Urban floods in Bangalore and Chennai: risk management challenges and lessons for sustainable urban ecology

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A number of major cities and towns in India reported a series of devastating urban floods in the recent decade. Mumbai flood 2005 followed by other major cities of South Asia like Dhaka, Islamabad, Rawalpindi also suffered with urban flooding. Census 2001 figured 285 million people in 35 metro cities of India, and is estimated to cross 600 million with 100 metro cities in 2021. Regional ecological challenges coupled with climatic variability are noted to aggravate flood risks and impact on affected communities. Urban flooding was primarily a concern of municipal and environmental governance, has now attained the status of 'disaster', which has drawn the attention of environmental scientists and disaster managers. Challenges of urban flooding in terms of drainage and flood mitigation including structural and non-structural measures and key issues of urban ecology in two major metropolitan cities of India – Bangalore and Chennai, have been studied. Risk management challenges in the context of land-use, city and population growth, wetland degeneration, waste disposal have been discussed.

Keywords: Bangalore, Chennai, cities, floods, urban ecology, wetlands.

Cities and floods

'If there could be such a thing as sustainable development, disasters would represent a major threat to it, or a sign of its failure.'[1] In 2000, 37% of Asia's population lived in cities and the proportion is projected to reach more than 50% by 2025. Unfortunately, the majority of Asian mega-cities and other urban localities occupy hazard-prone land. In the period 1994–2004 alone, Asia accounted for one-third of 1562 flood disasters. Urbanization in developing countries doubled from less than 25% in 1970 to more than 50% in 2006 (ref. 2). It is estimated that at least 13 cities of the world that are prone to natural hazards will have a population in the 10–25 million range, with nine of them in Asia. In 2001, there were 285 million people in India residing in 35 metro cities (cities having a population of above 1 million). This is estimated to exceed 600 million by 2021 in over a 100 metro cities as the trend is on a rise.

Recent events highlighted the man-made causes responsible for recurring and prolonged floods in South Asian cities like Dhaka, Mumbai, Chennai, Bangalore, Ahmedabad, Surat, Patna, Jamshedpur, Rawalpindi and Islamabad. Floods result from the overflow of land areas, temporary backwater effects in sewers and local drainage channels, creation of unsanitary conditions, deposition of materials in stream channels during flood recession, rise of groundwater coincident with increased stream flow, and other problems[3]. Disaster management the worldover is undergoing a paradigm shift from approach to 'response and relief' to 'prevention and mitigation'[4]. The call for a mix of resistance and preparedness for resilience towards flood risk in cities depends on management of urban ecology[5], including land use, water bodies, waste disposal, etc. Major implications of urbanization are the following[6,7].

Heat island effect

Surface and atmospheric temperatures are increased by anthropogenic heat discharge due to energy consumption, increased land-surface coverage by artificial materials having high heat capacities and conductivities, and the associated decreases in vegetation and water-pervious surfaces, which reduce surface temperature through evapotranspiration.

Loss of aquatic ecosystems

Urbanization has telling influences on the natural resources such as decline in the number of water bodies and/or depleting the groundwater.

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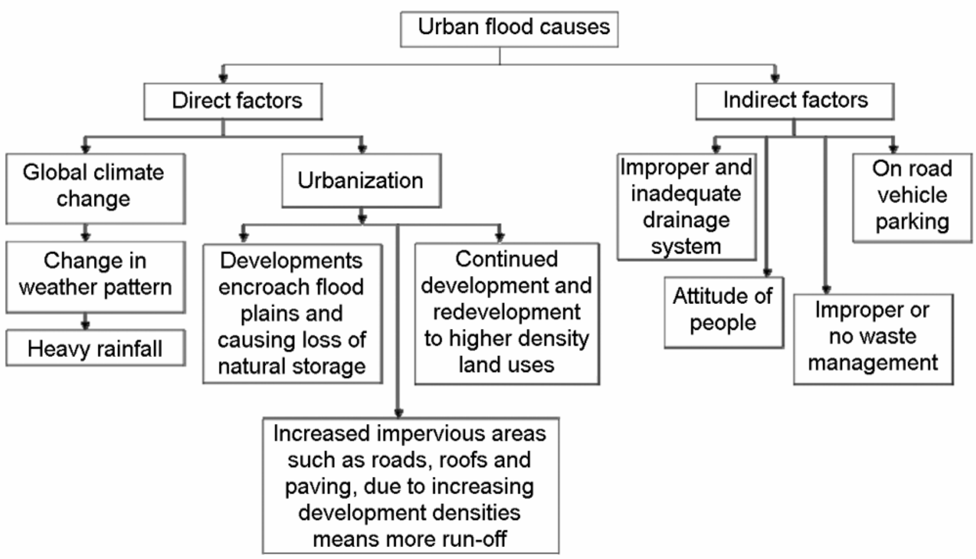


Figure 1. Causes of urban floods in India[32].

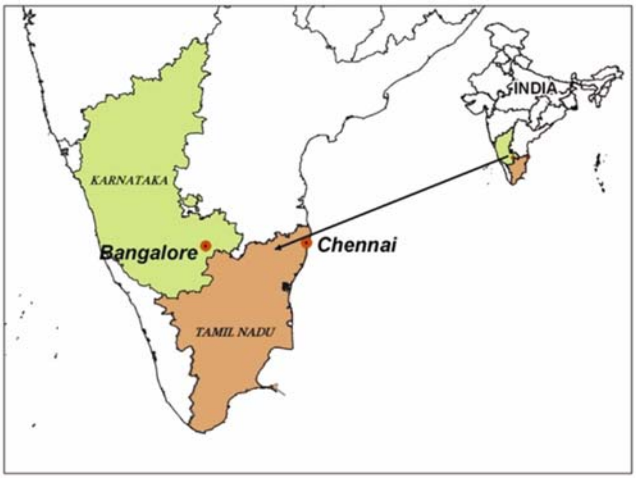


Figure 2. Map of India showing location of Bangalore and Chennai.

Loss of drainage capacity

Unplanned urbanization has drastically altered the drainage characteristics of natural catchments, or drainage areas, by increasing the volume and rate of surface run-off. Drainage systems are unable to cope with the increased volume of water and are often encountered with blockage due to indiscriminate disposal of solid wastes.

Disasters are events of environmental extremes which are inevitable entities of this living world, and linked to every component of the ecosystem. Urban flooding has been recognized as a 'disaster' only after the Mumbai flood in 2005. As revealed in Figure 1, the interaction of flood causes in urban environment indicates significance of urban ecology in disaster risk reduction[8]. The present article discusses the flood challenges and mitigation issues for two important metro cities of India, viz. Bangalore and Chennai (Figure 2). The aim of the study was to understand the problems of increasing flooding incidences in urban areas and related contexts of urban development and ecological issues. Data of secondary origin have been collected and interpreted in the context of flood risks and urban management. The article also conveys wider issues and lessons for flood challenges in Indian cities and towns.

Bangalore

Bangalore is located almost equidistant from both the eastern and western coasts of the South Indian peninsula. The mean annual rainfall is about 880 mm with about 60 rainy days a year. Bangalore is known as the 'IT city' or 'silicon valley' of India due to the presence of several software companies. It is the fifth largest city of India with population of about 7 million, located around 100 km from the Kaveri River. There has been a growth of 632% in urban areas of Greater Bangalore across 37 years (1973–2009). Encroachment of wetlands, floodplains, etc. is causing floodway obstruction and loss of natural flood storage in Bangalore[4].

The gap in the installed capacity of the wastewater treatment system (450 MLD) as against the estimated generation of domestic water (700 MLD) is evident. Bangalore has 134 flood-prone areas (Table 1). The City Corporation has identified these areas after a survey of critical locations which are prone to recurrent flooding. However, some areas in the city face the brunt of the rains more than the others and are more prone to flooding.

In 2005, flooding had worsened by unauthorized developments along three lakes. Choked drains led to residential areas being inundated, and traffic was severely affected. Thousands of office-goers were stranded on the city's waterlogged roads. Schools in the city were closed and several apartment complexes were flooded. Water entered some office buildings, including one of the offices of India's third largest software exporter, WIPRO. The flood left hundreds of people homeless and ailing due to various health problems and environmental challenges.

Built-up area (16% in 2000) has now increased to 23–24% in the metropolitan area of Bangalore. There are 542 slums located in the jurisdiction of Karnataka Slum Clearance Board (218) and Greater Bangalore City Corporation (324), out of which 310 are undeclared settlements according to 2001 Census. Temporal analysis of water bodies indicated a sharp decline of 58% in Greater Bangalore attributed to intense urbanization process, evident from 466% increase in built-up area from 1973 to 2007. Analysis revealed (Figure 3; Table 2) decline of wetlands from 51 in 1973 (321 ha) to merely 17 (87 ha) in 2007. The number of water bodies reduced from 159 to 93.

The lakes of the city have been largely encroached for urban infrastructure. As a result, in the heart of the city only 17 good lakes exist as against 51 healthy lakes in 1985. According to a study[6], the water bodies of the city have reduced from 3.40% (2324 ha; 5742.7 acres) in 1973 to just about 1.47% (1005 ha; 2483.4 acres) in 2005, with built-up area during the corresponding period increasing to 45.19% (30,476 ha; 75,307.8 acres) from 27.30% (18,650 ha; 46,085.2 acres).

Figure 4 shows unplanned settlements with very poor drainage. Enforcement of land-use laws and guidelines/plans has been observed to be poor. Field surveys (during July–August 2007) showed that nearly 66% of lakes are sewage-fed, 14% surrounded by slums and 72% showed loss of catchment area[6]. Also, lake catchments were used as dumping yards for either municipal solid waste, construction residue or building debris.

Bangalore city has a 180 km long primary and secondary storm-water drainage system, which often fails to take the load of the rains due to silt and garbage causing blockage. A provision of Rs 45 million has been made for the flood-management fund with 12 squads on call, of which six are rain and flood relief squads; 20 personnel have been assigned in each squad. The Jawaharlal Nehru Urban Renewal Mission (JNURM) project was launched in December 2005 and Bangalore has been allocated a budget for the next six years.

Table 1. Top five flood-prone areas identified in Bangalore city

Ejipura/Koramangala	:	National Games Village area
BTM Layout	:	I and II stage area
Shankarappa Garden	:	Magadi Road area
Brindavan Nagar	:	Mathikere area
Ambedkar College	:	Airport road area

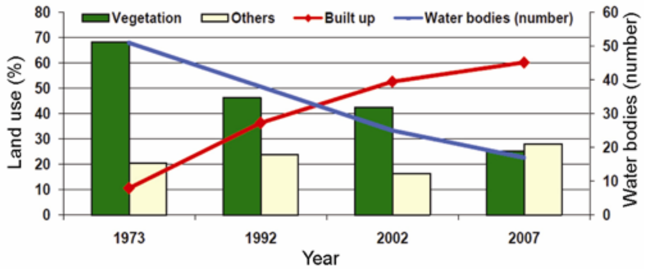


Figure 3. Land-use changes, 1973–2007.

Chennai

Topographically plain terrain with few isolated hillocks in the southwest, Chennai is bounded on the east by the Bay of Bengal and on the remaining three sides by the Kanchipuram and Tiruvallur districts. Chennai receives on an average approximately 1300 mm of rainfall per year – most of this (~800 mm) falls during the northeast (NE) monsoon in the months of October through December. The city is situated at approximately 13°N lat. and 80°E long. Chennai city currently encompasses an area of 172 sq. km, and the metropolitan area adds almost 400 sq. km of urban agglomeration to this figure. Chennai faces a number of risks, partly climate-related, but also human-induced such as waste disposal, water contamination and lack of drinking water, suburban sprawl and mismanagement in urban planning[7].

Due to the plain terrain Chennai lacks natural gradient for free run-off. This necessitates an effective storm-water drainage system. The sewage system in Chennai was originally designed for a population of 0.65 million at 114 litres per capita per day of water supply; it was further modified during 1989–1991, but is now much below the required capacity. Cooum and Adyar rivers in

Figure 4. Slums and high-density poor settlements.

Table 2. Loss of water bodies

Year	Bangalore city		Greater Bangalore	
	No. of water bodies	Area (ha)	No. of water bodies	Area (ha)
SOI	58	406	207	2342
1973	51	321	159	2003
1992	38	207	147	1582
2002	25	135	107	1083
2007	17	87	93	918

SOI, Survey of India, topographic maps (published in 1973); Source: Ramachandra and Uttam Kumar[6].

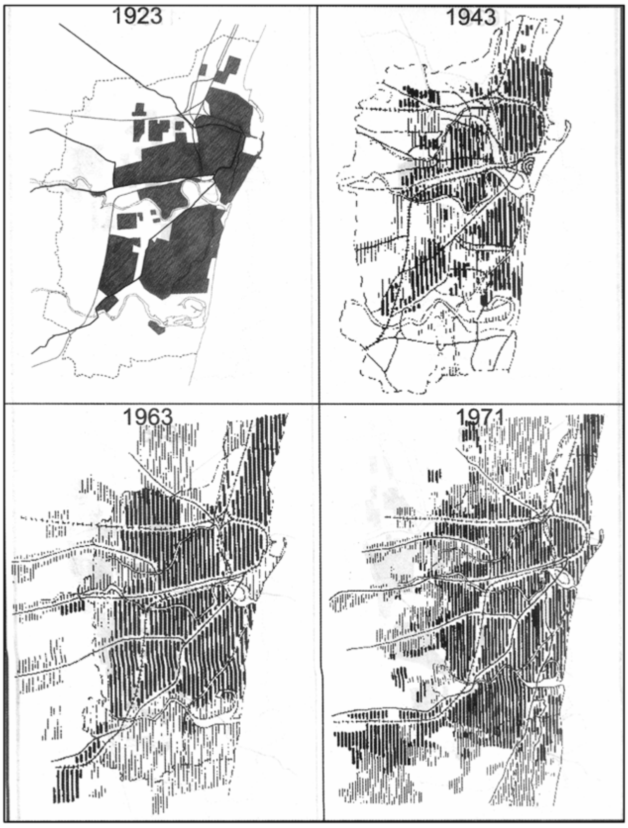


Figure 5. Growth of Chennai since 1923 (from Gupta and Nair[8]).

Chennai city are almost stagnant and do not carry enough water, except during the rains. These rivers play a major role during floods, collecting surplus water from about 75 and 450 tanks in their respective catchments. Chennai municipal area has a network of canals and channels within its boundary. Buckingham canal, originally a navigation channel and waterway till 1954, now serves only as a drainage channel.

The physical growth of Chennai from 1923 to 1971 is shown in Figure 5. The population has grown by eight times in the period 1901–2001 and per hectare population density has increased from 80 to 247. Chennai has a large migrant population from other parts of Tamil Nadu and other parts of the country, accounting for 21.57% of the Chennai population in 2001. There are three major water courses (Cooum, Buckingham Canal and Adyar) in Chennai city and the banks of all the areas encroached (Figure 6). Slums (number recorded to be 30,922) have developed here without basic amenities and are subjected to flood every year. They often pollute the water courses, thus worsening the health situation.

Several catastrophic floods in Chennai in the past (1943, 1976, 1985, 1996, 1998, 2005, 2010) were caused by heavy rain associated with depression and cyclonic storms, leading to floods in major rivers and failure of drainage systems. Chennai was severely flooded due to heavy rains (16–20 cm, attributed to a trough of low pressure from the Gulf of Mannar to the Southwest Bay off the Tamil Nadu coast) during 30 October–2 November 2002. Residential areas became 'islands' and were cut-off, paralysing life, services and trade, including transport, communication, etc. On 5 November 2004, heavy rainfall (6 cm within 24 h or less) caused flooding and waterlogging in many areas, inundating most of the slums[9]. A deep depression over the Bay of Bengal brought 42 cm rainfall in around 40 h during the NE monsoon of 2005. Several floods were reported during 2006, 2007 and 2008. Closing of schools due to flooding every year is common in many parts of Chennai. The Chennai Municipal Corporation has identified 36 localities as flood risk hotspots (Figure 7).

Since the beginning of the 20th century, Chennai has witnessed a steady deterioration of and decease in water bodies and open spaces (Figure 7). It is estimated that in Chennai city more than half of the wetlands have been converted for other uses. Chennai had about 150 small and big water bodies in and around the city, but today the number has been reduced to 27. The important water bodies include Adyar Estuary, Adambakkam lake, Ambattur lake, Chitlapakkam lake, Ennore creek, Korattur swamp, Madhavaram and Manali Jheels, Pulicat lake, Vyasarpadi lake, besides Buckingham Canal, Coovum and Otteri nullah. Ownership of water bodies is scattered among various government departments and is the root cause for lack of proper management. The Protection of Tanks and Eviction of Encroachment Act, came into effect on 1 October 2007. However, there has been lack of implementation of this law.

The green cover reduced rapidly across the city between 1997 and 2001. In some wards almost 99% of the green cover has been replaced by non-vegetative development. As a result, the water-holding capacity of the city's surface has gone down drastically. The reduced city's surface water-holding capacity combined with the augmented impermeable surface increased the peak flow up to 89% from 1997 to 2001 in some of the wards. Increased surface run-off and reduced retention capacity of the land cover almost stopped the groundwater recharging processes in the city. Slum impact and environmental degradation of Cooum river is shown in Figure 8 *a* and *b* (ref. 10).

Figure 6. Degradation of Madhuravayal lake.

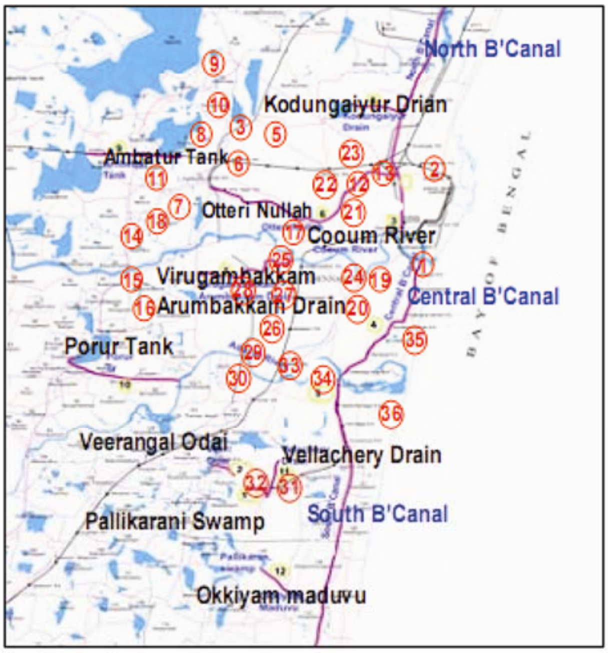
Meteorologically, there is no major upward or downward trend of rainfall during 200 years, and a decrease in the last 20 years with a contrast record of increasing floods has been experienced in Chennai. Causes of increased flooding identified are:

(a) Uncontrolled urban sprawl and loss of natural drainage. Drainage channels have been blocked and urban lakes filled and encroached, canals degraded and polluted, heavily silted and narrowed. A 1994 survey revealed waterways contamination and anaerobic digestion led to sludge accumulation causing hydraulic hindrances.

(b) Inadequacy of storm-water drainage system and lack of maintenance. The city has only 855 km of storm drains against 2847 km of urban roads. Plastic and polythene constituents to the storm-water stream along with poor or no maintenance aggravates flood.

(c) Increase in impervious surfaces. Paving of roadsides, parks and open areas causing flood severity and conditions for drought to follow.

(d) Lack of coordination between agencies. Lack of a unified flood control implementing agency that integrates



1. Tondiarpet
2. Royapuram
3. MKB Nagar
4. Sathyamoorthy Nagar
5. Kannadasan Nagar
6. Muthamizh Nagar
7. Pulianthope
8. Perambur
9. Kolathur
10. Villivakkam
11. Ayanavaram
12. Choolai
13. Periamet
14. T.P. Chathram
15. Virugambakkam
16. Arumbakkam
17. Choolaimedu
18. Anna Nagar
19. Ice House
20. Nammalwarpet
21. Purasawalkam
22. S.S. Puram
23. Kosapet
24. Mirsahibpet
25. Valluvar Kottam
26. Mambalam
27. Rangarajapuram
28. Trustpuram
29. Ashok Nagar
30. K.K Nagar
31. East Velachery
32. West Velachery
33. Saidapet
34. Adyar
35. Foreshore Estate
36. Tiruvanmiyur

Figure 7. Flood risk hotspots in Chennai metropolitan area (Source: Chennai Metropolitan Development Authority, www.cmdachennai.gov.in)

Figure 8. ***a***, A residential area backing onto the Cooum river[33]. ***b***, Cooum river narrowed by encroachments[10].

the functions of the Corporation, Development Authority, Public Works Department, Slum Clearance Board, Housing Board, etc.

All the waterways in Chennai are considered to be polluted, but the Cooum river and Buckingham Canal are widely recognized to be the worst. A Government-funded Flood Alleviation Scheme was launched in 1998, with a cost Rs 3000 million, focused mainly on structural measures. Adequacy of flow in the arterial drainage system, removing impediments, safeguard, against tidal and fluvial flooding, relocation and rehabilitation of encroachers were the main objectives. Cleaning of certain waterways and lakes was also undertaken under packages 2 and 3 of the scheme. Chennai City River Conservation Project was launched in 2000 to improve the waterways, with an estimated outlay of Rs 17,000 million. The Master Plan 1992–1993 incorporated Madras Metro Flood Relief/ Storm Water Drainage study outcomes in the form of structural and non-structural measures. Funds under JNURM project have been envisaged for implementation of underground sewerage schemes and detailed project reports are being developed. Thiru Vi Ka Industrial Estate has been proposed for rehabilitation and upgrading of sewerage system.

Discussion and lessons

Urban flooding is significantly different from flooding in rural areas as urbanization results in impermeable catchments causing flood peaks by up to three times[5]. Consequently, flooding occurs quickly due to faster flow times (in a matter of minutes). As a reference to discuss the growing flood menace in other cities in India, including Bangalore and Chennai, the lessons of the July 2005 floods in Mumbai are important to mention. The flood of 2005 was truly a disaster as it receded only after seven weeks and affected 20 million people. The floods killed 1200 people and 26,000 cattle. It destroyed more than 14,000 homes, and damaged more than 350,000; about 200,000 people had to stay in relief camps. The agricultural sector was heavily hit as 20,000 ha of farmland lost the topsoil and 550,000 ha of crop was damaged[11]. Unprecedented rainfall in one day was certainly one major cause of the floods; with a 24 h rainfall figure that exceeds the monthly average of 30 years. The rainfall data show that within a period of 18 h, the precipitation level rose to 944 mm in the suburban area, with maximum rain between 14.30 and 17.30 h on 26 July, a staggering 380.8 mm in 3 h. Between 14.30 and 20.30 h maximum rainfall of 647.5 mm was recorded, coinciding with the time people were trying to reach their homes from their work places.

The Mumbai flood of 2005 was followed by incidences of urban flooding as a regular phenomenon in many Indian cities, not only metros but in many towns as well. Floods were reported recently in cities like Ahmedabad, Bhopal, Bangalore, Calcutta, Chennai, Delhi, Gorakhpur, Hyderabad, Surat, Rohtak and Kurukshetra due to a combination of many factors like heavy or patchy rainfall, dam-water release or failure, inadequate drainage systems, blockade, housing in floodplains and natural drainage or riverbed and loss of natural flood-storages sites. It demonstrated on how unplanned, rapid urban development has stretched the natural ecosystems in and around a city to its limits, and made disaster from natural flood hazards inevitable[12]. Lessons drawn from the studies are summarized here on critical issues for future research and planning interventions.

Urban drainage

Some of the major hydrological effects of urbanization[13] are: (1) increased water demand, often exceeding the available natural resources; (2) increased wastewater, burdening rivers and lakes and endangering the ecology; (3) increased peak flow; (4) reduced infiltration and (5) reduced groundwater recharge, increased use of groundwater, and diminishing base flow of streams. Vegetation plays a vital role in evapotranspiration and soil-water storage components of this balance. The driving force behind the biodrainage concept is the consumptive water use of plants[14]. The role of biodrainage in controlling waterlogging and secondary salinization is important in urban flood mitigation[15].

Urbanization has marked effects on basin run-off in terms of higher volume, higher peak discharge, and shorter time of concentration[3,16]. As the risk of flooding increases with climate change, so does the importance of the major drainage systems. New design approaches, which explicitly design roads to act as drains, can radically reduce the duration of flooding. Litter management is critical to the management of urban drainage systems[17,18]. Often the best investment in drainage is better handling of solid waste to prevent systems from becoming rapidly blocked with debris[16,19]. Chennai witnesses 425 new vehicles on the road every day causing pressure for motorable and parking space. A total of 42.6 million people living in 8.2 million households have been living in slums of 640 cities/towns spread across 26 states and Union Territories, according to the 2001 Census. The slum population constitutes 4% of the total population of the country. Interestingly, the share of slums in urban population has grown in major metro-cities compared to smaller ones.

Flood impacts and risk assessment

Given the high spatial concentration of people and values in the cities, even small-scale floods may lead to considerable damage. In extreme cases urban floods can result in disasters that set back urban development by years or even decades. Velocity is also a major factor in determining per cent damage, with velocity floods capable of causing building collapse even in relatively shallow waters. Climate change is likely to amplify the challenge of pest and disease control, as new ecological niches appear that may sustain exotic pathogens and disease vectors[20]. For example, flooding may become more frequent in some geographic locations with climate change and can affect health through the spread of water-borne diseases[17]. Flood risk assessment is an essential part of flood risk management. The 'urban' approach includes a specific urban-type set of economic, social and ecological flood risk criteria, which focus on urban issues: population and vulnerable groups, differentiated residential land-use classes, areas with social and health care, but also ecological indicators such as recreational urban green spaces. Vulnerability assessment[21] represents, an important contribution to decrease and control of land damage caused by natural hazards, as it helps in strategies that limit weakness by integrating flood risk into urban development[22].

Ecological aspects

'All ecological projects (and arguments) are simultaneously political–economic projects (and arguments) and vice-versa. Ecological arguments are never socially neutral …[23]'. As work on disasters since the nineties increasingly focused on issues of human vulnerability and resilience, a more integrative approach has gained favour[24]. Hazards are now defined as 'human ecological interaction that can generate disaster'[25]. Urban ecosystems are the consequence of the intrinsic nature of humans as social beings to live together[6,26]. Ecosystem functioning is guided by abiotic steering variables related to hydrology, water quality and sediment load. These can be used as primary indicators of ecosystem condition and changes to them are first-order impacts. Floods and storms are an integral part of the ecosystem dynamics and have both positive and negative effects on human well-being[27].

Urban meteorology has come to require much more than observing and forecasting the weather of our cities and metropolitan areas[17]. Risks must be considered through continuing assessments of science, technology and application uncertainties, as well as in the costs and benefits associated with each of the urban issues and the proposed actions to mitigate adverse hazards or impacts[17]. Abrupt variability and increased uncertainties about rainfall pattern, periods, days and amount, and risk of weather extremes as an impact of global climate change[28] aggravated by ecological and anthropogenic factors as local climate actors[8] pose ever-increasing risk of flood disaster or waterlogging-led epidemics in urban areas.

Many of the water bodies, including man-made wetlands/lakes and natural depressions have disappeared due to human-induced succession filled with waste, and development or slum encroachments[5]. Urban wetlands in India have reduced to approximately 30% during the last 50 years. Wetlands hold the run-off generated from heavy rainfall, water discharge from reservoirs or channels or snow-melt events. They reduce the possibility of flooding in downstream or moderate flooding to some extent, depending on the magnitude of run-off. Wetland vegetation slows down the flow of flood water[29]. Wetlands reduce the need for expensive engineering structures[29]. Understanding by many of the professional engineers working on urban issues is not up to date with environmental aspects and they generally look for structural solutions which degrade the environment creating too many impervious areas and thereby increasing the temperature, flooding, pollution, etc.[30]. An integrated approach, therefore, needs to combine watershed and land-use management with development planning, engineering measures, flood preparedness, and emergency management in the affected lowlands, while taking into account the social and economic needs of communities in both the highland source areas, and also the lowland flood-prone areas[31].

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