnadi Braided channels

After sand mining

Mula river width drastically reduced, obstructed.
Island destroyed, vegetation removed

High flood risks

Reference links on confluences and Ramnadi floods

1. http://www.netmaptools.org/Pages/NetMapHelp/tributary_confluence_effects.htm
2. https://www.researchgate.net/publication/227554887_The_Ecological_Importance_of_Tributaries_and_Confluences
3. https://www.downtoearth.org.in/blog/environment/learning-from-past-mistakes-it-s-time-to-save-urban-rivers-73851
4. https://sandrp.in/2020/10/19/drp-nb-19-oct-2020-india-rivers-week-2020-is-sand-mining-killing-our-rivers/
5. https://www.indiawaterportal.org/articles/ram-nadi-citizens-pune-hunger-strike-save-their-river
6. https://timesofindia.indiatimes.com/city/pune/ramnadi-revival-gets-a-big-push-this-monsoon/articleshow/76652681.cms
7. https://www.google.com/url?sa=i&url=https%3A%2F%2Fsandrp.in%2Ftag%2Framnadi%2F&psig=AOvVaw3CbGP8gHiiCedZpwVCbmzP&ust=1615445780157000&source=images&cd=vfe&ved=2ahUKEwjt5afQkqXvAhXDnEsFHcoxBwUQr4kDegUIARCbAQ
8. https://m.timesofindia.com/city/pune/Residents-on-mission-Ramnadi/articleshow/51986439.cms

Chapter 9 – Recommendations for Pune City

Pune is a typical growing city of Urban India. When it comes to flood mitigation, it is vitally important that we understand the earlier landscape and how it is changed with modern landscapes over the years.

Urban flooding is result of combination of floods. Floods from the river because of release of water from upstream dams. Floods from sub watersheds of streams outside main catchment areas. Floods arising due to blocking or diverting of Natural drains. Wrongly designed, badly maintained or under capacity structured drainage system. Flood mitigation measures will largely depend on understanding type of flows. If we understand type of flows, we can understand mitigation of floods.

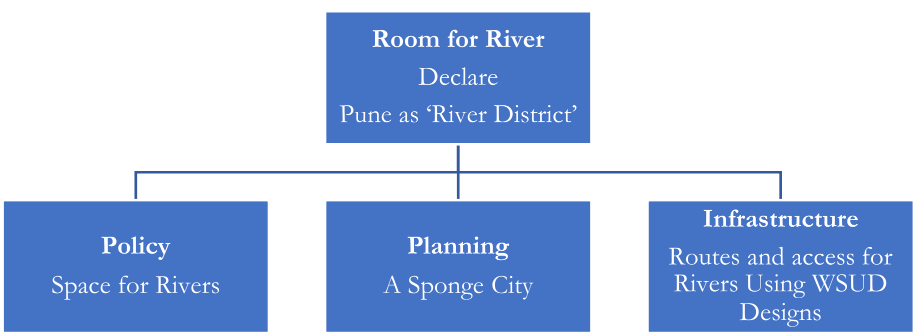
Types of Flows:

1. Surface flow / Overland flow / Horton's flow
2. Subsurface flow- just below the soil layer
3. Groundwater flows
4. Rains directly falling into river and stream channels or in a city.

Due to climate change aspect, we cannot control the 4th flow that is amount of rain falling. But we can mitigate the floods to an extent on surface, subsurface and ground water.

This report is unique where a holistic approach for recommendations and solutions which includes corrective and implementable methods for Surface water, subsurface water, Ground water and sub watersheds of Pune. The report does not include aspect of Dam management or catchment areas.

Room for River: Pune Specific PPI (Policy, Planning, Implementation):



The Room for the River program was originally conceptualized by Dutch flood mitigation initiative. "Room for the river" - For Pune city, we must focus on bringing back the original depth and width of rivers by removing solid waste, debris etc, increased capacity for storing water, relocating lost streams to their original morphological locations, expanding floodplains, creating buffer zones

Removing structures built into the river that disrupt water flow) etc. Making "room for the river" allows landscapes along rivers to be restored in order to act as "natural water sponges" in the event of a flood, it reduces water velocity allows water to percolate in ground in higher / source regions of streams.

Chapter 10 - Policy & Governance: Space for Rivers

Mitigation Matters: Policy solutions to reduce local flood risks

1. Policies for
    a. Preserving local water body
    b. Rainwater harvesting and Ground water recharge for bore wells
    c. Roof gardens, terrace gardens, Vertical gardens in residential areas.
    d. Permeable structures along water bodies
    e. Wastewater treatments by Bio retention, Bioswales etc
    f. Creating urban forests, Rain Gardens etc in Commercial places
    g. Developing aesthetic wetlands in new Commercial areas by reuse, recycle etc.
    h. Giving some incentives to farmers to maintain agricultural land and green zones along rivers
    i. Fishing community to be considered under policy
    j. Developing river eco-tourism models by involving agriculture and fishermen community and creating Urban forests.

2. Restrict development in forest or dense vegetation areas and raze structures which are obstructing natural flow of stream channels or find an alternative to it. Development on Hill top and hill slopes should be well thought considering slope and vegetation balance

3. Utilize CSR, CER funding towards protection of green zones, flood plains and other restoration techniques.

4. Plan for River restorations and not for Riverfronts.

5. Introduce Bonds for source region protection and Flood ready Infrastructure

6. Provision for relocating people from flood prone areas with help of NGO's

7. Creating new and innovative revenue sources for mitigation
8. Revival of river regulation policy and timeline for enforcement of the policy to be declared simultaneously.

9. Declaring green zone and buffer zones along river with strict adherence to flood lines and implement changes in Development Plans

10. Upgrading flood lines wrt flood plains and confluences and other buffer zones from time to time including catchments of Dams and catchments of Sub-watersheds after dams. Flood lines to be marked and implemented on ground for Rivers, tributaries, streams, and seasonal drains.

11. To mitigate and control the anthropogenic flooding situation soon, it is imperative to understand aquifer wise natural recharge areas and their disposition with respect to land use pattern and the geomorphic zones that overlie these aquifers.

12. Formation of Pune river monitoring committee for all the riverine areas under the jurisdiction of PMC, PCMC, PMRDA, Cantonment area, in association with NGOs.

Establishing smarter regulations to reduce flood risks

1. All Administrative zones of PMC, PCMC, PMRDA, Gram panchayat to come under one flood zoning map and one flood zone regulation policy
    a. Zoning in 4 categories – Scarp Zone, Spur Zone, Pediment Zone & Riverbanks
    b. Flood lines applicable to all rivers, streams, tributaries.
    c. All wetlands, Lakes, Buffer zones areas to be declared under "No Development Zone" and their areas to be defined & declared in public domain.
    d. All Green zone and buffer zone areas and other flood prone areas as per flood zone regulation policy applicable to rural & urban.
    e. NOC's given to Large development projects in public domain
2. Flood maps, flood line rules, land use prohibitions to be brought in open source using Google maps for quick information.
3. All Legal cases about encroachments must come in Public domain.
4. Existing development to retrofit / modify with New water sensitive design regulations – e.g. Stand alone or Large development projects along the banks must abide by Flood regulations where PMC, PCMC, PMRDA will invest along with owners.
5. Adopting stringent standards for new developments in flood plains- e.g. For new Developments or redevelopments of residential or non-residential structure as per flood zoning maps
6. Enforcement of flood lines and status of land use change through third party in form of NOC's published in public domain.
7. Enforcement of Policy for opting for Water sensitive designs: Use of permeable structures for compound walls, pavements etc instead of concretized structures in source regions, flood plains and in buffer zones. Replacing them with Water sensitive designs.
8. Geotagged location of each storm water chamber and line should be mapped for assessment of flash flood occurrence.
9. Redesigning building embankments along rivers / streams as they bring more havoc when breached during floods.

Policies for increasing resilience of the City

1. For preserving open spaces along the water bodies by allowing the River corridors space for flow. Provision in budgets to buy spaces for River corridors
2. For Storm water programs in flood plains of high risk. Pediment zones and River zone will require additional buffer zones. Buying of those spaces under different provisions. E.g. For prevention measures under Disaster Management.
3. Create Natural areas buyer Program under CSR / CER: The Willing Seller-Willing Restorer to run jointly under the Natural Areas Protection Program, which works with owners interested in selling their flood-prone properties with those who wish to restore under CSR / CER funding. E.g. Green zones or Riparian zone need protection. Such places can come under CSR / CER funding. City investing for City's Natural resources.
4. For Provision of funds to remove dumping and debris to be used in new constructions as foundations etc. Corporator's funds, / Public participatory funds could be utilized. Alternatively, PMC, PCMC, PMRDA can sell this debris to projects which need filling up.
5. For Implementing Flood line rules in Rural areas: should relate to Farming practices, planning of farmlands, for managing green covers.
6. For Encouraging landowners to opt for natural solutions to prevent erosion and run offs wherever possible. Farmers can utilize Agro forestry program funding. Increasing green and blue spaces etc.
7. For Existing development to retrofit with water sensitive design regulations – e.g. Stand-alone buildings or large development projects along the banks must co relate with proportion of softscape & flood resistant designs. Green roofs and water harvesting should be encouraged.
8. Adopting stringent standards for new developments in flood plains- For residential and commercial and small or big projects.
9. Policy for opting for Water sensitive designs: Introduction and multiple options for Water sensitive designs for compound walls, roofs, permeable paving, Water harvesting, recycle-reuse compulsory etc.

Planning – Smart City, Sponge City

Incorporating Green Infrastructure, or building "sponge cities," should be a core principle that helps us leverage land use planning while enhancing the effectiveness of flood hazard mitigation. There is a critical need for a framework that brings together these planning activities to bolster the resilience of communities everywhere.

"Sponge cities" focus on mimicking the hydrology that existed pre-development using micro-controls distributed throughout a developed site. These micro-controls are located near the source where runoff is generated and help deliver it back to its natural pathway (through permeable materials into the ground, or through evaporation into the air). Micro-controls can include bioretention filters, green roofs, wetlands, and other devices that reduce both runoff volume and speed. Rain can also be harvested in cisterns for landscape irrigation and other beneficial uses.

Properly implemented Sponge City can reduce frequency and severity of floods, improve water quality, and allow city to save water. Associated strategies like improving Green spaces can improve quality of life, improve air quality, and reduce urban heat Islands there by reducing Carbon footprints for SDG goals. Natural Infrastructure will also help in improving current state of Ground water recharge which is lacking currently.

1. **Absorb, clean, and use rainfall in ecologically friendly way** to reduce dangerous and polluted run offs. Every unit must absorb its rains in their premises. This can include
    a. Planning of Permeable roads, footpaths, and open landscape areas
    b. Planning of Roof top Gardens, Vertical Gardens, Terrace Gardens, kitchen gardens, Urban forests etc to reduce heat island effect.
    c. Promoting Rainwater harvesting in residential areas
    d. Promoting Rain Gardens in commercial and Institutional spaces
    e. Creating new Green and blue spaces - Lakes, Ponds, wetlands etc could be incorporated in all Govt Institutes, Research Institutes, and other public spaces etc
    f. Maintaining maximum permeable surfaces in areas of flash floods and around confluences.
    g. Promoting Urban Agriculture
2. **Planning Natural Urban Infrastructure**
    a. Planning for restoring rejuvenating 1st, 2nd, 3rd 4th, 5th order Streams, Rivers, and tributaries
    b. Planning for Improving water quality –By Use of swales, Bio retention techniques etc for improving water quality of storm and sewage drains into Infrastructure
    c. Planning corridors for waterways and restoring their original width and depth by removing all interventions.
    d. Creating Zone wise plans and correlating with Administrative zones:
        i. Scarp Zone
        ii. Spur Zone
        iii. Pediment Zone
        iv. Riverbank
3. **Planning for Natural streams and Aquifers:**
    To overcome the flooding situation and to restore the natural setup a streams and Aquifers, groundwater recharge is an essential component, which can be achieved by application of "Managed aquifer recharge" (MAR) as proposed by ACWADAM. Map of natural recharge areas for Pune's aquifers overlaid on watershed map is given in Section-1 of this report.

4. **Protecting Shallow Aquifer System:**

Underground interventions, especially foundations, basements etc. that lead to loss of valuable shallow aquifer storage. NOC given for foundations to be based on maps of Ground water systems.

5. **Designating & Creating Solid waste blockers** near bridges to obstruct Solid waste entering in rivers.
6. **Planning Rehabilitation programs for flood affected:** Disaster Management must plan for sufficient budget towards preventive mitigation measures
7. **Establish a Flood Prevention Committee Comprising** of Ecologist, Hydro geologist, Geologist, Botanist, Biodiversity expert, Urban Planner & Landscape designer with Ecological background and experience etc. Also, to include NGO's working on ground in water sector along with other Govt experts and different Govt departments like Disaster Management, Environment Department, Police, District Collector, Water & Sanitation dept, Drainage Dept, Revenue Dept etc.
8. **Planning for reducing densification of core areas:** It is important restricting development in buffer zones and flood plains
9. **Well-Planned City and Peri Urban areas:** Peri-Urban areas (Fringe villages) need to be well-planned considering concentration on geographical features so haphazard development can be avoided. City planning further to be modified / altered as per population density under each Administrative zone. The corrective measures to be planned for old structures with retrofitting appropriate water sensitive designs -
    a. For densely populated – E.g. Rainwater harvesting, Green roofs, Permeable concrete surfaces to reduce amount of water flowing outside the building.
    b. Moderately populated- e.g. permeable compound walls / Gabion Structures, Maintain proportion of Softscape to hardscape. Sewage drains with Bioswales, Storm drains with permeable material
    c. Sparsely populated – Open spaces to be utilized with Rain Gardens, Open green and blue spaces, Water sensitive Landscapes for Commercial building etc.

10. **Inclusion of urban stream restoration Program** - (channel development/repairs), watershed development in water budget of local governing bodies.
11. **Planning and revising Mapping of flood lines, Natural drains & Streams**- Restrict new development along these small streams up to 5 m on both sides. In DCPR Bye laws of Maharashtra it is 9 m from well channelized streams.
12. **Create new water sources** from existing streams channels/tracks as they are natural and will not cause any problems in future.
13. **Detail Channel Geomorphology and spatial study** of Study area and upcoming peri-urban areas to find out Constructible and Non- constructible areas and there's also a growing need for channel evolution models that are specifically designed to capture the complexities of urban watersheds and account for the differences in physiographic settings for sustainable development of the region.

14. **Create Public / Private River Monitoring system** using Apps/Security devices / Security Guards: to keep check on illegal construction and dumping, Solid waste etc along rivers
15. **Use of Satellite Remote Sensing:** Urban development intensity and spatial extent can be characterized by using satellite remote sensing data through mapping the impervious surface distributions.

Infrastructure- Route and Access for Rivers

Implementation of all the above concepts by using **Natural Infrastructure and Water Sensitive Urban Designs (WSUD)** for Structured and non-structured and Restoring Natural water bodies close to original state.

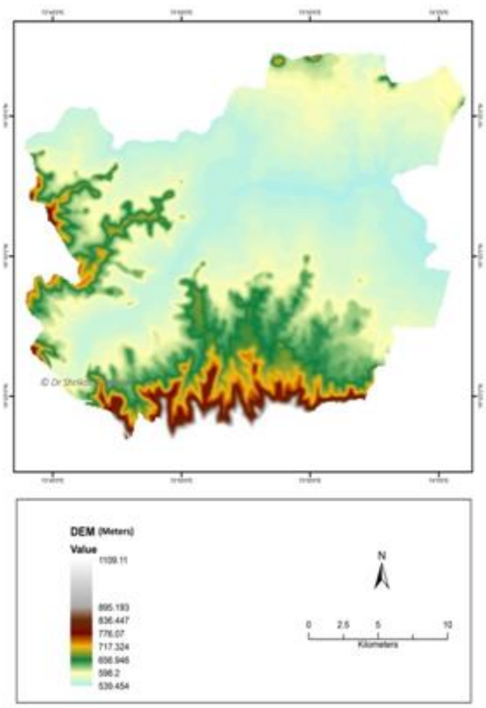
When rain saturates an urban drainage system, the system becomes overwhelmed and water flows into the streets and nearby buildings and homes. This is especially noticeable when the drainage infrastructure is old and in need of repair or replacement. When the water flows (and rises) into the streets, it may cause damage to cars, homes and/or buildings. It also creates potential health hazards from flow velocity and possible pollutants contaminating the water or electrocution due to drowned power lines etc. There are also the inconveniences, like power outages, business closures and disruption of transport services. All these problems are reoccurring in Pune city almost every monsoon.

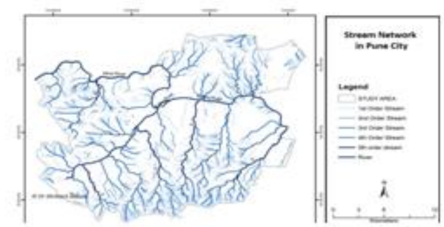
Surface Water: Pune city has not so far planned or undertaken any proactive measures to adopt with Climate Change. The fact remains that urban areas need to focus more on the root problem: the lack of resiliency in their drainage and sewer infrastructure and the need for progressive, sustainable alternatives for filtering, receiving and storing rainwater. Water sensitive Urban Designs is an answer to many issues to reduce the intensity.

Ground Water: ACWADAM's ongoing studies on Pune's Aquifers (ACWADAM, 2018) also reveal that the development of built infrastructure in the twin municipalities of Pune and Pimpri-Chinchwad covers roughly 200 km2 out of the total area of more than 450 km2. Even at conservative estimates, such infrastructure involves an excavation of at least 2 m, on average, below the vadose zone, i.e. in the shallow aquifer zone. This is evident when many excavations for foundations have needed large-scale dewatering, sometimes over months and years. The volume of such excavated 'aquifer material', therefore, is of the order of 400 million m3. The average specific yield or storativity value of the shallow aquifer (conservative) is 0.001. What this implies is a groundwater storage capacity of 400000 m3 or 400 million litres is reduced due to the progressive increase in infrastructure. In other words, a buffering capacity of 400 million litres is effectively lost just due to this factor apart from the reduced availability of groundwater resources in these two cities.

We are dividing Pune region in 4 zones and solutions are created based on ground research and work by reputed NGO's and experts in the field of Surface water, subsurface water and Sub watersheds of Pune city after the rivers enter the city. This is a practical approach suggested by the organizations who are part of creating this report.

River Zones in Pune sub watersheds to be correlated with Administrative zones:





Elevation Class (Mtr.)	Color	Wards (Administrative Division)	Villages
900-1109		-	Kolewadi, Yewalewadi, Bhilarewadi,
770-900		-	Holkarwadi, Yewalewadi, Bhilarewadi, Kolewadi, Handewadi, Kopare, Bavdhan
710-770		Kondhwe, Kopare, Aundh, Karve Rd	Handewadi, Holkarwadi, Wadachiwadi UruliDevachi, Bavdhan Mangalewadi, Yewalewadi Nandoshi, Sus
590-710		Bibwewadi, Dhanakawadi,Ambegaon Bk. and Kh. Dhayari, Kirkatwadi, Kondhwe, Warje, Shivane, Bavdhan, Aundh, Karve Rd, Sahakar Nagar, Hadapsar	Handewadi, Holkarwadi, Wadachiwadi, Undri, Pisoli UruliDevachi
539-590		Tilak Road,Sahakar Nagar,Vishrambaug Wada,Pune Cantonment, Ghole Road, Dhole Patil Road, BhavaniPeth, WarjeKarve Nagar, Karve Rd, Mhalunge,Aundh, Mundhwa, Yerwada, Sangamwadi, Khadki Cant, wagholi, Lohegaon	Khadakwasla, Nanded, UruliDevachi

1. Scarp Zone- Space for maintaining natural flow
2. Spur Zone- Space for maintaining natural flow
3. Pediment Zone –sufficient space along rivers, streams etc
4. Riverbank – Space to accommodate buffer zones

Implementation is further divided as per following with a deadline to be created by Wadnere Committee -

1. **Immediate action** – e.g. Removal of debris, bridges, Widening of rivers, tributaries, and streams near confluences. Revision of Dam safety manual etc
   a. In riverbed
   b. On Riverbank
   c. In Riverbed

Sr. No.	Issues	Timeline
	All Departments of PMC - Removal of Channelization of Mutha River to be replaced by water sensitive Natural designs –	1 year

	e.g. series of wetlands, Retention/ Detention ponds, Green zones, buffer zones etc	
	Removal of embankments to streams and tributaries and seasonal drains- Customized Water sensitive urban designs as per the morphological features and hydrology and pollution level of that area. - e.g. Bio retention for streams with sewage, erosion control natural infrastructures	
	Building Dept: ▪ Removal of Earlier debris from old constructions to be shifted to a designated place, away from rivers ▪ Removal / shifting of all existing constructions in flood lines	Within 6 months before Monsoon 2021
	Solid Waste Dept: ▪ Removal of Solid waste from all water bodies ▪ Creating solid waste blockers along banks and outfalls. ▪ Vegetative fencing along the banks with Bamboo & shrubs at Chronic spots. ▪ Regular and routine inspections throughout the year, ▪ External audit by Flood Hazard Committee	Within 6 months before Monsoon 2021
	PWD: ▪ Removal of redundant old bunds, Weirs, Old discarded bridges, and causeways which have become dangerous and obstruct the flows	1 year
	Drainage Dept: ▪ Removal of old, abandoned chambers, pipelines, and cemented structures from the riverbed. ▪ Regular and routine inspections throughout the year, ▪ External audit by Flood Hazard Committee	Within 6 months before Monsoon 2021

2. On Riverbanks

Sr. No.	**Issues**	**Timeline**
	PMC, PCMC, Cantonment & Gram panchayats: Removal of concrete embankments to be replaced by Water Sensitive structures, e.g. Gabion bunding wherever most important	Wadnere Committee to decide
	PMC, PCMC, Cantonment & Gram panchayats: Removal of debris raised to create platforms in blue lines, in Green zones etc and to be shifted at designated dumping land.	Within 6 months before Monsoon 2021

	Solid Waste Dept: Removal of all concretized Ganesh tanks to be temporarily replaced by portable tanks during festival. Alternative arrangement for immersion to be made at societies, townships, gated colonies etc to reduce stress on rivers.	Within 6 months before Monsoon 2021
	Local wards & Corporators: Removal of unnecessary Concrete Ramps, steps, shades etc	Within 6 months before Monsoon 2021
	WRD: Constant monitoring system with help of Drones and sensors to stop encroachments, dumping debris and Solid waste. ▪ Provision in Budget ▪ Heavy fines ▪ Installing Flood line alarm systems ▪ Revenue Dept: No Land use change. Reservations of buffer zones, flood lines, Maps superimposed on Google in public domain	Ongoing

3. **Long term Planning & Management**- e.g. Ecological restorations, Improvement in structured drainage system etc
4. **Continued / Consistent Management:**
    a. Maintenance of drainage lines,
    b. Monitoring and surveillance along banks against encroachments in form of Drone or Mobile App.
    c. Removal of Solid waste Etc.
    d. Monitoring, Maintaining Wetlands, Bioswales, Bioretention treatment areas etc.

Source Regions: Measures to increase permeability & reduced velocity

e. by developing closed canopy forests
f. Maintain/ Increase mosaic character of land use
g. restoring natural channels as much as possible
h. No hardscapes/ Concrete structure without mapping aquifers in source regions.
i. Individual farm owners will not change Natural water Channels
j. No flattening of landscape
k. Protection of catchments

5. **Flood plains and confluences:**
    a. Maintaining river width and Meanders is most important for flood mitigation.
    b. Creating Riparian forests, Green zones to be maintained stringently
    c. Creating series of wetlands and detention basins

d. At severe damaged banks, embankments with gabion structures without reducing width of river
e. Ratio of softscape to hardscapes in buildings
f. Bank stabilisation with canopy vegetation, Green zone protection
g. No construction along banks in floodplains
h. Maintain environmental flows as mandated by NGT
i. Remove in channel construction / obstructions / debris / solid waste
j. Create vigilant monitoring system for bank protection
k. Widen, deepen & Free up all streams
l. No constructions or changing cross section in Red & Blue lines
m. Planning and restoring seasonal drains and upgrading constructed Drainage system
n. Reducing siltation by natural bank stabilization and restoring meanders and removing obstructions in flow.

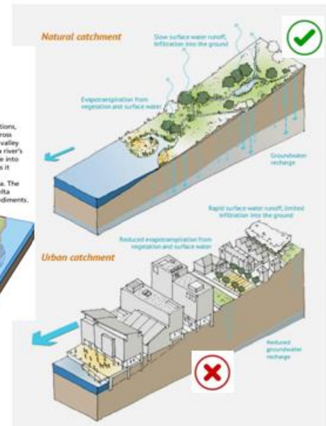
6. Agri- Environment Measures in Rural areas

a. Utilization of forests to optimum
b. Using fallow lands for flood control measures
c. Use of retention and detention ponds
d. Public awareness and active participation in managing floods
e. Retaining water through natural media must have priority over soft run off. – Combination of use of detention ponds, retention ponds, wetlands, soil, vegetation as per the local conditions should be used.
f. In event of heavy and lasting rainfall measures to reduce sediment yield could be more beneficial-creating mosaic of forests in a landscape could reduce sediments. – Riparian woodlands and meadows should be encouraged
g. Restore River's natural flood zones

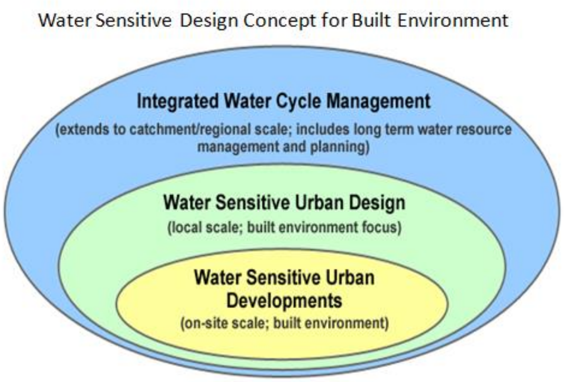
New Urban Infrastructure will require an inclusive approach for increasing resilience of the city to mitigate climate change, meeting SDG goals of Smart city understanding the Natural resources and meeting Urban needs towards Water security, safety, and quality.

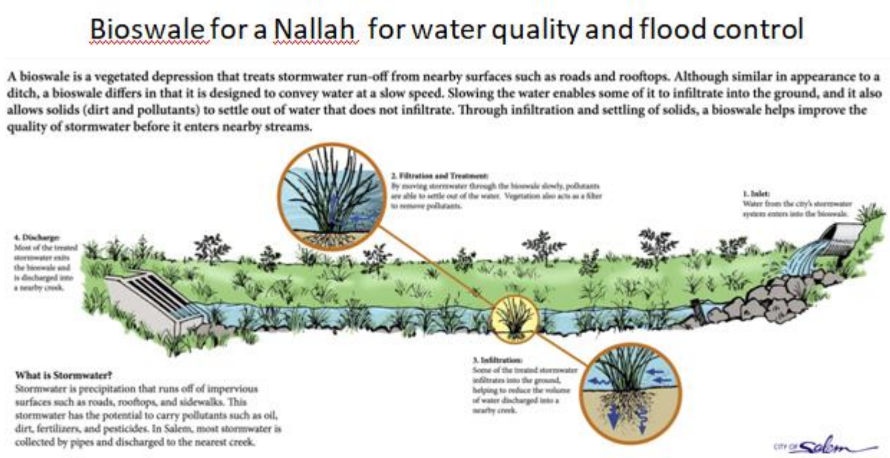
Urban Planning:

1. River zones, correlating with Administrative zones



2. Using Water Sensitive Urban Designs: Structured for built environment





3. Nallahas along the roads

Nallahs along roads

Bioswales

4. Smart city planning for footpaths

Rain water harvesting designed for smart city foot path

a. 

5. Public areas – footpaths, roadside spaces, culverts etc to have permeable designs

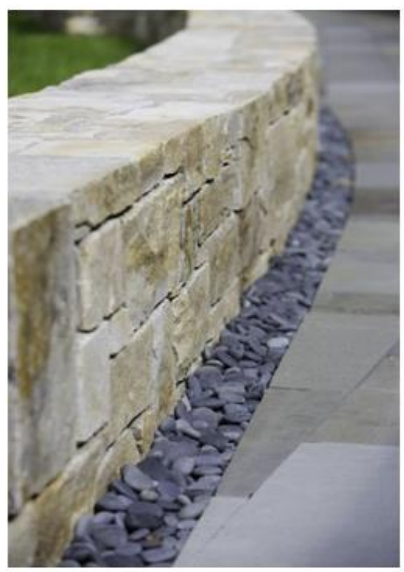
Permeable surfaces as per natural gradient Morphological Characteristics

a. 

6. Private properties
   a. Proportion of Hardscape to softscape as per river zones

Proportion of soft and hard scape

Permeable retaining wall and storm drain



b. Rainwater harvesting in residential and commercial spaces

Rain water harvesting for Moderately dense areas

Densely populated areas – Rain water harvesting, Green Roofs

For Commercial Buildings

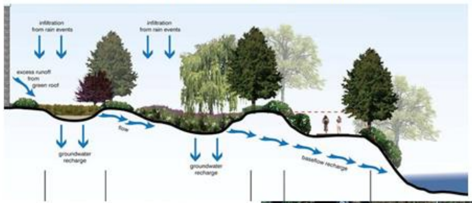
c. Reducing runoffs

Reducing Run offs

7. Source Region planning:

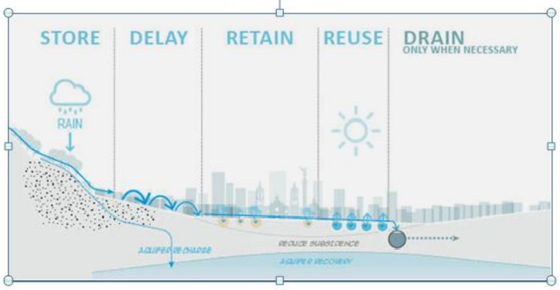
On Hill Slopes after reserving recharge areas of streams

Meandering storm water on hill slopes



Permeable retaining wall on hill slope

For Hill Slopes



8. Flood plain & Buffer zones planning
   Removing concretized structures to be replaced by Water sensitive designs

a.

Bank Stabilization using natural materials.

Coco coir mats & logs

9. Erosion and sediment control

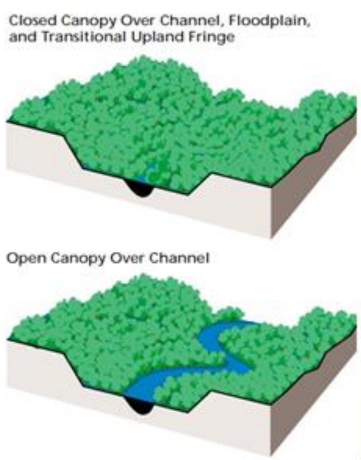


Figure 1.25: Examples of vegetation structure in the stream corridor. *Plant communities play a significant role in determining the condition and vulnerability of the stream corridor.*

10. Flood prone areas:
    a. Land use in form of parks and playgrounds that can tolerate occasional flooding.
    b. Buildings and bridges to be elevated and designed to withstand temporary inundation.
    c. Drainage systems to increase their capacity for detaining and conveying high stream flows; for example, by using rooftops and parking lots to store water.
    d. Techniques that promote infiltration and storage of water in the soil column, such as infiltration trenches, permeable pavements, soil amendments, and reducing impermeable surfaces to be incorporated into new and existing residential and commercial developments to reduce runoff from these areas.

e. Wet-season runoff by reducing the width of concretized street and incorporating vegetated swales and native plants along streets
f. Moving of vulnerable structures
g. Developing a flood information and notification system (FINS) to address the need for prompt notification of flood conditions in urban areas where streams rise and fall rapidly. E.g. Ambil Stream. FINS should be based on a large network of stream flow gauging and rainfall stations which will broadcast information within minutes of being recorded via radio telemetry. The system automatically notifies the IITM and Disaster Management dept in the region when rainfall and stream flow indicate the likelihood of flooding, giving these agencies additional time to issue warnings and evacuate areas if necessary.
h. Quantifying Channel Maintenance In stream flows. The channel maintenance quantification approach is facilitated by site-specific hydrologic, sediment, channel geometry, and vegetation data.
i. Calculating effects of bridges on river hydrograph characteristics and displacement of water on ephemeral river ecosystems like Pune.

Conclusion

Even as India struggles with the water crisis – extreme droughts or extreme floods every year, we have failed to take care of our rivers. Flawed models of natural resource management and careless urban lifestyles have had a disastrous impact on the state of rivers. The River is our most visible source of water and unfortunately the most neglected too.

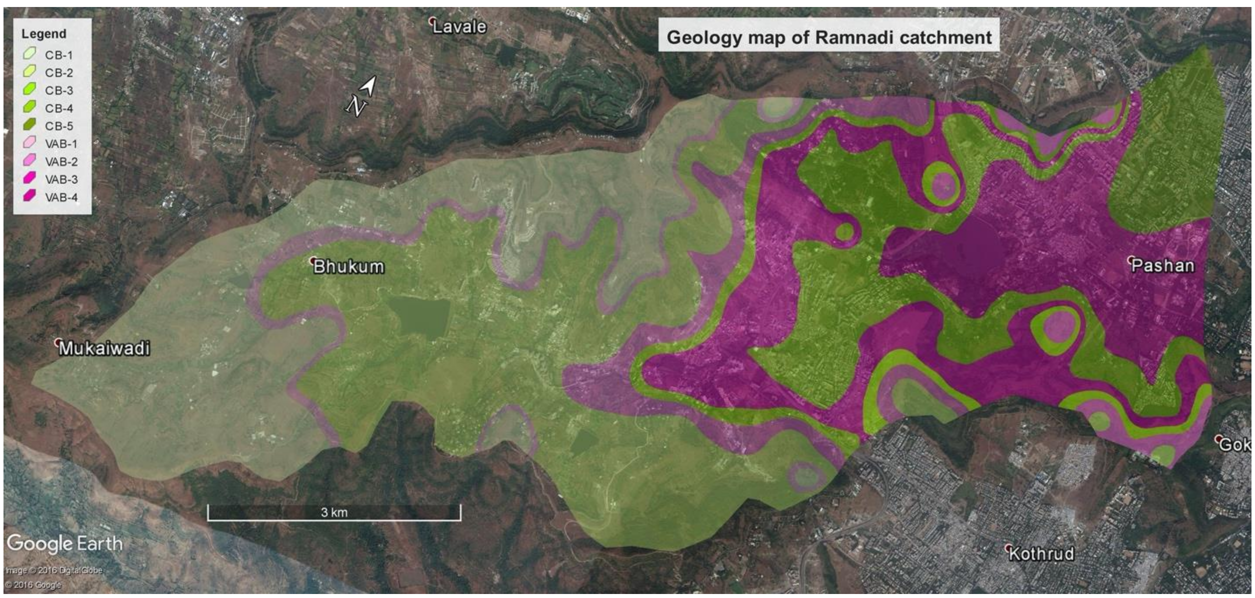
We must accept and adapt ourselves to the changing climate - shorter spells of intense rains and hotter summers. Pluvial and fluvial flooding are turning river floods more gruesome. Each year, there is loss of life, livelihoods and built capital. Each year crores of Rupees are allocated for disaster management, and yet lost lives are impossible to compensate.

Flooding is a natural characteristic of every river. It is harmful to humans when we disregard the rivers in urban planning, change their channels and build structures within their flood lines. The only way to adapt we to the changing climatic situation is to plan human settlements and activities with the least disruption to riverine ecosystems. For this, we must make the necessary changes in policy, governance practices and lifestyles of urban citizen.

The rivers are the reason why human settlements have thrived and prospered for centuries, and today their very existence of the rivers is threatened by human callousness.

Case study 1 – Stresses on Ram Nadi

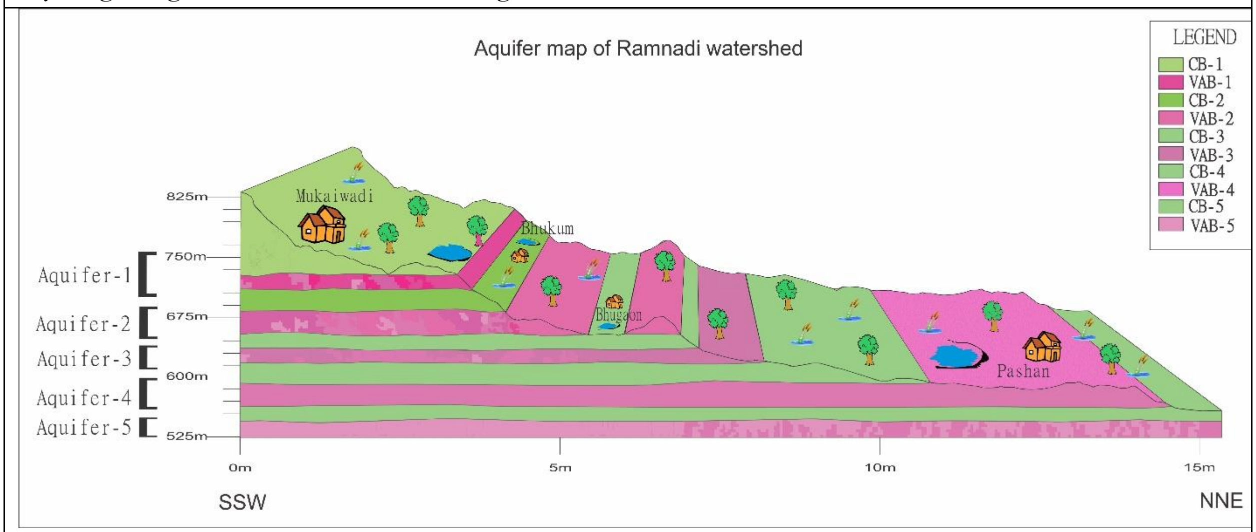
Ramnadi is tributary of Mula river. The river flows in a north-easterly direction and finally confluences Mula river near Baner. The total watershed area is about 63 km2. The highest point is situated near Bhukum (800 m above MSL). The lowest point is situated near Baner (560 m above MSL). The watershed comprises vesicular amygdaloidal basalt 1 (VAB -1) is exposed at higher elevation in Mukai wadi area, while VAB - 5 is exposed at lower elevations in Baner area. Pashan lake is located on VAB-4. Bhugaon minor irrigation tank and Bhukum percolation tank are located on CB-2 and Mukai wadi tank is at the contact of VAB-1 and CB-2. The topography of the area is rugged and undulating, in the upper part of the basin and even in the valley portions. However, after Someshwarwadi, the valley tends to become comparatively flatter.



ACWADAM have mapped 5 aquifers in Ramnadi watershed. The typical lithological setup has been identified in the Ramnadi watershed involving amygdaloidal basalt capped by red tuffaceous layers and underlain by compact basalt. Aquifer 1 is the thickest aquifer in the watershed and compact basalt constitute major portion in this aquifer, while amygdaloidal basalt is approximately 13 m in thickness. It is exposed in upper reaches of the watershed and is largely unconfined in nature. Aquifers 2,3,4 are intermediate aquifers. Aquifer 2, 3 exposed at Bhukum and Bhugaon area are unconfined in nature. While borewells in this area tap aquifer-4 as confined aquifer but the same lithologies are exposed at Bavdhan and Pashan, where it is an unconfined aquifer. Aquifer 5 acts as unconfined aquifer at Pashan and Baner area, while it is confined at Bavdhan and at higher elevation in Pashan as shown in figure below.

In the watershed, thick vegetation cover has been observed along entire stretch and especially along the Ramnadi river course. Less disturbed ecosystem in upper and middle reaches than lower reaches because of human interventions to the nature. The proliferation of urbanization in the lower reaches and recently even in its upper reaches have surely affected both the aquifer storage capacities and recharge. Moreover, groundwater abstraction increased due to (urbanization). With reduction in natural recharge and the loss of aquifer material has implied a gap between demand and availability of groundwater resources. While studies on groundwater quality are in progress, quality of groundwater based on random samples seems to have deteriorated, because of many factors.

Hydrogeological units overlaid to Google Earth



Aquifer system of Ramnadi watershed

Changing precipitation patterns and increased intensity of rainfall along with the aforementioned factors is likely to result in a higher probability of urban flooding, particularly in the downstream portions of the Ramnadi watershed.

For two decades, Ram Nadi has been in spotlight due to urban encroachment. Areas such as Bhukum to Baner, having new constructions, are facing flash floods. Despite that, plotting and construction activities at the source of Ram Nadi are increasing day by day. Half of Bhukum has hilly terrain, which lies offshoot of Sahyadri range. From Manas Lake to Bhugaon Village, this river flows like a minor stream, with sewage and construction debris being deposited in the stream along its way.

In the last 5 to 6 years, construction activities have increased near Paud-Pirangut area, so its impact is seen on total landscape of concerned area. It is observed that, flash flooding is activated mainly in rainy season because of dumping construction debris and sewage deposition, ultimately blocking the natural flow of stream.

Retaining Wall in Ram Nadi Channel (front and Back view)

Dumping in Ram Nadi Channel

Construction & Dumping near channel

The second part of Ram Nadi flows from Bavdhan to Pashan area. Due to unplanned construction activities, 20% of total streams of this watershed have non-exist. At both sides of Bavdhan road, near Chandani Chowk, around 7 first order and 3 second order streams have vanished. Sagar Cooperative Society, Vinyan nagar society and Shinde nagar area are located on streams, which have disappeared. The eastern sides of Bavdhan, foothills are excavated (300 slope) and totally occupied by commercial and residential buildings. Pashan Lake, having historical importance has been destroyed due to dumping of sewage and construction debris.

Pashan - Sus road is constructed in east- west direction on north- south Pashan hill cutting the hill against slope and residential development from State Bank Nagar to Pashan Lake which covers half the hills are the main cause of obstructing the natural flow of water.

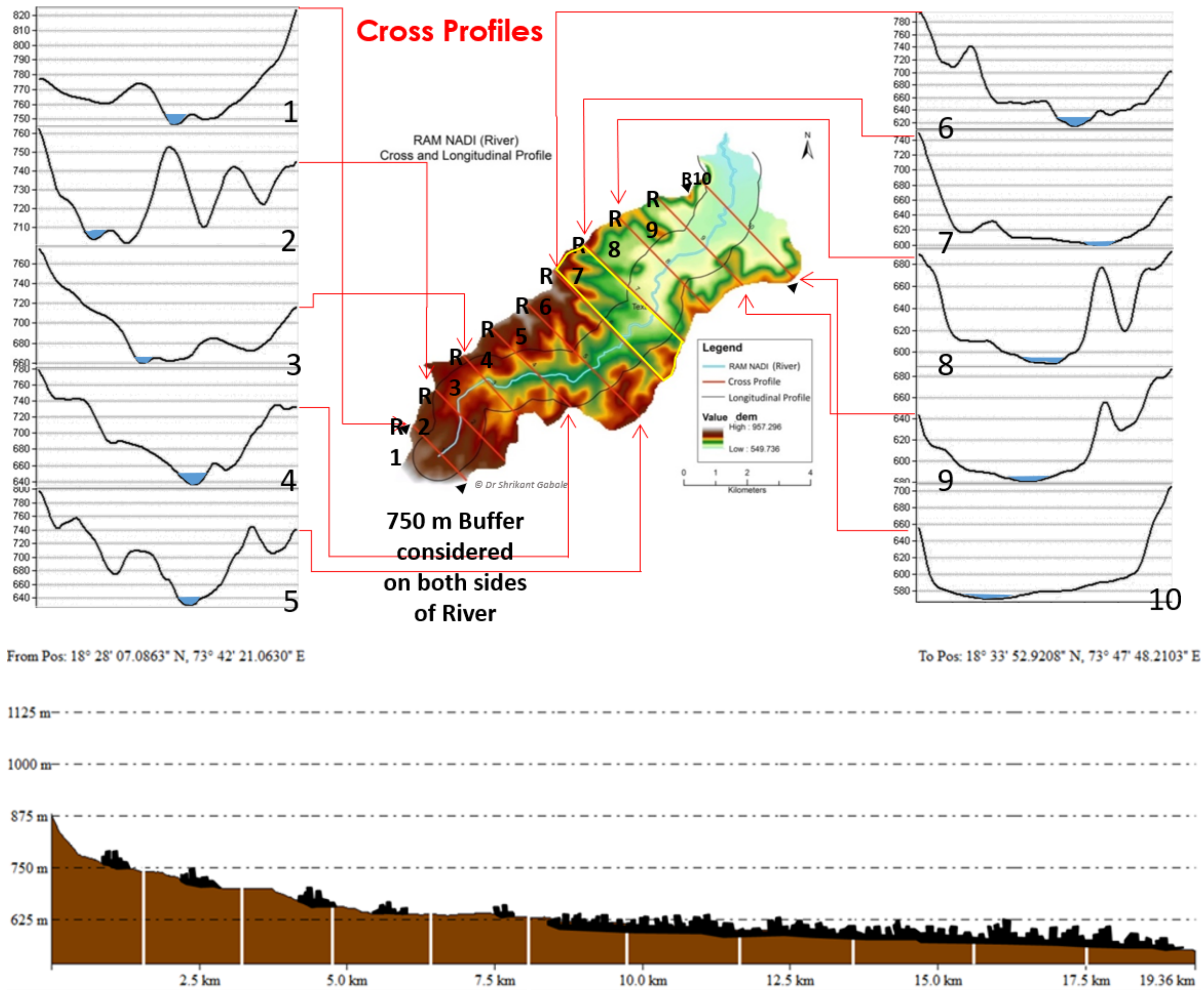
Ram Nadi has no proper flood line demarcation done till today. Reason behind the flash floods, according to residents, is the careless attitude of local government (PMC) towards encroachment into the flood lines of City Rivers / natural streams of Ram Nadi.

Construction on Hill Slope (Bavdhan Area) **Construction on Stream (Banner - Pashan Road)**

The width of the river channel has decreased by illegal construction activity dumping of construction debris near the confluence of Ram Nadi and Mula River. Due to reduction in width of Ram Nadi its channel is burdened by fluctuating volume of water causing harmful conditions for surroundings. Construction of retaining wall along the channel banks by PMC may create problem of flood in monsoon due to reclamation of land in flood zone by builders or societies. Also, the construction of retaining wall has reduced its width which covers almost 15% of the channel area creating problems like, overflow of sewage which gets mixed with river stream spreading all over causing waterlogs and back wash.

Sewage dumping in channel Pashan Gao than **Silt deposition near Pashan Lake**

Sewage dumping and unwanted vegetation in channel (Bhugaon)	**Construction on stream near Chandani chowk – Bavdhan**



Latitudinal Slope / Degree / Gradient analysis done by Profiles and buffer around Ram Nadi

Areas such as Bavdhan, Bhukum, Pirangut and some part of Karve Nagar fall under this watershed study area. Few areas are within Pune city boundary which covers up to R6 – R10 region. Area between profiles R5 to R7 is more prone to problems as the slope of average 5º -10º (i.e. 1:5) is feasible for construction, and most of the development in recent years has been seen in these parts of study area, causing various environmental problems including flash floods, obstruction to natural flow of streams and also increase in non-existence of many streams. The intensity of development in this area was such that the width of Ram Nadi (River) flowing through the city is literally reduced to 4-5 m i.e. comparatively nothing.

Longitudinal Slope / Degree / Gradient analysis of Ram Nadi

	Altitude (MSL) HEIGHT (M)	SLOPE (DEGREE)	%
Longitudinal Profile	225	17	30

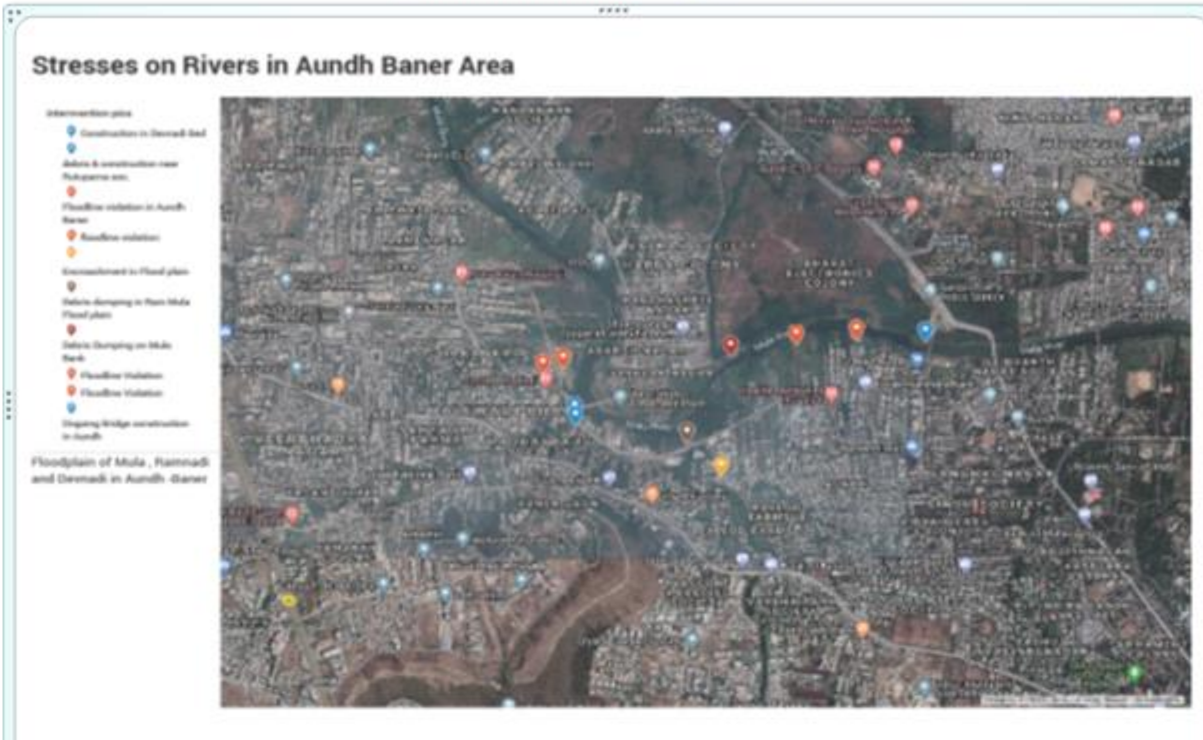
The longitudinal profile of the river along with the urbanization explains the important relationship with the overall topography of the watershed. It is clearly observed that the source region of the river is having less expansion of the settlements, which is since the source of the river is always at a high altitude and slope. Any river or stream can have overland flow when there is enough water and a particular degree of slope. The longitudinal profile of the river explains the status of the river from the source to its mouth. Ram Nadi has a source elevation of around 875 m from the mean sea level. The graded profile of this river explains that it has been altered by the anthropogenic activities.

From the source to the elevation of around 629m (5.750), there are few settlements. It can be depicted from the profile that the slope gradient plays a dominant role in the expansion of the settlements in the source region. Below 629m, there is an abrupt change in the landscape. This is indicated by the degree of slope which gently decreases towards the confluence. The gently sloping land has favoured the human activities in the form of construction of buildings and infrastructure along with its expansion. There is a high density of settlement and population growth in this section of topography. It also explains that the human intervention is more in this region.

The longitudinal profile of the river clearly explains that anthropogenic activities have altered the landscape according to human needs. Above 629m (5.75 0), the terraced profile clearly indicates the change in landscape. Below 629m (R5), the profile is gently sloping favouring expansion of human settlements and infrastructure. Most of the settlements in this basin area lie in between 2.610 to 5.750slope. Due to saturation and unavailability of plain land there are some settlements which lie in between 90 to 300 slope regions. Although these slopes are not favourable for settlements, slopes are altered to form settlements and this type of development is increasing observed in early years from confluence to source of rivers.

Case Study 2 – Stresses on Mula river & Tributaries

Mula Stresses – Ambedakar Bridge – Rajiv Gandhi Bridge



Structures and redundant structures, Pipelines in Riverbed

Concretized ramp in river bed
Bridge construction
Debris from Bridge
Solid waste

Actions –
Remove Ramp
Remove Debris
Remove Solid waste

Large scale structures in riverbed

Actions :
New Ghat structures
Counters
Redundant pipelines to be removed

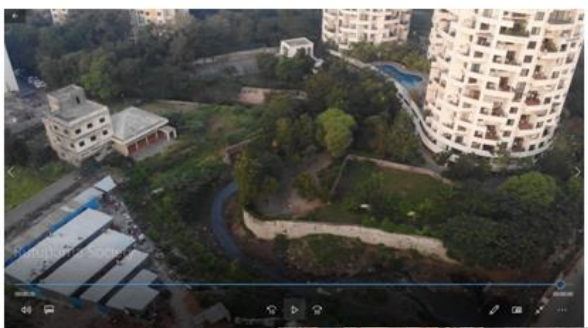
Mula River in peri urban areas

Deforestation
Concretization
Infrastructure in flood lines

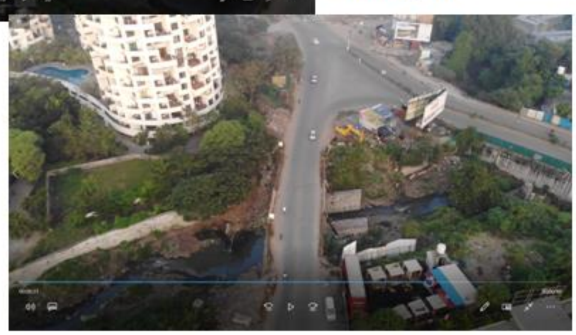
Ramnadi Stresses in Flood Plain: Cross section changed, Flood lines violated, Road Construction, Debris, Redundant old drainage lines

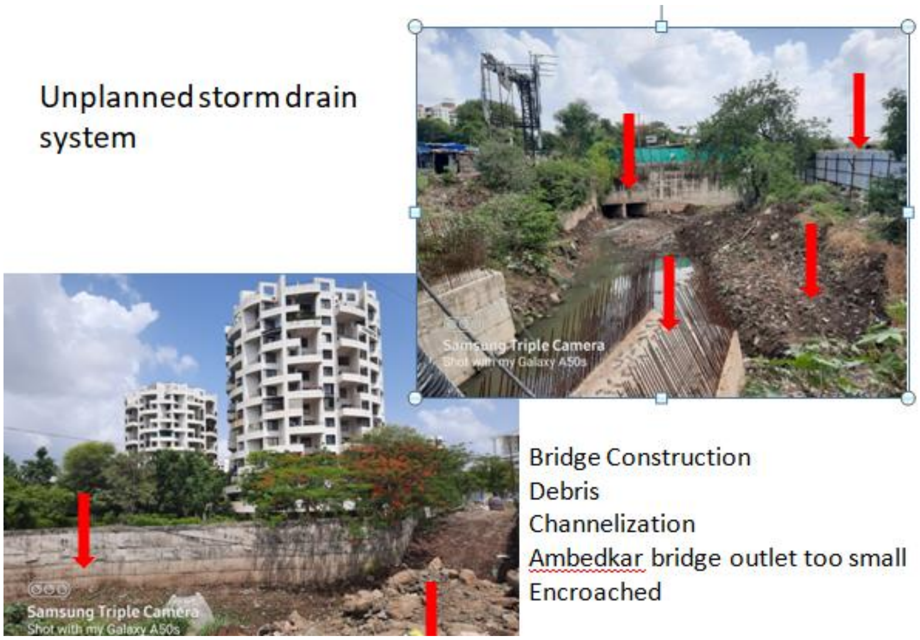
PMRDA – New developments in Flood Plain

Debris dumping,
flood lines violated

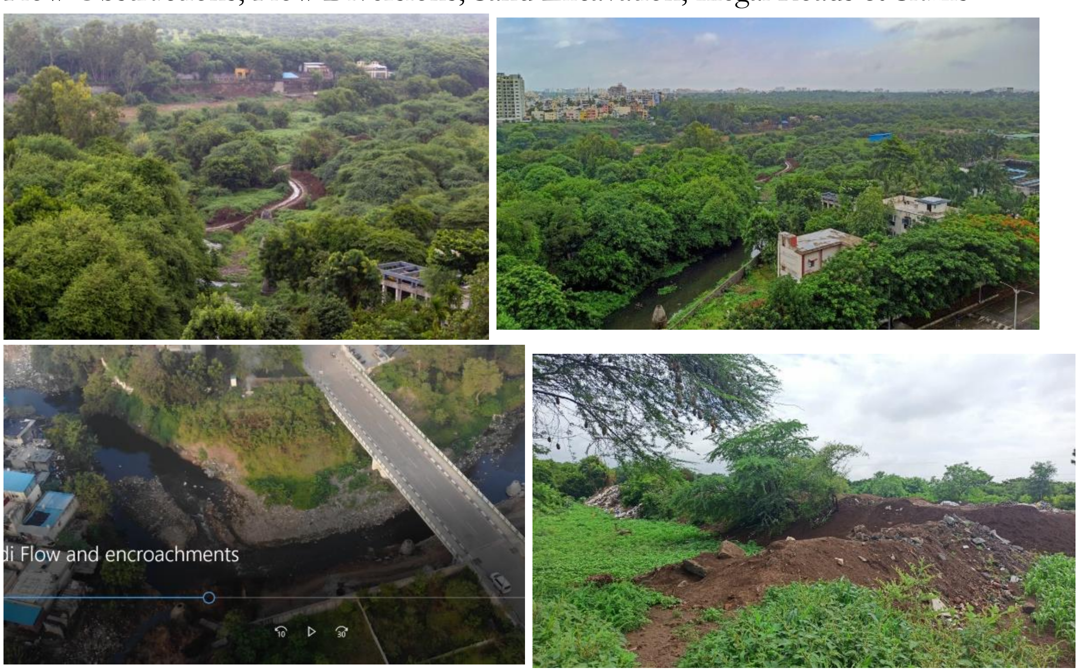


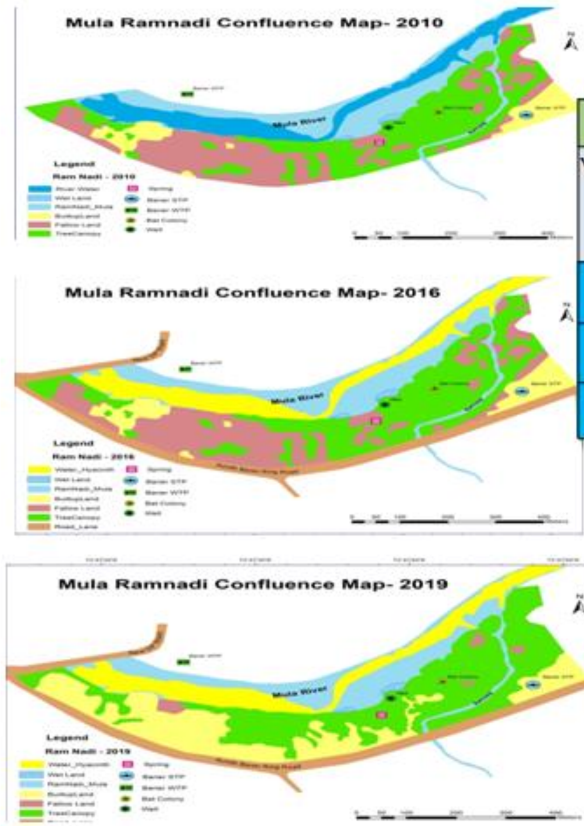
Flood lines encroached, flow diverted, cross section changed





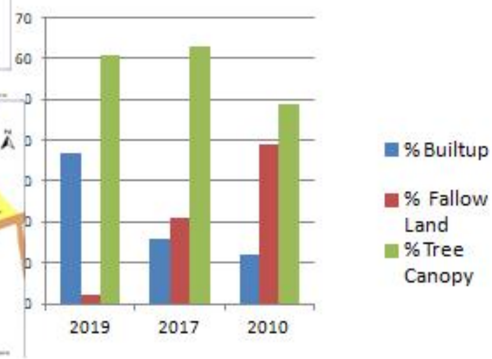
Flow Obstructions, Flow Diversions, Sand Excavation, Illegal Roads & Slums





Dumping in buffer zones

Land Type				
Year	Built up Land	Fallow Land	% Built up	% Fallow Land
2010	21587	72337	12	39
2016	29846	38536	16	21
2019	68807	3825	37	2



Fallow lands converting to build up lands in green zones of flood plains

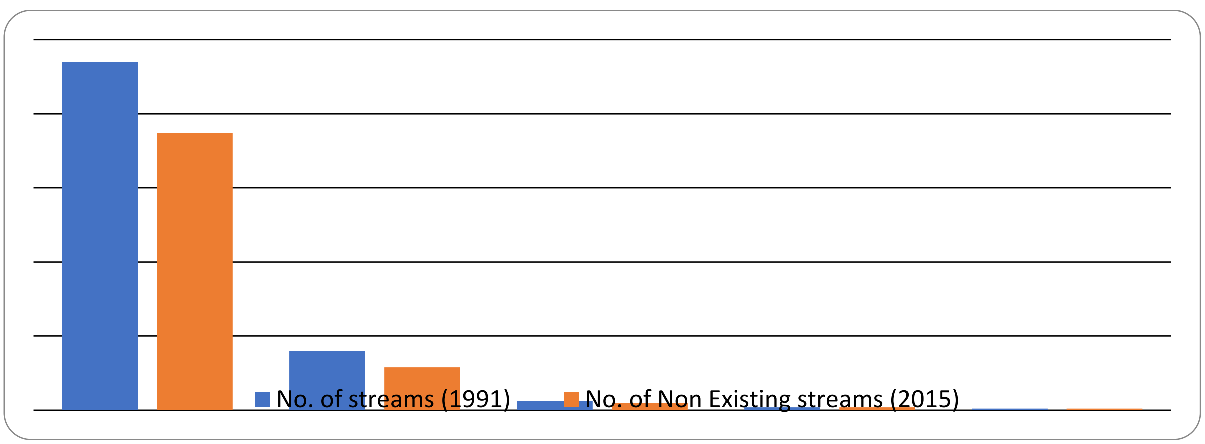
Heavily encroached stream meeting Mula river at Vishrantwadi

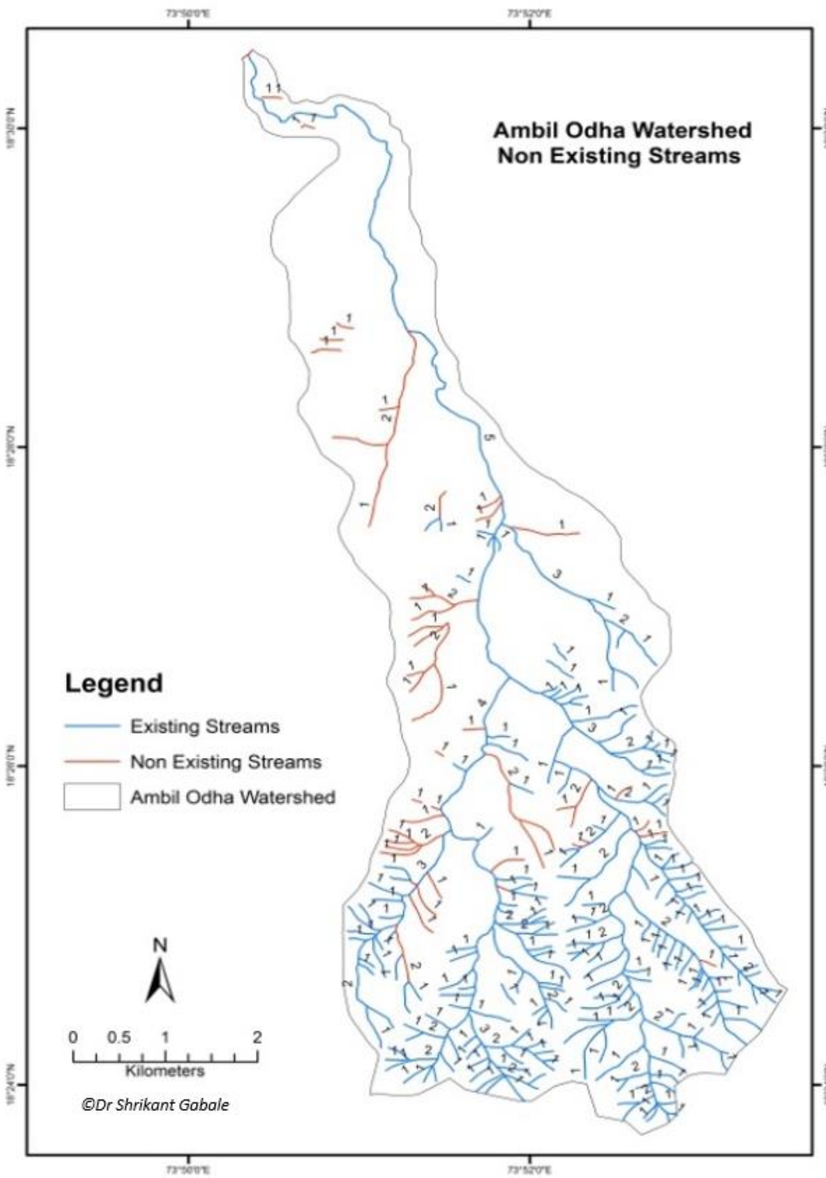
Case Study 3 – Stresses on Ambil Stream

The floods in Ambil odha are consequences of concretisation especially in the recharge zones of the main aquifers and narrowing of stream channels both of which lead to increased overland flow that is beyond the carrying capacity of the narrowed channels, resulting into anthropogenic flash foods. Avoiding such flash floods in the future require an understanding of the relationship between surface water and groundwater interactions and the ecological approaches required for correctable and preventable measures.

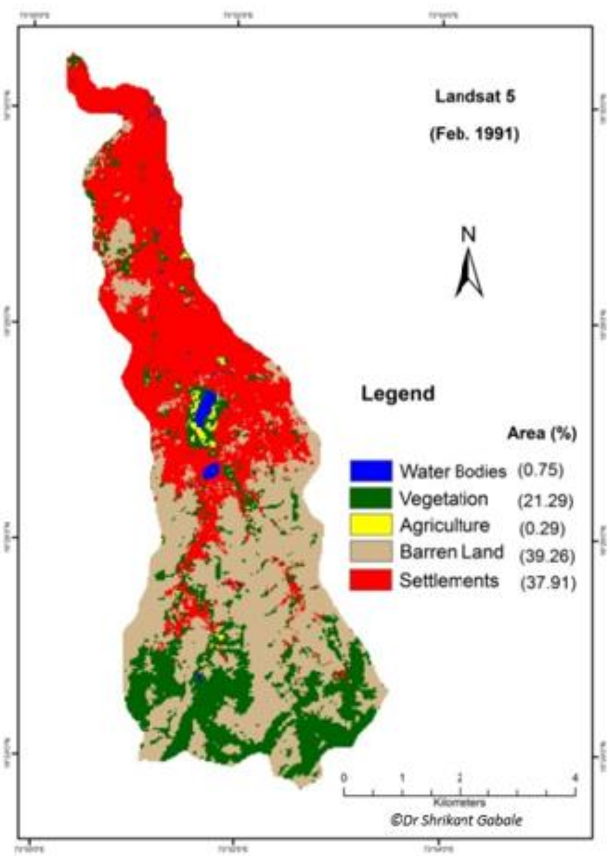
Ambil Odha stream watershed analysis (Dr. Shrikant Gabale)-

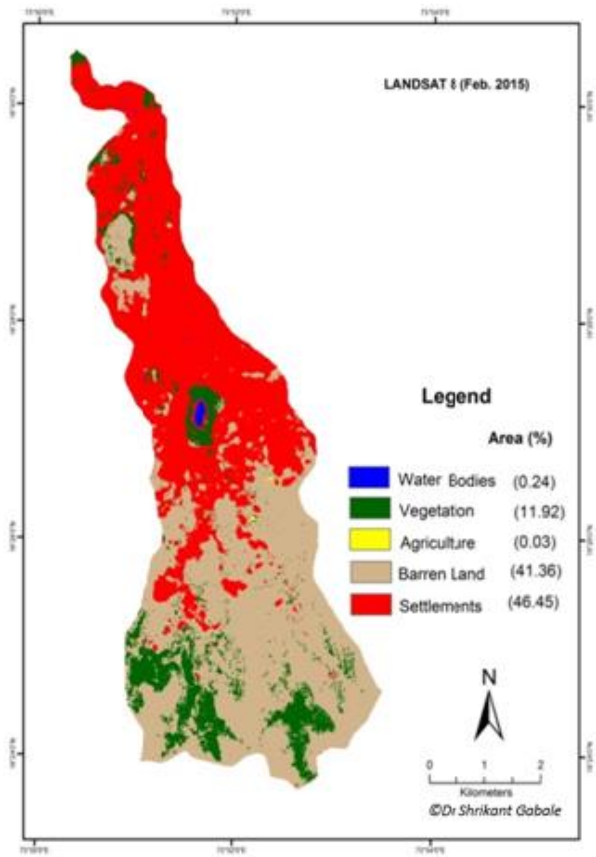
Year	**1991**			**2015**		
Order	No. of streams	Length (km)	(%)	No. of Non Existing streams **(Available streams)**	Length (km)	(%)
1st Order	235	67.38	59.10	187	54.587	57.03
2nd Order	40	21.05	18.46	29	15.55	16.25
3rd Order	6	10.41	9.13	5	10.41	10.88
4th Order	2	5.62	4.93	2	5.58	5.83
5th Order	1	9.55	8.38	1	9.59	10.02
	284	**114.01**		**224**	**95.717**	





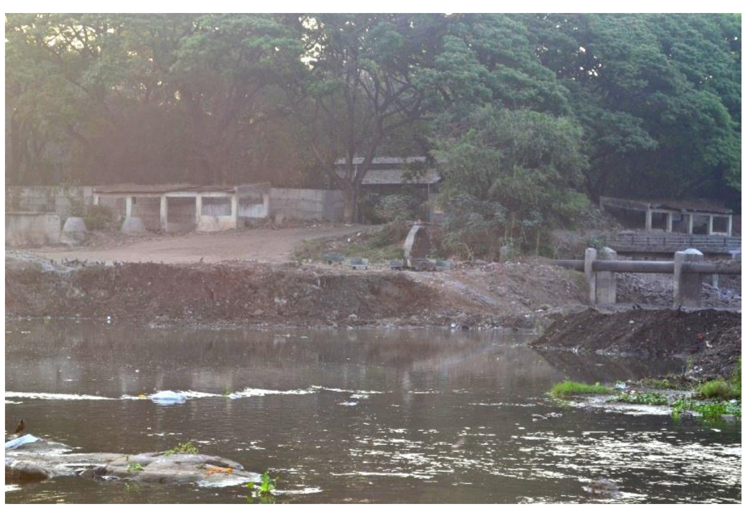
Land use-Land Class maps for Ambil Odha watershed (study by Dr. Shrikant Gabale)





LU – LC (1991) LU – LC (2015)

At Ambil odha mouth, a pipeline runs right across its width, from Vaikunth, quite close to the stream bed. It is an obstacle to the flow. Garbage gets trapped between stream bed and the pipe, creating a bund like structure providing further obstruction to the flow.



Ambil Odha mouth

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The city of Pune has been experiencing repeated episodes of urban flooding every monsoon. The floods take place in a relatively short period of time, but inundate large tracts of land, with several feet deep water. This report conducts a root cause analysis of the flooding events in Pune, discusses potential solutions and makes policy recommendations for integrated measures for flood mitigation.

The report is prepared by Jeevitnadi, Unity Geospatial, ACWADAM and Ecological Society.