# Increasing Frequency Of Urban Floods: Lessons From Bengaluru Floods, 2022

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## Abstract

*In 2022, Bengaluru was hit by (131.6 mm) intense rainfall causing floods that led to a standstill in the city. This study examines the underlying causes of floods and the impact of urbanisation and poor planning. Secondary data sources, such as government reports and news articles, were used to identify the factors that contributed to the floods. The results indicate that rapid urbanisation and inadequate planning significantly contributed to floods. The city's infrastructure was unable to cope with the volume of rainwater, leading to flooding in low-lying regions. The lack of proper drainage systems in the construction of buildings and roads exacerbated the situation. The study also emphasises the impact of climate change on the frequency and severity of extreme weather events like floods. It suggests that policymakers and urban planners must incorporate climate change predictions when devising and implementing development plans. The study concludes by urging immediate action to address the fundamental causes of the floods, including infrastructure improvements, better land-use policies, and sustainable urban development. By implementing these measures, Bengaluru can decrease the chances of future flooding and ensure a more resilient future for its citizens. The study underscores the need for urban development that is conscious of the changing climate patterns, which can result in safe, sustainable, and prosperous cities.*

***Keywords:*** *Drainage, Floods, Planning, Urbanisation, Watershed*

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## 1. Introduction

Of all natural disasters, floods are the most common. Floods are said to occur when water accumulates over land that is normally dry, causing it to be submerged for a significant amount of time. Although floods are generally classified as natural disasters, most floods today result from a complex interaction between human activities and natural phenomena (Raven et al 2013). A number of factors contribute to flooding. Heavy rainfall is a very common cause of floods. Overflow of coastal waters and dam and levee breaches can also lead to the submergence of land. Based on the cause of submergence, floods may be classified into several types. River floods are said to occur when a body of flowing water, such as a river or stream, overtops its banks and water spills over and inundates adjacent land. This may happen because peak seasonal precipitation or rapid melting of snow due to sudden rise in temperature cause excessive quantities of water to drain into river channels, exceeding their carrying capacity. Such floods are a regular occurrence for many rivers and support many ecosystems that are adapted to such inundation. However, they can cause extensive damage when floodplains are densely populated. Coastal floods occur when storm surges or extreme tides cause a short-term increase in sea level. The rise in sea level because of global warming and the increasing frequency and intensity of cyclones has made more coastal areas vulnerable to this type of flooding. Flash floods are a type of flood that is especially devastating on account of the speed of their occurrence and their unpredictable nature. They occur soon (usually less than 6 hours) after heavy rain. They can also be caused by a dam or levee failure, and also when the flow of a river is suddenly blocked by debris or ice jam. Urban areas can be affected by all the above-mentioned types of floods. However, the term urban flood is used to denote floods that are pluvial, caused by intense and/or prolonged rain, and not by the overflowing of a water body. The process of urbanization involves extensive modification of the natural landscape, including removal of vegetation, draining of wetlands, paving of surfaces and construction of buildings. Rainwater is not absorbed by the mostly impervious urban surfaces that are covered by roads and buildings. Consequently, intense showers of rain generate runoff from roads and other built-up surfaces that easily overwhelm the carrying capacity of stormwater drainage systems, leading to flooding. The problem is made worse by the fact that city growth takes place with total disregard for natural drainage routes. Unlike other types of flooding, pluvial flooding is a direct, quick and localized consequence of rainfall (Ochoa-Rodriguez et. al).

## 1.1 Urban Floods In India

Floods in India were almost synonymous with riverine floods. Consequently, agencies responsible for the management of flood-related disasters tended to focus on floods caused by overflowing rivers. In the present century, urban floods have been a recurring phenomenon. Hyderabad (2000), Delhi (2002, 2003, 2009 and 2010), Chennai (2004, 2015, 2017), Mumbai (2005, 2020), Surat (2006), Kolkata (2007), Jamshedpur (2008) and Guwahati (2010) experienced severe flooding. The devastation caused by floods in Mumbai in 2005 forced the National Disaster Management Authority (NDMA), the apex body for disaster management in India, to recognize urban floods as a separate type of disaster. The NDMA noted an increase in urban flood disasters in India and issued guidelines for their management in 2010. It also identified several factors which placed Indian cities at greater risk from urban floods. The foremost among them is the highly seasonal character of Indian rainfall. Most of India receives 75 to 80% of its annual rainfall during the summer monsoon season which extends from June to September. Intense spells of rain are also experienced due to other weather systems such as depressions and cyclones which can dump large quantities of water in a very short span of time. Coastal towns and cities are especially vulnerable to flooding from storm surges, a problem made worse by sea level rise (Anshu et.al, 2019). A flood can also occur due to the sudden release of water from dams. Conversely, a failure to ensure the timely release of water from dams can cause the dams to burst, causing sudden and massive flooding in downstream areas. NDMA has observed that the urban heat island effect has led to an increase in rainfall in urban areas. The intensity of rainfall is further exacerbated by changes in weather patterns induced by global climate change. The urban stormwater drainage system (where it exists) is outdated and cannot cope with the increased intensity of rainfall. Most systems were designed for a rainfall intensity of 12 to 20 mm and are unable to handle rainfall of higher intensity. The systems have failed to keep pace with the growth of cities. As cities grew in size, drains should have been widened. The unfortunate reality, however, is that existing drains have been encroached upon. Further, the systems are poorly maintained and do not work even to their designed capacity, either because they are broken or are choked with silt and/or plastic and other solid waste. City growth, whether planned or unplanned, has failed to take into account the natural flow of water (NDMA). Thus, a complex combination of natural and human-made factors is responsible for the problem of urban flooding.

## 2. Study Area

Bengaluru, also known as Bangalore, is a rapidly growing and diverse city located in the southern part of Karnataka state in India. Located at coordinates 12.97°N 77.56°E, Bengaluru spans across an area of 1741 Km2. While most of the city falls under the jurisdiction of the Bangalore Urban district in the state of Karnataka, the adjoining rural regions are part of the Bangalore Rural district. The city has a rich history, and in recent years has emerged as a global hub for technology and innovation, also the capital city of the state. It is situated on the Deccan Plateau, at an average elevation of 900 meters above sea level. The city is surrounded by several hills, including the Nandi Hills and the Chamundi Hills. The climate in Bengaluru is moderate throughout the year, with temperatures ranging from 15°C to 35°C (Census, 2011). The city is also known for its numerous lakes and parks, including the Lalbagh Botanical Garden and Cubbon Park. Bengaluru is home to several major research institutions, including the Indian Institute of Science, the National Aerospace Laboratories, and the Indian Space Research Organization. The geography of Bengaluru provides a unique setting for research in fields such as ecology, geology, and urban planning.

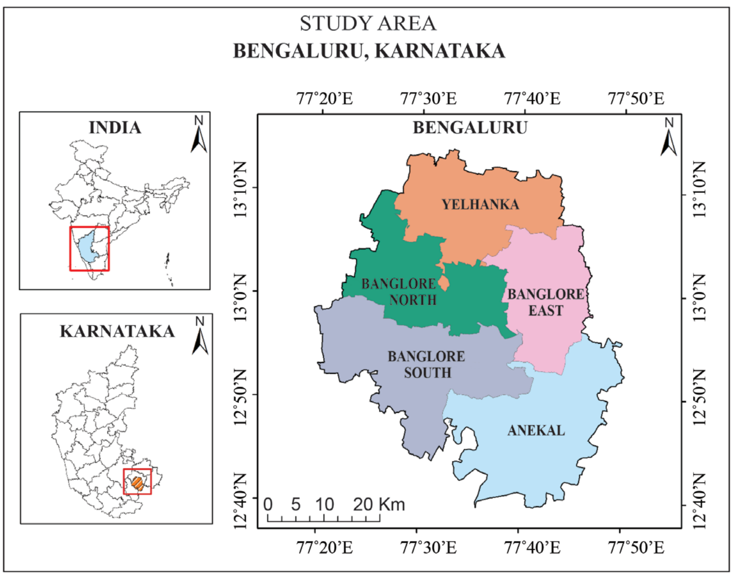


**Figure 1 : Study Area - Bengaluru, Karnataka**

## 3. Data & Methods

IMD gridded data with 0.25° × 0.25° spatial resolution spread over Indian land mass has been used as the ground validation in the present study. This study utilized data such as a 30 m resolution Digital Elevation Model (DEM) of the basin obtained from the US Geological Survey website, extracted from the Shuttle Radar Topographic Mission (SRTM).

In ArcGIS, the digital elevation model (DEM) was utilized to demarcate watersheds by converting the raster to the polyline. The process of automatic extraction of the watershed and drainage network was accomplished using ArcGIS 10.2 software. Specifically, the watershed tool within the hydrology toolbox of ArcGIS 10.2 was utilized for delineating the drainage of Bengaluru. The topography of Bengaluru is characterised by an undulating terrain with hills, valleys, and plateaus. Generally, the land surface slopes towards the southeast, resulting in dendritic to sub-dendritic drainage patterns in the area, which are connected to a system of lakes.

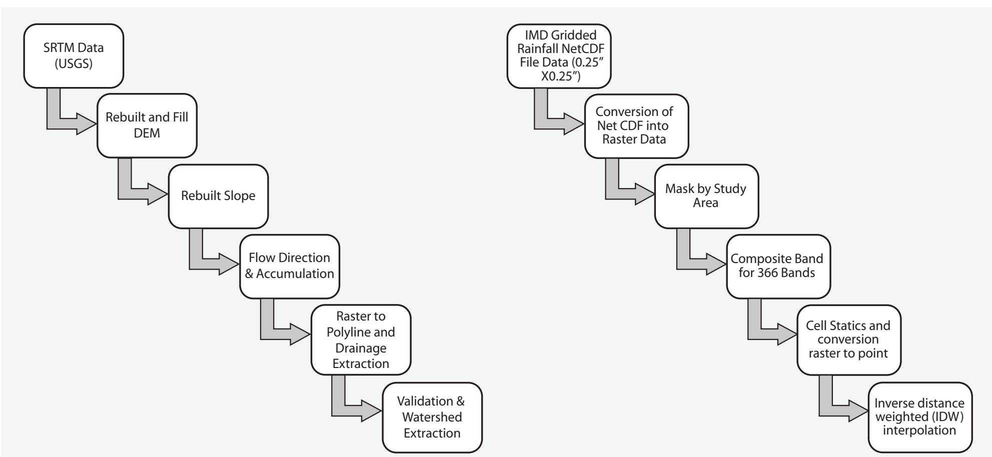


**Figure 2 : Stepwise Methodology to Extract Data (a) Elevation and, (b) Rainfall**

Bengaluru is situated in the tropics and has a semi-arid climate. The rainfall patterns of Bangalore from 1901 to 2000 exhibited a wide range of variability, with the annual rainfall fluctuating from 500 mm to 1350 mm, whereas the average annual rainfall was

970 mm. The city primarily receives its rainfall during the Southwest monsoon, but the Northeast monsoon can also bring precipitation if cyclonic formations are closer to Bengaluru. Although Bengaluru lies in a rain shadow region, it is not entirely obscured by hill ranges. In the years 2017-2021, the annual rainfall recorded in the capital city of Karnataka was 1,696 mm, 1,050 mm, 950 mm, 1,200 mm, and 1,500 mm, respectively. Data from India Meteorological Department (IMD) shows that in 2022, Bengaluru experienced a total of 1,958.6 mm of rainfall, with more than 2.5mm of rain recorded in 90 days. On September 5, 2022, the city experienced its heaviest rainfall of the year, with 131.6 mm of rainfall inundating a significant portion of the city.

## 3.1 Urban Floods in Bengaluru, 2022

Bengaluru is one of India's largest cities. Located on the Mysuru Plateau (a part of the Deccan Plateau) at a height of 949m above sea level, the city is known for its pleasant climate. Although it is generally flat, a prominent ridge runs down its centre from NNE to SSW. No major river is found in, or close to, Bengaluru, although the Arkavathi and South Pennar rivers originate in the nearby Nandi Hills. Vrishabhavathi, a minor tributary of Arkavathi, carries much of Bengaluru's sewage.

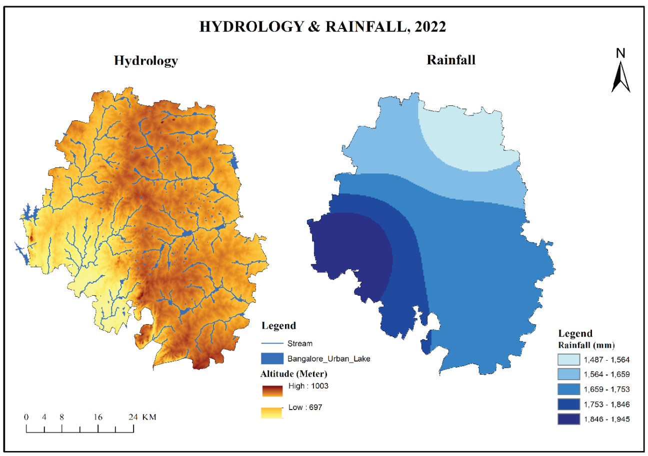


**Figure 3 : The intense Rainfall Raised the Water Level in the Urban Lakes. In other Words, Lake Surface Area must Increase due to Intense Rainfall. Hint: Author should Analyse Pre and Post-Flood Urban Lake Area. Hydrology (SRTM 30m) and Annual Rainfall Map of 2022 (0.25X0.25 IMD, Pune)**

Bengaluru started as a small settlement around a mud fort built by Kempe Gowda, a local chief, in 1537. It rose to prominence when the British used it as an administrative and military centre from 1831 to 1881. It became the capital of the Indian state of Mysore in 1956, and subsequently of Karnataka in 1973. The location of several public sector manufacturing units in the city in the 1950s created employment opportunities that attracted a stream of migrants. Simultaneously, Bengaluru also emerged as an educational hub. In the post-liberalisation era in the 1990s, the city emerged as the centre of information technology in India with many domestic and multinational companies locating their offices within it, making it famous as the Silicon Valley of India. However, in September 2022, Bengaluru was in the news for totally different reasons. Many portions in the southeast, east and northeast of the city were submerged under water for two days while it was lashed by heavy rains, causing many lakes to overtop their banks. Normal life came to a standstill amidst power outages and traffic disruptions, affecting posh localities and the poorer quarters alike. Areas with higher elevations also experienced flooding as the clogged drains were unable to discharge the rain surge. The water supply came to a halt as pumping stations of the Bengaluru Water Supply and Sewerage Board went underwater in many areas. This resulted in immense suffering people and great financial loss to individuals and the economy as a whole. Among the worst affected areas was Bellandur, Yemalur, Mahadevapura and Manyata Tech Park. State Disaster Relief Forces (SDRF) had to be called in to help and visuals of residents being rescued in boats and tractors flooded social media.

***The rain that was too much***

Rainfall records from 1901 to 2000 show that the average annual rainfall of **Bengaluru** is 970 mm. The lowest rainfall recorded in a year in this period is 500mm while the highest is 1350mm. **Higher rainfall is recorded in May and then again in September-October and September** is generally the rainiest month. This year Banglore has experienced higher rainfall than the normal usual, with 1466.6mm of rainfall having already been received by September.From June to August 2022, the city received 769 mm of rain, nearly 80% higher than the average for the period. 370mm of rain was received in August 2022, making it the second-wettest August ever recorded. An analysis of weekly rainfall in Bengaluru Urban District in June, July and August showed that rainfall was 60% more than the Long Period Average in as many as 5 weeks within that period (**Sangomla**, 2022). More rain came on the 4th and 5th of September as a wind shear zone was formed between westerlies in the south and easterlies in the north. This created instability in the atmosphere that was laden with moisture from the monsoon winds. The effect of the ongoing La Nina may have also played a part (Sangmola, 2022). 131.6 mm of rain was dumped on the city in just 12 hours, proving too much for the city's infrastructure.

The above data shows that Bengaluru received above-average rainfall in 2022. The distribution of rainfall within the city is shown in Figure 2. Intense rainfall on the 4th and 5th of September triggered the floods. But was flooding an inevitable consequence of the heavy rain? P. Mukhopadhyay, a monsoon modelling expert at the Indian Institute of Tropical Meteorology, Pune (quoted by Ramesh, 2022) maintains that the intense rainfall was predicted and "very much within the accepted range". There are instances when more rain has been received in a single day in September. 180 mm of rain was received on September 12th, 1988 and 132.3 mm was received in a single day in September 2014. However, the rains did not cause flooding to the same extent on both previous occasions.

***Did global warming play a role?***

The impact of climate change on weather patterns across the world is undeniable. However, its relationship with increased incidences of urban flooding is yet to be conclusively established. Heavy monsoon rains caused devastating floods in Pakistan between June and October 2022. The simultaneous occurrence of floods in parts of America, Africa and Asia and severe drought in Europe and China in 2022 is widely attributed to climate change. A warming atmosphere has a greater capacity to hold moisture which can then be released in the form of intense precipitation. Urban pluvial flood risk is expected to increase significantly in the future as a result of climate change (Ochoa-Rodriguez, et al.). A study of rainfall data from 165 stations across India reveals that the intensity of extreme point rainfall events (highest 24-hour rainfall) has gone up considerably after 1960. Record rainfall events on different time scales, from hourly to annual, have also taken place in recent decades (Khaladkar, et. al., 2009). In the case of Bengaluru, the Long Period Average (LPA) rainfall between 1981 and 2010 is 986.1mm. Rainfall since 2010 has been in excess of the LPA. The average rainfall between 2010 and 2021 was 1146.62 mm, which is 16% over the LPA (Ramesh, 2022).

Currently known as the Silicon Valley of India or the IT capital of the country, Bengaluru (or Bangalore) was once better known as the Garden City or a Pensioners Paradise. Parks and lakes covered a large part of the city area. The population of the city has increased from 745,999 in 1950 to 12, 326,532 in 2020 (population.un.org.wpp). Bengaluru's size increased from 69 square km. in 1901 to 161 sq. km. in 1981, and 221 sq. km. in 2001 (Yashasvini et. al., 2019). In 2006, 741 sq. km. was denoted as Greater Bengaluru after merging the area of Bengaluru city with 8 neighbouring urban local bodies and 111 villages. The growing population has been accommodated at the cost of the city's lakes and green cover. Between 1973 and 2017, Bengaluru has seen a 1028% increase in paved surfaces, an 88% decline in vegetation cover and a 79% decline in wetlands (Ramachandra et.al., 2017) In 1800, Bengaluru had 1452 water bodies with a storage capacity of 35 thousand million cubic feet (TMC) of water. Rainwater is collected in these water bodies, reducing the possibility of floods. In 2016, only 194 of these lakes remained and their storage capacity had been reduced to 5 TMC (CAG Report, 2021).

What makes the situation worse is the lack of interconnectivity between the lakes. The rajakaluves (a clear path that allowed stormwater to flow from one waterbody to another) that connected these lakes are blocked due to encroachment by land grabbers and also the accumulation of solid waste. A study of floods in the city (Sanganal) identifies an increase in the built-up area, paved surfaces, encroachment of natural water courses and low-lying areas, inadequate capacity and encroachment of storm water drains and increasing density of population as the major causes of floods in Bengaluru. The study found that streets lacked sufficient rainwater outlets and that existing outlets were choked with dirt and debris. In some cases, rainwater outlets had been rendered non-functional after road widening had been undertaken. Another study by Ramachandra and Majumdar (2009) similarly blames the siltation of tanks and encroachment of nalas and lake bodies and the choking of steams and stormwater drains for floods in Bengaluru.

The 2021 Audit Report by the Comptroller and Auditor General (CAG) raised serious concerns over the increase in the frequency of flooding in the city of Bengaluru while the city also suffered from the depletion of groundwater table levels. The Performance Audit (PA) "revealed that Bengaluru witnessed large-scale encroachment of lakes/ drains and depletion of natural drainage systems. The changes in land use such as the decrease in vegetation cover and open spaces and increase in the built-up area resulted in the loss of interconnectivity between water bodies impacting the effective recharge of groundwater and increase in runoff of stormwater" (CAG Report, 2021). The report also expressed concern over the decline in the storage capacity of existing water bodies due to siltation to only 1.2 TMC. Several lakes under the jurisdiction of the Municipal authorities had been identified as disused lakes which were now vulnerable to encroachment. The failure to recognise surface runoff as a water resource and formulation a policy for its management was also highlighted as a major lapse on the part of governing agencies.

The highly fractured governance system in Bengaluru makes the problem of flood management even worse. While Bengaluru Development Authority is the principal planning authority, Bengaluru Metropolitan Management Authority is responsible for planning in the Bengaluru metropolitan region. There are separate agencies for the management of water and wastewater (Bengaluru Water Supply and Sewerage Board), and transport (Bengaluru Metropolitan Transport Corporation), while fire services are the responsibility of the Karnataka Fire Emergency services (Jha, 2022). Professionals working with each agency have a narrow, sectoral approach. Coordination between these multiple agencies is a challenge in the best of times, and more so in times of crisis.

## 4. Results and Discussion

It is obvious from the above that floods in Bengaluru resulted from a combination of higher than normal rain and poor land management that prevented the city landscape from absorbing or draining the rainwater. The city had already received above average rain from June to August in 2022 and an intense spell of rain on 4th and 5th September finally triggered the flood. This spell of rain may have been heavy, but it was not unprecedented. Clearly, the city was not prepared to meet such an eventuality. Heavy precipitation events are likely to become more common in the near future and city planners and administrators would do well to gear up to meet them.

Flooding results from almost every above-average rainfall event due to unplanned urbanization. Increase in paved surfaces, reduction in green cover and reclamation of wetlands for urban development means that even small amounts of rain can overwhelm the inadequate rainwater infrastructure. In the case of Bengaluru, many of the numerous lakes that dotted the city had either disappeared or greatly reduced in size. The catchment area of the remaining lakes had been greatly altered, leading to silting of the waterbodies. Ramachandra's study (2009) shows that the storm water drains connecting the lakes are blocked by encroachments and solid waste accumulation.

## 5. Conclusions and Suggestions

The above discussions reveal that the immediate cause of devastating floods in Bengaluru (and in other urban areas) was an extreme point rainfall event. The frequency of such events is increasing due to global warming and climate change. However, while the floods may have been triggered by high-intensity rainfall, the underlying cause is poor urban planning and a total lack of preparedness for urban flood disasters. Urban areas are planned and developed without due consideration for the various components of the hydrological cycle and water infrastructure. Impermeability of surfaces and obstruction of water flow in urban areas increases peak flows in cities to up to 7 times that of rural areas (Tucci, 2006). In the pre-urbanised scenario, 40% of precipitation reenters the atmosphere through evapotranspiration, 50% infiltrates into the soil and runoff accounts for a mere 10%. Post-urbanisation, evapotranspiration returns only 25% of the precipitation to the atmosphere. Another 30% infiltrates into the soil while the remaining 45% becomes part of rainwater drainage (Tucci, 2006). The complex nature of urban flooding is summarized in Figure 4.

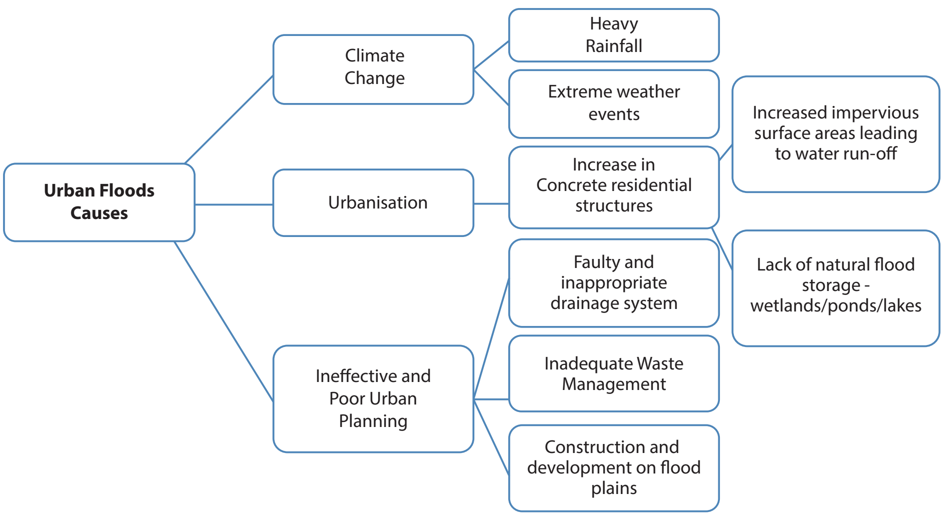


**Figure 4 : Urban Flooding in Bengaluru**

Bengaluru requires an integrated approach to flood management. A combination of watershed management, land use planning and developmental planning is the need of the hour. The following steps can be taken to mitigate the problem of urban floods:

- The first step towards mitigation of urban floods is flood vulnerability and risk mapping. Areas most vulnerable to floods must be identified and factors enhancing flood risk must be addressed.
- Once areas prone to flooding are identified, land use planning must be undertaken at the micro-level. Parks can be developed in high flood-risk areas. This will help in enhancing urban amenities while also ensuring protection from floods.
- The natural flow of water must be taken into account when plans for the development of the city are drawn up.
- Green infrastructure should be developed for absorbing and storing stormwater. This is more cost-effective and efficient than grey infrastructure in controlling floods.
- Preservation of natural vegetation will help in reducing runoff and increasing groundwater recharge. This will help in mitigating floods while also raising the water table.
- Rainwater harvesting must be made mandatory. Soakaways can be built to collect water from rooftops and let it seep into the ground. This should be made a part of building codes.
- Infiltration trenches can be constructed along streets and highways and in housing complexes so that rainwater can drain into them, reducing the intensity of the rain surge.
- Pervious paving should be carried out in areas of low traffic.
- Lakes, wetlands and other waterbodies, including rajakaluves, must be preserved (or rejuvenated) as they help in storing excess stormwater. Areas around them should be well vegetated to reduce siltation. The flow of water into these bodies must be free and unobstructed. They must be protected from encroachment by the enactment of strict laws that are seriously enforced.

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