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REVIEW ARTICLE

Modeling, mapping and analysis of urban floods in India—a review on geospatial methodologies

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Abstract
An increasing trend of urban floods in India from past several years causes major damages on Indian cities. By 2050, more than half of the population in the developing countries like India are expected to migrate to urban regions. Urbanization is triggered in developing countries as people migrate to cities in search of employment opportunities resulting in formation of new slums. With high density of population concentration in cities, urban floods are triggered leading to a significant impact of human life and economy of the country. The review focuses on addressing the urban flood occurrence in India and its relationship with population growth climate change. The study also describes the impact of urban floods to the environment and integrated methodologies adopted over decades for the prediction and effective mitigation and management during a disaster event.

Keywords Urban floods · Floods · Models · Urban systems · Resilience

Introduction

Globally, the occurrence of floods has been unprecedented resulting in huge economic and social losses (Simonovic et al. 2021). In India, a country with varying topography and climatic conditions, the frequency of floods recorded in cities is increasing drastically (Dhiman et al. 2018). In 1960, 18% of the country population was urban which increased to 28% in the year 2000 and 35% in the year 2019 with an average urbanization of around 2.5% per year. Urban population is expected to go beyond 50% by 2050, in search of employment opportunities and with the development of Smart Cities (Sukhwani et al. 2020). An increase in the urbanization results in uncontrolled increasing settlements, industrial growth and infrastructure development (Al Jarah et al. 2019). Several urban areas in the world are not functioning well because of the population growth, improper planning, lack of knowledge, canal encroachments, demolishing of water bodies, leading to the stress on the urban areas (Ferronato and Torretta 2019). Among important cities in India, the average annual rainfall varies from 2932 mm in Goa and 2401 mm in Mumbai on the higher side, to 669 mm in Jaipur on the lower side (Malik 2017). Increase in population and settlement results in overloading of existing drainage system in cities resulting in urban floods (Vorobevskii et al. 2020). Climate change also plays a major role in triggering floods by changing monsoon pattern, land use land cover, increase of greenhouse gases, demographic and socioeconomic changes (Loo et al. 2015). A change in climatic pattern also leads to the increase in sea level resulting as a threat to all coastal cities (Mimura 2013). To mitigate urban flood disasters, innovative approaches may be adopted to reduce the loss caused by the climate change on urban flooding, which may hinder the growth of city and associated economy (Miller and Hutchins 2017). To fulfill the challenges of climate change and its impacts on urban flooding, the problems need to be addressed (Huynh Thi Lan and Pathirana 2011). The present review article focuses on urban floods in India and the tools that can be adopted for the modeling of floods and help in disaster mitigation and management purposes.

Covering an area of 3,287,263 km^2 (1,269,346 sq. mi), from the Himalayas in the north to the Indian Ocean in the south, India is one of the oldest and richest cultural heritage

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countries in the world with several major rivers such as Ganga (2525 km), Godavari (1465 km), Cauvery (800 km), Krishna (1401 km), Mahanadhi (851 km), Narmada (1312 km) and Yamuna (1370 km). With the population of around 1.36 billion population, India is severely affected by hazards such as monsoon floods, flash floods, earthquake, drought, landslides and urban floods recently (De et al. 2013). With the increase in the movement of population towards cities, based on the census report (2011), Mumbai has the highest population followed by Delhi (India). Table 1 lists the percent growth of population over a decade gap in the major metropolitan cities in India. Hyderabad population has increased 113.04%, which is more than twice the amount when compared to 2001 population (UNDP 2012). Bangalore, Chennai and Surat are the major cities, where the population increased about 96.30, 63.18 and 83.33% in 2011 compared to 2001 respectively. Population growth leads to the burden on metropolitan cities in terms of facility creation, infrastructure, roads, railway network, canals, rivers, etc. Improper design and planning result in economic loss and loss of human life, and one of the best examples for such scenario is Chennai floods in Tamil Nadu that occurred in the year 2015.

History of floods in India

India is one of the fast developing urban systems and a country with a drastic increase in population over decades (Sun et al. 2020). With a vast number of flood events recorded in India, some of the major floods are listed in Table 2. Due to the migration of population towards cities, a massive amount of population is exposed to urban floods (Lyu et al. 2019). In 1943, around 5000 to 10,000 people died in Rajputna floods, and the second largest flood event recorded in India was in 2013 that lead to over 5700 causalities (UNDP 2012). Figure 1 shows the percentage of floods in South Asian context. Occurrence of floods over decades has a huge impact on Indian population and resulted in economic loss (Parida et al. 2021). Table 3 lists the yearly total area affected due to floods and its impact to the population since 1953.

(*Source: EM- DAT and local, regional data)

(Source: CWC)

Urban flood occurs in cities, metropolitans and developed areas (Rahman et al. 2016). In India, urban floods are recently emerging disaster due to the development of urban settlement (Gupta 2020). Many people migrate towards cities in search of employment opportunities and to lead a comfortable life (Moses et al. 2017). Population and over-explosion is two of the major issues in India as it is the second most populated country in the world behind China (Suresh et al. 2018). Recently, frequency of urban flood occurrences is increasing in India, and it is identified that metropolitan cities such as Bangalore, Chennai, Hyderabad, Kolkata, Delhi, Ahmedabad, Surat, Guwahati and Mumbai are affected by urban floods at a larger magnitude (Surampudi and Yarrakula 2020).

In 2005, 26th of July, Mumbai faced 944 mm (37.17 inches) of rain causing huge floods that made lots of people stranded, losing their homes, livelihood, etc. Economic loss due to the flood event was estimated nearly 100 million dollars (Das et al. 2007). Figure 2 shows the images captured during the disaster occurrence in Mumbai city.

Jammu and Kashmir faced highest flood of the century between 2nd and 26th September of 2014 as shown in Fig. 3. Floods in Jammu and Kashmir were a result of high-intensity rainfall over a short period of time, effect of climate change and lack of capacity in the drainage system that failed to withstand the substantial quantity of water, resulting in overflow, which ultimately caused floods (Mishra 2015).

Table 1 Major cities and population of India

Rank	City	State	Population (2001)	Population (2011)	Difference in population	Growth percent
1	Mumbai	Maharashtra	11,978,450	12,442,373	463,923	3.87
2	Delhi	Delhi	9,879,172	11,007,835	1,128,663	11.42
3	Bangalore	Karnataka	4,301,326	8,443,675	4,142,349	96.30
4	Hyderabad	Telangana	3,637,483	7,749,334	4,111,851	113.04
5	Chennai	Tamil Nadu	4,343,645	7,088,000	2,744,355	63.18
6	Ahmedabad	Gujarat	3,520,085	5,577,940	2,057,855	58.46
7	Kolkata	West Bengal	4,572,876	4,486,679	−86,197	−1.88
8	Surat	Gujarat	2,433,835	4,462,002	2,028,167	83.33
9	Pune	Maharashtra	2,538,473	3,115,431	576,958	22.73
10	Jaipur	Rajasthan	2,322,575	3,073,350	750,775	32.32

*Source: Census India

Table 2 History of major floods in India

S. no	Year	Place of flood disaster	Country	Fatalities
1	1943	Rajputna floods	India	5000–10,000
2	1955	Northern India floods	India	1700
3	1961	Bihar floods	India	1000
4	1968	Rajasthan, Gujarat monsoon	India	4892
5	1978	Northern India monsoon rain	India	3800
6	1979	Morbi dam burst	India	2000–5000
7	1992	Northern India monsoon rain	India/Pakistan	1834
8	1993	South Asian monsoon rain	India/Pakistan/Bangladesh/Nepal	3084
9	1998	Eastern India monsoon rain	India/Bangladesh	3838
10	2004	Eastern India monsoon rain	India/Bangladesh	3076
11	2005	Mumbai, Maharashtra monsoon rain	India	1503
12	2008	Monsoon floods	India	2400
13	2010	Leh floods	India/Pakistan	Above 125
14	2013	North India floods	India	5700
15	2014	Kashmir J&K floods	India	300–400
16	2015	South Indian floods	India	500–600
17	2016	Assam floods	India	30 (nearly)
18	2017	Gujarat floods	India	More than 200
19	2018	Kerala floods	India	More than 445
20	2019	Kerala floods	India	121
21	2020	Assam floods	India	149

Chennai city experienced one of the severe floods between 8th November and 14th December 2015, due to the heavy rainfall of 1049 mm (41.3 inch), three times its monthly rainfall (J. and Chandar 2015). The flooding in Chennai city was worse due to years of improper development and poor levels of flood preparedness (UNDP 2012; Sundaram and Yarrakula 2017). Nearly 500 deaths were recorded, and property loss was estimated about 3 billion US dollars (200 billion rupees). Most of the city was submerged in water due to urban floods (Seenirajan et al. 2017). Figure 4 shows the image captured during the disaster.

With the advancement in technologies, several early warning systems are implemented, and experts are educating the general public about the seriousness of a disaster event. Fatalities are recorded at a higher rate due to the lack of awareness of people towards protective measures and emergency situations, improper planning of structures, encroachments in dried water bodies, occupying pavements, dumping garbage in drainage and pathways, etc.

Causes of urban floods

Global warming, urbanization and improper land use patterns are the major reasons that triggers urban flooding (Handayani et al. 2020). Global warming leads to climate change resulting in sudden and intense rainfall like cloud burst which causes floods. Improper settlement distribution, encroachment on river bed or lakes, improper planning and lack of draining network design maintenance, garbage dumping and siltation are some of the reasons for urban floods (Hasnat et al. 2018). Improper planning and maintenance of runoff water during heavy rainfall lead to the rise in the water level in rivers and lakes leading to flash floods in urban settlements (Ancona et al. 2014; Chung et al. 2015). Encroachment of dried-up areas of lakes, river bed and establishing settlements is the main reason for urban flooding (García-Pintado et al. 2015; Konrad 2016). An increase in urbanization leads to the variation in the catchment areas resulting in the development of impervious regions that reduces infiltration and increases the runoff leading to floods (Gebre SL 2015; Du et al. 2019). Ghimire (2013) studied the impacts of extreme climate rainfall and developed model rainfall profiles for representing rainfall under different conditions (Ghimire 2013). Flooding in cities is caused by slow accumulation of flood or runoff water and rapid inundation of water in low-lying areas (Jang 2015). Cities located near coastal region experience high tide from storms causing inflow of seawater causing floods (Lund 2012). Flash flood are triggered by sudden and intense rainfall; such floods can be predicted by using an effective process oriented urban flood model (Suarez et al. 2005; Tazyeen and Nyamathi 2015). Figure 5 illustrates the major factors that influence urban floods.

Table 3 Year-wise flood damages from 1953 to 2016

S. no	Year	Area affected (m ha)	Population affected in millions	Fatalities	Total damages (INR) in crore
1	1953	2.29	24.28	37	52.4
2	1954	7.49	12.92	279	57.231
3	1955	9.44	25.27	865	102.725
4	1956	9.24	14.57	462	53.627
5	1957	4.86	6.76	352	23.369
6	1958	6.26	10.98	389	43.966
7	1959	5.77	14.52	619	86.198
8	1960	7.53	8.35	510	63.169
9	1961	6.56	9.26	1374	31.369
10	1962	6.12	15.46	348	94.885
11	1963	3.49	10.93	432	36.611
12	1964	4.9	13.78	690	66.607
13	1965	1.46	3.61	79	7.135
14	1966	4.74	14.4	180	88.43
15	1967	7.12	20.46	355	155.431
16	1968	7.15	21.17	3497	211.095
17	1969	6.2	33.22	1408	404.435
18	1970	8.46	31.83	1076	287.827
19	1971	13.25	59.74	994	632.484
20	1972	4.1	26.69	544	158.194
21	1973	11.79	64.08	1349	569.001
22	1974	6.7	29.45	387	569.016
23	1975	6.17	31.36	686	471.637
24	1976	11.91	50.46	1373	888.685
25	1977	11.46	49.43	11,316	1201.848
26	1978	17.5	70.45	3396	1454.764
27	1979	3.99	19.52	3637	614.203
28	1980	11.46	54.12	1913	840.504
29	1981	6.12	32.49	1376	1196.504
30	1982	8.87	56.01	1573	1644.876
31	1983	9.02	61.03	2378	2491.606
32	1984	10.71	54.55	1661	1905.562
33	1985	8.38	59.59	1804	4059.268
34	1986	8.81	55.5	1200	3748.525
35	1987	8.89	48.34	1835	2569.72
36	1988	16.29	59.55	4252	4630.3
37	1989	8.06	34.15	1718	2405.33
38	1990	9.303	40.259	1855	1708.92
39	1991	6.357	33.889	1187	1488.329
40	1992	2.645	19.256	1533	3344.532
41	1993	11.439	30.409	2864	3282.485
42	1994	4.805	27.548	2078	1794.59
43	1995	5.245	35.932	1814	3702.308
44	1996	8.049	44.729	1803	3005.743
45	1997	4.569	29.663	1402	2831.181
46	1998	10.845	47.435	2889	8860.721
47	1999	7.765	27.993	745	3612.76
48	2000	5.382	45.013	2606	8864.544
49	2001	6.175	26.463	1444	7109.416

Table 3 (continued)

S. no	Year	Area affected (m ha)	Population affected in millions	Fatalities	Total damages (INR) in crore
50	2002	7.09	26.323	1001	2574.543
51	2003	6.12	43.201	2166	11,325.866
52	2004	5.314	43.725	1813	3314.385
53	2005	12.562	22.925	1455	7439.672
54	2006	1.096	25.224	1431	19,790.922
55	2007	7.145	41.402	3389	13,283.677
56	2008	3.427	29.91	2876	9589.935
57	2009	3.844	29.537	1513	32,551.758
58	2010	2.624	18.297	1582	19,520.586
59	2011	1.895	15.973	1761	7857.892
60	2012	2.141	14.689	933	10,944.648
61	2013	7.546	25.927	2180	47,348.751
62	2014	12.775	26.505	1968	15,548.077
63	2015	4.478	33.203	1420	57,291.098
64	2016	7.065	26.555	1420	5675.325

Impacts of urban floods

Urban floods result in higher causalities and economic loss compared to any other type of floods, as they hit urban settlement directly (Rubinato et al. 2019). Urban floods disturb human's socioeconomic activities at local, regional and even national level (Wang 2015). One of the major impact of flood event is loss of lives by drowning and transmission of diseases by water (Dewan 2015). Due to overpopulation and complex urban networks, relocation of people during the disaster event is a challenging task resulting in loss of livelihood (Satterthwaite et al. 2010). Restoration of flood hit location is time consuming and challenging in India due to lack of awareness, facilities, participation and group activities (Safiah Yusmah et al. 2020). During a flood event, evacuation proves to be a complex task because of population, locating the survivors, prioritizing emergency rescues, etc. (Rufat et al. 2015). Few major issues faced during an urban floods are listed below.

- Transportation obstruction, submergence of roads under water during urban floods (Suarez et al. 2005).
- Urban flood causes various waterborne diseases affecting water quality and chances of epidemics causing distress to the people (Ouyang et al. 2012).
- Urban pluvial floods lead to severe damages and disruption in highly urbanized and populated areas (Simoes et al. 2015).
- Flood also causes severe damage to crop and any vegetation (Baky et al. 2012; Kwak et al. 2015).
- In India, major cities such as Chennai, Mumbai and Kolkata are near to coastal region making them vulnerable to coastal flooding (de Sande et al. 2012).

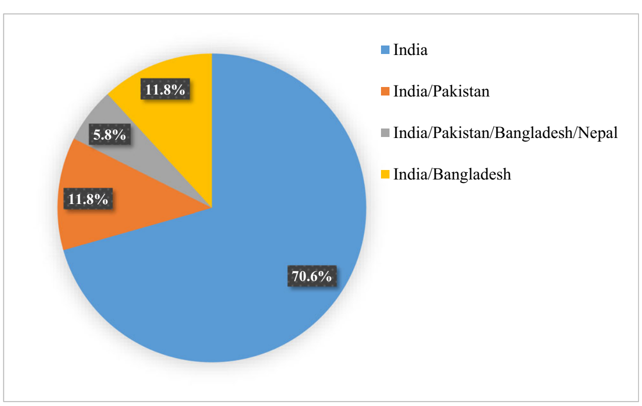

Fig. 1 Floods in India and nearby contributing countries

Fig. 2 Mumbai floods 2005 (people following a single, safe pathway for evacuation from the flooded area)

Fig. 3 Jammu and Kashmir floods 2014 (view of J&K submerged in massive flood)

- Higher level of precipitation in monsoon seasons causes flooding in low-lying regions especially poorly planned areas, where the economy of the people is affected directly (Ramlal and Baban 2008).
- Urban floods cause heavy economic and property loss. Major metropolitans such as Chennai, Mumbai faced millions of dollars loss because of urban floods (Ramlal and Baban 2008).
- Daily activities were obstructed. Evacuation of people was cumbersome due to high population

Factors influencing urban floods

Climate change

Climate change plays an important role in urban floods (Zhou 2014; Emilsson and Ode Sang 2017). The abrupt change in climate affects the season and monsoons of a particular area resulting in unexpected rainfall which results in flash floods (Mujumdar et al. 2020). Flash floods are considered to be dangerous because of their uncertainty (Lakshmi and Yarrakula 2018). A large amount of rain could cause damage to property, livestocks as well as loss of life of humans (Kanianska 2016). Flash floods over the urban region are critical than flood over river basin. One of the major challenges faced by the global countries across the world is climate change (Kundzewicz et al. 2014). The impact of climate change is inevitable in the present decade and has a direct effect on the urban population (Milesi and Churkina 2020). Several models and technologies are being developed for the prediction of climate change, yet few limitations are faced in implementation of the models at real time (Singh and Singh 2012). Combination of numerical and satellite-based models integrated with artificial intelligence is widely used in the prediction of the disaster event precisely and is successfully adopted in near real-time analysis (Sun and Scanlon 2019).

Fig. 4 Chennai floods 2015 (view of Chennai submerged in storm water flood)

Climate resilience will be an essential factor in adaptation of the effects of climate change (Carter et al. 2015). Global cities, particularly Asian cities, should follow urban flood resilience schemes mainly aiming on land use and environment aspects (Albano et al. 2015; Qi et al. 2020). The ability of a city or urban region to withstand a series of shocks and stress is referred as urban resilience (Kim and Lim 2016). Urban climate resilience is withstanding and adapting the change in the climate system over a period of time and ensuring proper methods and ways to understand the conditions for survivability (Egerer et al. 2021). Ecological and economic resilience should be promoted through urban governance and institutions (Meyer and Auriacombe 2019). Urban resilience results in disaster risk and hazard reduction (Ferreira and Lourenco 2019). Factors such as heavy storm, lack of storm drainage systems, population explosion and urbanization are considered as the major contribution for urban flood risk, whereas climate change also proves to be an important factor in the event of flood occurrences which contributes heavier and frequent storms (Morita 2014). Due to global warming, meteorological research is exercised vastly for predicting the changes in the characteristics of rainfall/storm (Wu et al. 2016). Several methods are used for modeling the flood frequencies, such as considering global warming and rainfall intensities, vulnerability assessment of flood-prone urban areas using greenhouse flood data (Shrestha and Lohpaisankrit 2017). Double CO_2 conditions indicate the possibility of increase in both the magnitude and frequency of flood events (Fowler and Hennessy 1995). Morita (2014) developed a damage potential curve using a simple return period shift method (RPS) from the present damage potential curve for studying the changes in the damage potential curve of post global climate change conditions (Brown and Saunders 2020). An increase in precipitation intensity and a decrease in snowpack (glaciers) are some of the adverse effects of climate change (Sivalingam et al. 2021). Rain-generated floods occur more at areas having an increase in frequency and intensity of heavy rainfall (Tabari 2020).

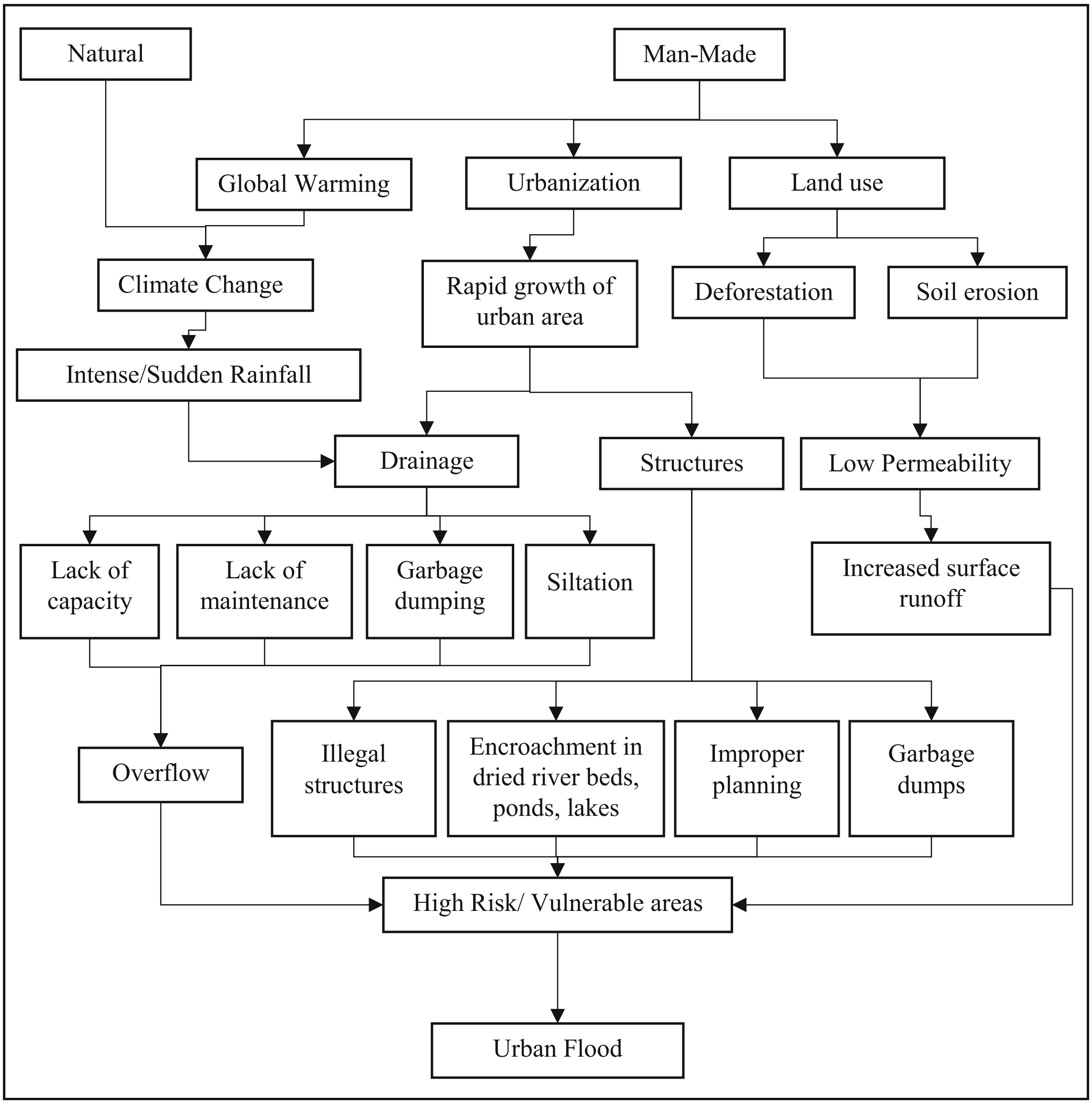

Fig. 5 Major factors that influence urban floods

Land use and land cover on urban floods

Land cover data consists of regions covered by naturally formed features such as forest, mountains, wetlands (Barredo and Engelen 2010), whereas land use resembles the use of landscape for various human uses (Anderson et al. 1976). Adopting traditional methods, it is a time-consuming process to monitor large area and identify the land use land cover pattern (Reddy et al. 2019). Recent advancement in technologies leads to the use of images obtained from satellites for determining land use land cover pattern (Alam et al. 2020). In order to estimate the changes over a period of time, change detection analysis of the features is estimated using temporal analysis by analyzing land cover land use maps (Alawamy et al. 2020). Land use change affects the climate through activities like deforestation, urbanization (Arshad et al. 2020). Flood losses are estimated by various methods such as GIS tools and remote sensing imageries (Elkhrachy 2015). Remotely sensed data are used progressively for mapping land use and land cover; such land use and land cover information provides a detailed report of regions that are more prone to flood loss (Gómez et al. 2016). Reclassification of existing land use classes into desired groups results in better information on estimation of flood occurrences and damage assessment (Prütz and Månsson 2021). Temporal analysis of urban change by detecting the change in land use and land cover shows the status of surface water situation (Hua 2017). Based on the change in urbanization, a model is constructed to simulate the response of surface water environment (Mason et al. 2014). The model identifies the direct effect of urbanization in water surface quantity and quality. Primary and secondary losses caused by flood events can be prevented through better planning of land use, especially in urban areas (Loucks and van Beek 2017). Direct and indirect losses can also estimate and be prevented by using better flood emergency measures (Tanoue et al. 2020). Integration of flood models, urbanization, delineation of watershed (flood prone areas) zones and land use land cover information help in minimizing the flood damage (Abdrabo et al. 2020). Local governing authorities must ensure that the planning of urban infrastructures is in approved law and regulations (Ahluwalia 2019). Land use, climate condition and demographic data combined for modeling urban transport system, ensuring a reliable transport system during urban storm flood event (Revilla-Romero et al. 2015; Andimuthu et al. 2019). Future land use scenario is also computed for exploring impacts at the time of excess of expected flood event (Krause et al. 2019).

Importance of urban flood models

Urban flood models are designed and implemented for the prediction and estimation of impact of floods (Xing et al. 2019). Nowadays, mathematical, physical and numerical methods are applied for monitoring the effects and impacts of floods (Croci et al. 2014). Space technologies are widely used for estimating the influence of climate change and its impacts on future urban flooding (Ferreira 2020). Delineation of drainage pattern, watershed and water resource management are effectively carried out using GIS and remote sensing tools (Conesa-Garcia et al. 2010; Carbone et al. 2014; Devaraj and Yarrakula 2020). Huong et al. (2013) used land use simulation model (Dinamica EGO), atmospheric model (WRF), land surface model with vegetation (Noah LSM) and 1-D/2-D urban-drainage model SWMM-Brezo for estimation of flood inundation zones and hazard mapping (Huong and Pathirana 2013). Complex vegetation and water composition is troublesome for creating urban flood inundation models (Talbot et al. 2018). Malinowski et al. (2015) used high-resolution satellite image for overcoming this difficulty (Malinowski et al. 2015). Timbadiya et al. (2014) addressed the simulation of floods and the development of stage–discharge relationship along a river (Timbadiya et al. 2014). 1D hydrodynamic models using MIKE11 are widely used for calibration and validation using low- and high-flood data for forecasting floods (Singh et al. 2020). Tarekegn et al. (2010) conducted a study to integrate remote sensing, GIS with SOBEK 2D flood model (Tarekegn et al. 2010). Digital elevation model (DEM) from ASTER and a GIS procedure are developed to modify the terrain of the river and channel bathymetry and suggested to use ASTER 15-m high accuracy DEM for 2D hydrodynamic modeling (Ettritch et al. 2018). Wang et al. (2008) experimented several methods for developing a grid-based hydrological model for simulating storm water inundation (Wang et al. 2008). Grids of the city, land use and land cover, DEM from the 1:500 digital maps were used and concluded that remote sensing and hydrological models can be integrated to solve problems relating to hydrologic influences (Szypuła 2019). Zhang et al. (2015) investigated Nash–Sutcliffe efficiency (NSE) of the SWAT model and proposed that SWAT shows better model results of wet seasons on comparison with dry seasons (Vorobevskii et al. 2020). SWAT-SC models show significant performance of runoff simulation in the dry period (Budamala and Baburao Mahindrakar 2021). Kulkarni et al. (2013) modeled and designed web GIS-based flood tool, in which the flood impacts were monitored for coastal lying city floods (Kulkarni et al. 2013). Mason et al. (2013) used advanced technologies such as synthetic aperture radar (SAR) for mapping urban floods (Mason et al. 2014). Synthetic aperture radar (SAR) sensors are capable of mapping flood because of its advantage of all weather, day and night mapping capability (Surampudi and Yarrakula 2020). Continuous development of SAR sensors resulted in generation of high-resolution data for monitoring urban floods (Suresh and Yarrakula 2020). Li et al. (2014) used constrained Delaunay triangular irregular network (CD-TIN) data to model urban surfaces; such fine-constrained features provide information on accurate urban water depressions (Li et al. 2014). Gichamo et al. (2012) described about accurate river model, exact representation of the river stream, geometry of the floodplain and concluded that model parameters need to be accurate for predicting the possible river flow magnitude and water levels in the stream (Gichamo et al. 2012). Chen et al. (2009) used Green–Ampt model for infiltration calculation and GIS-based urban flood inundation model (GUFIM). These models replaced physical model, showing high performance and accurate results (Chen et al. 2009). Syme et al. (2004) investigated different models for modeling of urban floods, a quasi-2D model (1D network), 2D raster routing models, full 2D regular grid hydrodynamic models (finite difference), full 2D irregular grid hydrodynamic models (finite element) and finally combination of 1D hydrodynamic models with one of the models to achieve near complete solution (Syme et al. 2004). Audisio et al. (2011) examined the occurrences of flood from historical data and used the data from documents, maps, GIS techniques, field surveys of urban development. The author compared two main flood events: one from the present and the other from the past to display the resemblance and deviations that have changed over years (Audisio and Turconi 2011). Mark et al. (2001) combined physical-based model and GIS and used MOUSE for configuring urban drainages. Free surface flow network and sewer pipe system interaction is modeled in a simple way for representation of real-life situation of urban floods (Ole et al. 2021). Bamford et al. (2008) integrated modeling approach will be useful in effective understanding of flood events (Bamford et al. 2008). Chen et al. (2008) studied surface flood flow modeling, building coverage ratio (BCR), and conveyance factors (CRFs) are introduced to urban inundation model (UIM)(Chen et al. 2008). Turner et al. (2013) used light detection and ranging (LIDAR) technology for flood modeling. Multi-platform (mobile, terrestrial and airborne) LIDAR data is combined to form a composite dataset, and TIN (triangular irregular network) model is generated for modeling accurate flood events (Turner et al. 2013).

Research developments on urban floods

Advancements in field of urban flood modeling 1D/2D(Chen et al. 2008; Audisio and Turconi 2011; Kulkarni et al. 2013; Li et al. 2014; Supriya et al. 2015; Budamala and Baburao Mahindrakar 2021), GIS and remote sensing techniques and various methods are frequently used for urban flood modeling and estimation (Dey and Kamioka 2007; S.M.J.S.Samarasinghea et al. 2010; Ranger et al. 2011; Suroso et al. 2013; Zeng et al. 2015; Zhang et al. 2015). Table 4 shows the various studies and research works on urban floods, flood management, flood risk assessment, flood forecasting, mitigation and management, flood routing, flood modeling, magnitude of floods and simulations. Various researchers who have done different works on urban floods from 2001 to 2015 are listed. Around 35 research finding have been observed from various works. In most of the studies, HECRAS, LISFLOOD, Mike 11, SWMM, TUFLOW, TELEMAC and XP-SWMM are used to monitor urban floods (De et al. 2013; Tazyeen and Nyamathi 2015; Komi et al. 2017; Fleischmann et al. 2017, 2018; Abdessamed and Abderrazak 2019; Vercruysse et al. 2019; Dehghanian et al. 2020).

Urban flood management and recommendations

Important guidelines are framed by NIDM (National Institute of Disaster Management) India for effectively managing urban floods. They also include some of the measures for urban floods such as early warning system and communication, design and management of urban drainage systems.

Urban flood management includes:

- Watershed analysis for managing and estimating urban floods.
- Vulnerability analysis and risk assessment.
- Estimating flood inundation level for respective rainfall.
- Designing spatial decision support systems.
- National and state level flood disaster information systems.
- Establishing urban flood cells.
- Emergency flood response teams.
- Awareness programs and training for both civilians and rescue teams.

Flood management decision support system describes about the category of floods based upon the flood impact and warnings issued for the types of flood. Table 5 shows the effect of flood and necessary action to be taken, provided by national disaster management authority.

Management of floods in urban areas plays a vital role in safety of people and sustaining socioeconomic conditions (Notaro et al. 2014). Periodical maintenance and cleaning of drainage facility by removal of garbage increases water infiltration capacity and decreases the surface runoff. Such measures lead to minimizing human loss and economic damages (Haider et al. 2003). Reliable technologies, early warning systems and mitigation are lacking in many developing countries around the world (Hansson et al. 2008). Management of floods also includes effective and improved city planning (Shimokawa et al. 2016), modeling the flow of floods (Chen et al. 2008) and clearing the path for the flow of water without any obstruction into the sea ensuring minimal damage caused by the flood. Yan et al. (2011) proposed that urban flood and rain water can be utilized for better use by building water collection systems, water transportation system, efficient rain water harvesting systems, etc. (Yan et al. 2011). Fanghong et al. (2012) proposed that urban flood studies are key for management and use of rain water at times of water stress or drought conditions. Benefits of urban storm water resources are analyzed and can be used to improve sustainable development of the area (Fanghong et al. 2012). Sande et al. (2012) stated that, in recent technologies such as remote sensing and GIS, it is important to use high-resolution digital elevation models (DEM), which determines the flood risk area by referring the elevation (de Sande et al. 2012). In urban drainage systems, water detention storages are designed and developed to minimize the impact/effect of urban floods (Jang et al. 2007). Prawiranegara (2014) studied on basin wide flood risk assessment and suggested that proper spatial planning and urban resilience policies reduce the flood risk exposure (Prawiranegara 2014). Digital city concept shows managing urban floods by integrating urban storm water cycle with proper urban planning. Both structural and non-structural strategies are utilized for effective flood management. During the event of urban floods, local governments must provide shelter in public structures such as sports halls, schools, auditoriums and malls that are situated in high elevation where the flood cannot be reached (Melgarejo and Lakes 2014). Research effort was to get progress on data collection, analysis and development of models. Empirical and synthetic data collection provides consistent, reliable data. Lo et al. (2015) studied visual sensing for acquiring dynamic image information and used spatio-temporal information for automated remote analysis of urban flood monitoring. By

Table 4 Research work and the models used in flood studies

S. no	Author	Type of study	Modules/software	Models/method
1	Dehghanian et al. 2020	Food source area identification	ArcGIS	HEC RAS and Mod Clark—ANN-GA
2	Vercruysse et al. 2019	Flood modeling	City Catchment Analysis Tool	CityCAT
3	Abdessamed and Abderrazak 2019	Hydrological modeling and hydraulic modeling	ARCGIS	HEC HMS and HEC RAS
4	Fleischmann et al. 2018	Flood regulation	Map Window GIS	MGB-IPH hydrologic and hydraulic model—two-directional coupling
5	Fleischmann et al. 2017	Flood regulation	Map Window GIS	MGB-IPH hydrologic and hydraulic model—one-directional coupling
6	Komi et al. 2017	Hydrological modeling	LISFLOOD	One-directional, coupling-Lisflood and Lisflood-FP
7	Albano et al. 2015	Flood risk management	Geospatial tools, open source tools	FOSS model, flood risk management (FRM)
8	García-Pintado et al. 2015	Flood plain monitoring	LISFLOOD-FP, HSPF is a US EPA program.	Ensemble Kalman (EnKF), EO-based operational flood forecasting, fully automated aqua processing service (FAAPS)
9	Getahun and Gebre 2015	Flood inundation	HEC-RAS,GIS(ArcGIS), HEC-GeoRAS	Multi-criteria AHP techniques, analytical hierarchical process (AHP)
10	Mugume et al. 2015	Resilience of urban drainage	MATLAB, SWMM	Global resilience analysis (GRA) approach
11	Revilla-Romero et al. 2015	Flood forecast and monitoring	Comparison	Global flood detection system (GFDS), global flood awareness system (GloFAS), MODIS
12	Supriya et al. 2015	Flood discharge	Datafit 9, Arc Map (GIS)	Generation of Thiessen polygons, annual maximum daily stream flow, regression analysis
13	Tazyeen et al. 2015	Flood routing urbanized lakes	Unit, flood hydrographs	Design flood hydrograph, inflow–storage–discharge (ISD) meth-od
14	Zeng et al. 2015	River and water flow extraction	Worldview-2, GIS	Natural-rule-based connection (NRBC)
15	Zhang et al. 2015	Simulation of water quality and supply	(SWAT), SWAT-SC	Seasonal calibration scheme, Nash–Sutcliffe efficiency (ENS), daily runoff simulations
16	Li et al. 2014	Urban storm flood	ArcGIS, numerical simulation.	• Constrained Delaunay triangular irregular network (CD-TIN)
17	Morita 2014	Urban floods	XP-SWMM	Flood damage prediction model (FDPM)
18	Notaro et al. 2014	Urban flood damage modeling	PBRMSE, PBIAS statistics	Bayesian model averaging (BMA)
19	Ouma et al. 2014	Urban floods	GIS, AHP-GIS	Analytical hierarchy process (AHP), urban flood risk index (UFRI)
20	Prawiranegara 2014	Basin-wide flood risk assessment	GIS, ArcGIS	Spatial multi-criteria analysis (SMCA)
21	Zhou 2014	Urban floods (drainage)	Drainage models and review of models.	Sustainable urban drainage system (SUDS), LIUDD (low impact urban design and development)
22	Carbone et al. 2013	Urban flood control	Comparing rain gauges with radar.	Thirty-eight automatic tipping-bucket rain gauges. Detecting movement of storm.
23	Croci et al. 2013	Urban flood	1D/2D flow routing, MIKE 11 DHI	URBFEP (urban flood equivalent pipe), depth–duration–frequency (DDF) curves
24	Mason et al. 2013	Urban floods	Synthetic aperture radar (SAR)	Increased double scattering
25	Suroso et al. 2013	Flood risk	TOPAZ, GIS	GSSHA (gridded surface subsurface hydrologic analysis) method.
26	Ouyang et al. 2012	Urban storm rainfall runoff	SWMM	COD, TSS, TP, storm rainfall runoff simulation
27	Audisio and Turconi 2011	Urban floods	GIS	Comparison of two flood events using GIS
28	Ranger et al. 2010	Urban floods risk, climate change	GIS, climate models	SRES A2 scenario, PRECIS, WXGEN. Adaptive regional input–output model
29	Barredo et al. 2010	Flood risk mitigation	Spatial analysis techniques (GIS)	Land use modeling, flood risk mapping, cellular automata-based model

Table 4 (continued)

S. no	Author	Type of study	Modules/software	Models/method
30	Conesa-Garcia et al. 2010	Flood magnitude	HEC-RAS, HEC-GeoRAS	Hydraulic geometry, SCS dimensionless unit hydrograph, automatic hydrologic information system (AHIS)
31	Samarasinghe et al. 2010	Flood risk analysis	HEC-HMS, HEC-RAS, ALOS PALSAR	Hydrologic/hydraulic analysis, topographical analysis, satellite data analysis
32	Chen et al. 2009	Urban floods	GIS	GIS-based urban flood inundation model (GUFIM)
33	Solaimani 2009	Flood forecasting	HEC-RAS, HEC-GeoRAS, SMADA	Digital elevation models (DEM), triangular irregular networks (TIN)
34	Bamford et al. 2008	Urban floods	NIMROD Data, InfoWorksCS, InfoWorks 2D	2D modeling, integrated urban drainage
35	Chen et al. 2008	Urban floods	HEC-RAS, LiDAR	Coupled 1D sewer flow and 2D urban inundation modeling, UIM 5M and 10M, BCR
36	Dey et al. 2007	Urban basin floods	EPA-SWMM, MESHSIM, RIVSIM, INTERFACE	Sewerage network, river network and 2D mesh network
37	Jang et al. 2007	Urban floods	SWMM	Single or more hydrologic models paired pre and post event of flood.
38	Suarez et al. 2005	Urban flood	GIS	Climate events and model, urban transportation modeling system (UTMS)
39	Syme et al. 2004	Urban floods	ISIS, LISFLOOD, TUFLOW, TELEMAC	2D/1D hydraulic modeling
40	Haider et al. 2002	Urban floods	Rubar 20	2D models, computational fluid dynamics
41	Ole et al. 2021	Urban floods	MOUSE models	Storm water drainage modeling, inundation mapping using GIS

identifying the root causes and characteristics of urban floods, suitable methods and models can be practiced for urban flood management (Lo et al. 2015).

Urban flood risk/hazard assessment

Urban regions exposed and vulnerable to hazard (urban floods) are called (urban flood) risk zone (Solaimani 2009). Many researchers, policy makers, government authorities explained on flood mitigation, management processes and flood risk zone assessment (McGuigan et al. 2015). Lhomme et al. (2013) introduced new concept like urban resilience for reducing urban flood risk (Lhomme et al. 2013). The possibility of flood occurrence over an area and the magnitude of damage or economy loss decides the flood risk over that particular region (de Sande et al. 2012). Assessment of risk and vulnerable zones is needed for effective implementation of flood prevention and mitigation (Marconi et al. 2016) and developing risk reduction strategies. Figure 6 shows the relationship between risk, hazard, exposure and vulnerability.

Flood risk is essential for evacuation planning and can be done by mapping flood hazard areas (Paquier et al. 2015). Addo et al. (2011) identified the number of building exposed to floods, using aerial photographs for estimating the population at risk (Appeaning Addo et al. 2011). Damage assessment includes three major factors such as flood water velocity, maximum water level discharged and flood event duration. Flood

Table 5 Flood management decision support system (NDM Guidelines, 2010)

S. no	Category of flood	Warning	Impact/Action
1	None	No threat of floods	Normal functioning of the urban system
2	Minor	Minor flooding in some areas	Some inconvenience to the public
3	Moderate	Inundation of low-lying areas	Roadways disruption, evacuation not required
4	Major	Inundation of large areas	Evacuation required, disruption in all mode of transportation
5	Severe	Large-scale inundation of many parts of the cities	Complete evacuation, total loss and large level disaster affecting everything

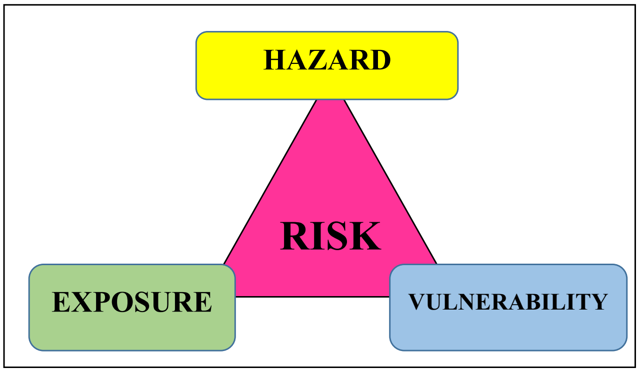

Fig. 6 Relationship between risk, hazard, exposure and vulnerability

preparedness, disaster response and management during large-scale floods require hazard mapping to improve services and recovery measures. Suitable planning and strengthening the policies result in reduction in disaster risk and maintaining considerable funds, and estimating vulnerability assessment towards disaster events such as urban floods minimizes the collateral damage caused by it.

Conclusion

Every year, India is facing several flood events, and the property as well as loss of lives is also increasing enormously. Due to rapid urbanization, the flood peaks increase 1.8 to 8 times, and volume increased by 6 times; as a result flash, floods are occurring in a matter of minutes. To manage the urban floods in an efficient manner, flood inundation mapping, vulnerable areas in terms of demographic data are to be identified properly. The challenging tasks can be achieved by modeling floods with the available data including high-resolution satellite data, good quality of digital elevation models, rainfall and drainage network. The present review article addresses the frequency of urban floods in India, impacts of urban floods, climate change impacts, urban floods in south Asia, importance of modeling. Apart from this, the government has to create awareness and encourage the people to acquire the knowledge in pre and post disaster events. Public involvement, education can effectively reduce the impact of urban floods.

Improvements in flood inundation modeling tools are developing over decades enabling the researchers and decision makers in prediction of disaster events. Introduction of space based datasets paved way for the development of hydrological models, aiming at monitoring and modeling flood events. Even though technological advances utilize various parameters as input, there is no "perfect model" derived which can be adopted for exact prediction of the climatic variation. Hydrological and hydraulic flood modeling are characterized by several parameters such as topography, flood depth, extent of inundation, time of inundation and velocity of water flow. Models existing require high-resolution input to offer a flood risk assessment information.

Development in space technology addresses the data challenge of providing high-resolution datasets, whereas limitations exist in the cost of operation and acquisition of the datasets. Existing SRTM and ASTER DEM are widely used as a topographical dataset for several researches across the world which does not provide results at good accuracy resulting in developing a realistic model at lesser accuracy. Development of empirical methodologies proved to be a significant method for flood modeling and post disaster assessment.

With several research work focusing on statistical and machine learning-based approaches for modeling floods at higher accuracies, models developed are improving and assisting in understanding the disaster event. However, researchers focusing on flood modeling are tempted towards developing a model with higher accuracies considering the identical parameters as input. Considering the research community being wide open for new ideas, new approaches have to be focused on selecting the input parameters, which might assist in developing an innovative model.

Author contribution KY conceptualized the idea, and provided the necessary resources to carry out this research and supervised SS and SD throughout this study. SS carried out the review and wrote the manuscript. SD provided essential technical inputs that helped improve the manuscript.

Data availability The dataset utilized/analyzed during the current study will be available from the corresponding author upon request.

Declarations

Ethics approval All ethical practices have been followed in relation to the development, data analysis, writing and publication of this research article.

Consent to participate Consent to participate is 'Not applicable' for the manuscript.

Consent for publication None of the data used belongs to any person in any form.

Competing interests The authors declare no competing interests.

References

Abdessamed D, Abderrazak B (2019) Coupling HEC-RAS and HEC-HMS in rainfall–runoff modeling and evaluating floodplain inundation maps in arid environments: case study of Ain Sefra city, Ksour Mountain. SW of Algeria. Environ Earth Sci 78:586. https://doi.org/10.1007/s12665-019-8604-6

Abdrabo KI, Kantoush SA, Saber M, Sumi T, Habiba OM, Elleithy D, Elboshy B (2020) Integrated methodology for urban flood risk

mapping at the microscale in ungauged regions: a case study of Hurghada, Egypt. Remote Sens 12:1–24. https://doi.org/10.3390/rs12213548
Ahluwalia IJ (2019) Urban governance in India. J Urban Aff 41:83–102. https://doi.org/10.1080/07352166.2016.1271614
Al Jarah SH, Zhou B, Abdullah RJ et al (2019) Urbanization and urban sprawl issues in city structure: a case of the Sulaymaniah Iraqi Kurdistan region. Sustain 11. https://doi.org/10.3390/su11020485
Alam A, Bhat MS, Maheen M (2020) Using Landsat satellite data for assessing the land use and land cover change in Kashmir valley. GeoJournal 85:1529–1543. https://doi.org/10.1007/s10708-019-10037-x
Alawamy JS, Balasundram SK, Hanif AHM, Sung CTB (2020) Detecting and analyzing land use and land cover changes in the Region of Al-Jabal Al-Akhdar, Libya using time-series landsat data from 1985 to 2017. Sustain 12. https://doi.org/10.3390/su12114490
Albano R, Mancusi L, Sole A, Adamowski J (2015) Collaborative strategies for sustainable EU flood risk management: FOSS and geospatial tools—challenges and opportunities for operative risk analysis. ISPRS Int J Geo-Inf 4:2704–2727. https://doi.org/10.3390/ijgi4042704
Ancona M, Corradi N, Dellacasa A, Delzanno G, Dugelay JL, Federici B, Gourbesville P, Guerrini G, la Camera A, Rosso P, Stephens J, Tacchella A, Zolezzi G (2014) On the design of an intelligent sensor network for flash flood monitoring, diagnosis and management in urban areas position paper. Procedia Comput Sci 32:941–946. https://doi.org/10.1016/j.procs.2014.05.515
Anderson JR, Hardy EE, Roach JT, Witmer RE (1976) A land use and land cover classification system for use with remote sensor data. https://pubs.usgs.gov/pp/0964/report.pdf
Andimuthu R, Kandasamy P, Mudgal BV, Jeganathan A, Balu A, Sankar G (2019) Performance of urban storm drainage network under changing climate scenarios: flood mitigation in Indian coastal city. Sci Rep 9:7783. https://doi.org/10.1038/s41598-019-43859-3
Appeaning Addo K, Larbi L, Amisigo B, Ofori-Danson PK (2011) Impacts of coastal inundation due to climate change in a CLUSTER of urban coastal communities in Ghana, West Africa. Remote Sens 3:2029–2050. https://doi.org/10.3390/rs3092029
Arshad Z, Robaina M, Shahbaz M, Veloso AB (2020) The effects of deforestation and urbanization on sustainable growth in Asian countries. Environ Sci Pollut Res 27:10065–10086. https://doi.org/10.1007/s11356-019-07507-7
Audisio C, Turconi L (2011) Urban floods: a case study in the Savigliano area (North-Western Italy). Nat Hazards Earth Syst Sci 11:2951–2964. https://doi.org/10.5194/nhess-11-2951-2011
Baky A, Zaman AM, Khan AU (2012) Managing flood flows for crop production risk management with hydraulic and GIS modeling: case study of agricultural areas in Shariatpur. APCBEE Procedia 1:318–324. https://doi.org/10.1016/j.apcbee.2012.03.052
Bamford TB, Balmforth DJ, Lai RH, Martin N (2008) Understanding the complexities of urban flooding through integrated modelling. In: Proc 11th Int. Conf. on Urban Drainage. Edinburgh. IWA London, UK
Barredo JI, Engelen G (2010) Land use scenario modeling for flood risk mitigation. Sustainability 2:1327–1344. https://doi.org/10.3390/su2051327
Brown PT, Saunders H (2020) Approximate calculations of the net economic impact of global warming mitigation targets under heightened damage estimates. PLoS One 15:1–27. https://doi.org/10.1371/journal.pone.0239520
Budamala V, Baburao Mahindrakar A (2021) Enhance the prediction of complex hydrological models by pseudo-simulators. Geocarto Int 36:1027–1043. https://doi.org/10.1080/10106049.2019.1629646
Carbone M, Garofalo G, Tomei G, Piro P (2014) Storm tracking based on rain gauges for flooding control in urban areas. Procedia Eng 70:256–265. https://doi.org/10.1016/j.proeng.2014.02.029
Carter JG, Cavan G, Connelly A, Guy S, Handley J, Kazmierczak A (2015) Climate change and the city: building capacity for urban adaptation. Prog Plan 95:1–66. https://doi.org/10.1016/j.progress.2013.08.001
Chen A, Djordjević S, Leandro J et al (2008) Simulation of the building blockage effect in urban flood modelling. In: Conference: 11th International Conference on Urban Drainage
Chen J, Hill AA, Urbano LD (2009) A GIS-based model for urban flood inundation. J Hydrol 373:184–192. https://doi.org/10.1016/j.jhydrol.2009.04.021
Chung H-W, Liu C-C, Cheng I-F, Lee YR, Shieh MC (2015) Rapid response to a typhoon-induced flood with an SAR-derived map of inundated areas: case study and validation. Remote Sens 7:11954–11973. https://doi.org/10.3390/rs70911954
Conesa-Garcia C, Caselles-Miralles V, Sanchez Tomas JM, Garcia-Lorenzo R (2010) Hydraulic geometry, GIS and remote sensing, techniques against rainfall-runoff models for estimating flood magnitude in ephemeral fluvial systems. Remote Sens 2:2607–2628. https://doi.org/10.3390/rs2112607
Croci S, Paoletti A, Tabellini P (2014) URBFEP model for basin scale simulation of urban floods constrained by sewerage's size limitations. Procedia Eng 70:389–398. https://doi.org/10.1016/j.proeng.2014.02.044
Das SK, Gupta RK, Varma HK (2007) Flood and drought management through water resources development in India. WMO Bull 56:179–188
de Sande B, Lansen J, Hoyng C (2012) Sensitivity of coastal flood risk assessments to digital elevation models. Water 4:568–579. https://doi.org/10.3390/w4030568
De US, Singh GP, Rase DM (2013) Urban flooding in recent decades in four mega cities of India. J Indian Geophys Union 17:153–165
Dehghanian N, Saeid Mousavi Nadoushani S, Saghafian B, Damavandi MR (2020) Evaluation of coupled ANN-GA model to prioritize flood source areas in ungauged watersheds. Hydrol Res 51:423–442. https://doi.org/10.2166/nh.2020.141
Devaraj S, Yarrakula K (2020) Evaluation of Sentinel 1–derived and open-access digital elevation model products in mountainous areas of Western Ghats, India. Arab J Geosci 13:1103. https://doi.org/10.1007/s12517-020-06108-w
Dewan TH (2015) Societal impacts and vulnerability to floods in Bangladesh and Nepal. Weather Clim Extrem 7:36–42. https://doi.org/10.1016/j.wace.2014.11.001
Dey AK, Kamioka S (2007) An integrated modeling approach to predict flooding on urban basin. Water Sci Technol A J Int Assoc Water Pollut Res 55:19–29. https://doi.org/10.2166/wst.2007.091
Dhiman R, VishnuRadhan R, Eldho TI, Inamdar A (2018) Flood risk and adaptation in Indian coastal cities: recent scenarios. Appl Water Sci 9:5. https://doi.org/10.1007/s13201-018-0881-9
Du J, Cheng L, Zhang Q et al (2019) Different flooding behaviors due to varied urbanization levels within river basin: a case study from the Xiang River Basin, China. Int J Disaster Risk Sci 10:89–102. https://doi.org/10.1007/s13753-018-0195-4
Egerer M, Haase D, McPhearson T, Frantzeskaki N, Andersson E, Nagendra H, Ossola A (2021) Urban change as an untapped opportunity for climate adaptation. NPJ Urban Sustain 1:22. https://doi.org/10.1038/s42949-021-00024-y
Elkhrachy I (2015) Flash flood hazard mapping using satellite images and GIS tools: a case study of Najran City, Kingdom of Saudi Arabia (KSA). Egypt J Remote Sens Sp Sci 18:261–278. https://doi.org/10.1016/j.ejrs.2015.06.007
Emilsson T, Ode Sang Å (2017) Impacts of climate change on urban areas and nature-based solutions for adaptation. In: Kabisch N, Korn H, Stadler J, Bonn A (eds)Nature-based solutions to climate change adaptation in urban areas: linkages between science, policy and practice. Springer International Publishing, Cham, pp 15–27

Ettritch G, Hardy A, Bojang L, Cross D, Bunting P, Brewer P (2018) Enhancing digital elevation models for hydraulic modelling using flood frequency detection. Remote Sens Environ 217:506–522. https://doi.org/10.1016/j.rse.2018.08.029

Fanghong L, Aifang G, Duo L (2012) Utilization efficiency and potential analysis of urban storm flood resources. Energy Procedia 16:1283–1287. https://doi.org/10.1016/j.egypro.2012.01.205

Ferreira TM (2020) Recent advances in the assessment of flood risk in urban areas. MDPI. https://doi.org/10.3390/books978-3-03936-831-0

Ferreira TM, Lourenço PB (2019) Disaster risk reduction and urban resilience: concepts, methods and applications. In: Noroozinejad Farsangi E., Takewaki I., Yang T., Astaneh-Asl A., Gardoni P. (eds) Resilient structures and infrastructure. Springer, Singapore. https://doi.org/10.1007/978-981-13-7446-3_17

Ferronato N, Torretta V (2019) Waste mismanagement in developing countries: a review of global issues. Int J Environ Res Public Health 16:1060. https://doi.org/10.3390/ijerph16061060

Fleischmann A, Siqueira V, Paris A et al (2017) Coupled hydrologic and hydraulic modeling of Upper Niger River Basin. In: EGU General Assembly 2017 19(EGU2017-884). https://meetingorganizer.copernicus.org/EGU2017/EGU2017-884.pdf

Fleischmann A, Siqueira V, Paris A, Collischonn W, Paiva R, Pontes P, Crétaux JF, Bergé-Nguyen M, Biancamaria S, Gosset M, Calmant S, Tanimoun B (2018) Modelling hydrologic and hydrodynamic processes in basins with large semi-arid wetlands. J Hydrol 561:943–959. https://doi.org/10.1016/j.jhydrol.2018.04.041

Fowler AM, Hennessy KJ (1995) Potential impacts of global warming on the frequency and magnitude of heavy precipitation. Nat Hazards 11:283–303. https://doi.org/10.1007/BF00613411

García-Pintado J, Mason DC, Dance SL, Cloke HL, Neal JC, Freer J, Bates PD (2015)Satellite-supported flood forecasting in river networks: a real case study. J Hydrol 523:706–724. https://doi.org/10.1016/j.jhydrol.2015.01.084

Gebre SLGY (2015) Flood hazard assessment and mapping of flood inundation area of the awash river basin in Ethiopia using GIS and HEC-GeoRAS/HEC-RAS model. J Civ Environ Eng 05. https://doi.org/10.4172/2165-784x.1000179

Ghimire S (2013) Application of a 2D hydrodynamic model for assessing flood risk from extreme storm events. Climate 1:148–162. https://doi.org/10.3390/cli1030148

Gichamo TZ, Popescu I, Jonoski A, Solomatine D (2012) River cross-section extraction from the ASTER global DEM for flood modeling. Environ Model Softw 31:37–46. https://doi.org/10.1016/j.envsoft.2011.12.003

Gómez C, White JC, Wulder MA (2016) Optical remotely sensed time series data for land cover classification: a review. ISPRS J Photogramm Remote Sens 116:55–72. https://doi.org/10.1016/j.isprsjprs.2016.03.008

Gupta K (2020) Challenges in developing urban flood resilience in India. Philos Trans R Soc A Math Phys Eng Sci 378:20190211. https://doi.org/10.1098/rsta.2019.0211

Haider S, Paquier A, Morel R, Champagne JY (2003) Urban flood modelling using computational fluid dynamics. Proc Inst Civ Eng Water Marit Eng 156:129–135. https://doi.org/10.1680/wame.2003.156.2.129

Handayani W, Chigbu UE, Rudiarto I, Surya Putri IH (2020) Urbanization and increasing flood risk in the Northern Coast of Central Java-Indonesia: an assessment towards better land use policy and flood management. Land 9. https://doi.org/10.3390/LAND9100343

Hansson K, Danielson M, Ekenberg L (2008) A framework for evaluation of flood management strategies. J Environ Manag 86:465–480. https://doi.org/10.1016/j.jenvman.2006.12.037

Hasnat GNT, Kabir MA, Hossain MA (2018) Major environmental issues and problems of South Asia, Particularly Bangladesh BT. In: Hussain CM (ed) Handbook of environmental materials management. Springer International Publishing, Cham, pp 1–40

Hua AK (2017) Land use land cover changes in detection of water quality: a study based on remote sensing and multivariate statistics. J Environ Public Health 2017:5–7. https://doi.org/10.1155/2017/7515130

Huong HTL, Pathirana A (2013) Urbanization and climate change impacts on future urban flooding in Can Tho city, Vietnam. Hydrol Earth Syst Sci 17:379–394. https://doi.org/10.5194/hess-17-379-2013

Huynh Thi Lan H, Pathirana A (2011) Urbanization and climate change impacts on future urban flooding in Can Tho City, Vietnam. Hydrol Earth Syst Sci Discuss 8:10781–10824. https://doi.org/10.5194/hessd-8-10781-2011

Jang J-H(2015) An advanced method to apply multiple rainfall thresholds for urban flood warnings. Water 7:6056–6078. https://doi.org/10.3390/w7116056

Jang S, Cho M, Yoon J, Yoon Y, Kim S, Kim G, Kim L, Aksoy H (2007) Using SWMM as a tool for hydrologic impact assessment. Desalination 212:344–356. https://doi.org/10.1016/j.desal.2007.05.005

Kanianska R (2016) Agriculture and its impact on land-use, environment, and ecosystem services, landscape ecology - the influences of land use and anthropogenic impacts of landscape creation, Amjad Almusaed. IntechOpen. https://doi.org/10.5772/63719. Available from: https://www.intechopen.com/chapters/51201

Kim D, Lim U (2016) Urban resilience in climate change adaptation: a conceptual framework. Sustainability 8. https://doi.org/10.3390/su8040405

Komi K, Neal J, Trigg MA, Diekkrüger B (2017) Modelling of flood hazard extent in data sparse areas: a case study of the Oti River basin, West Africa. J Hydrol Reg Stud 10:122–132. https://doi.org/10.1016/j.ejrh.2017.03.001

Konrad CP (2016) Effects of urban development on floods. US Geol Surv:1–4

Krause A, Haverd V, Poulter B et al (2019) Multimodel analysis of future land use and climate change impacts on ecosystem functioning. Earth's Futur 7:833–851. https://doi.org/10.1029/2018EF001123

Kulkarni A, Mohanty J, Eldho TI et al (2013) A web GIS based integrated flood assessment modelling tool for coastal urban watersheds. Comput Geosci 64. https://doi.org/10.1016/j.cageo.2013.11.002

Kundzewicz ZW, Kanae S, Seneviratne SI, Handmer J, Nicholls N, Peduzzi P, Mechler R, Bouwer LM, Arnell N, Mach K, Muir-Wood R, Brakenridge GR, Kron W, Benito G, Honda Y, Takahashi K, Sherstyukov B (2014) Flood risk and climate change: global and regional perspectives. Hydrol Sci J 59:1–28. https://doi.org/10.1080/02626667.2013.857411

Kwak Y, Arifuzzanman B, Iwami Y (2015) Prompt proxy mapping of flood damaged rice fields using MODIS-derived indices. Remote Sens 7:15969–15988. https://doi.org/10.3390/rs71215805

Lakshmi ES, Yarrakula K (2018) Review and critical analysis on digital elevation models. Geofizika 35:1–13. https://doi.org/10.15233/gfz.2018.35.7

Lhomme S, Serre D, Diab Y, Laganier R (2013) Analyzing resilience of urban networks: a preliminary step towards more flood resilient cities. Nat Hazards Earth Syst Sci 13:221–230. https://doi.org/10.5194/nhess-13-221-2013

Li Z, Wu L, Zhu W, Hou M, Yang Y, Zheng J (2014) A new method for urban storm flood inundation simulation with fine CD-TIN surface. Water 6:1151–1171. https://doi.org/10.3390/w6051151

Lo S-W, Wu J-H, Lin F-P, Hsu C-H(2015) Visual sensing for urban flood monitoring. Sensors 15:20006–20029. https://doi.org/10.3390/s150820006

Loo YY, Billa L, Singh A (2015) Effect of climate change on seasonal monsoon in Asia and its impact on the variability of monsoon

rainfall in Southeast Asia. Geosci Front 6:817–823. https://doi.org/10.1016/j.gsf.2014.02.009
Loucks DP, van Beek E (2017) Urban water systems. In: Water resource systems planning and management: an introduction to methods, models, and applications. Springer International Publishing, Cham, pp 527–565
Lund JR (2012) Flood management in California. Water 4:157–169. https://doi.org/10.3390/w4010157
Lyu H, Dong Z, Roobavannan M, Kandasamy J, Pande S (2019) Rural unemployment pushes migrants to urban areas in Jiangsu Province, China. Palgrave Commun 5:92. https://doi.org/10.1057/s41599-019-0302-1
Malik A (2017) Remote Sensing and GIS : a tool for flood management in urban India. In: 2nd International Conference on Recent Research and Innovations in Social Science and Education. pp 1–8
Malinowski R, Groom G, Schwanghart W, Heckrath G (2015) Detection and delineation of localized flooding from WorldView-2 multispectral data. Remote Sens 7:14853–14875. https://doi.org/10.3390/rs71114853
Marconi M, Gatto B, Magni M, Marincioni F (2016) A rapid method for flood susceptibility mapping in two districts of Phatthalung Province (Thailand): present and projected conditions for 2050. Nat Hazards 81:329–346. https://doi.org/10.1007/s11069-015-2082-2
Mason DC, Giustarini L, Garcia-Pintado J, Cloke HL (2014) Detection of flooded urban areas in high resolution synthetic aperture radar images using double scattering. Int J Appl Earth Obs Geoinf 28:150–159. https://doi.org/10.1016/j.jag.2013.12.002
McGuigan K, Webster T, Collins K (2015) A flood risk assessment of the LaHave River Watershed, Canada using GIS techniques and an unstructured grid combined river-coastal hydrodynamic model. J Mar Sci Eng 3:1093–1116. https://doi.org/10.3390/jmse3031093
Melgarejo L-F, Lakes T (2014) Urban adaptation planning and climate-related disasters: an integrated assessment of public infrastructure serving as temporary shelter during river floods in Colombia. Int J Disaster Risk Reduct 9:147–158. https://doi.org/10.1016/j.ijdrr.2014.05.002
Meyer N, Auriacombe C (2019) Good urban governance and city resilience: an afrocentric approach to sustainable development. Sustain 11:5514. https://doi.org/10.3390/su11195514
Milesi C, Churkina G (2020) Measuring and monitoring urban impacts on climate change from space. Remote Sens 12:1–25. https://doi.org/10.3390/rs12213494
Miller JD, Hutchins M (2017) The impacts of urbanisation and climate change on urban flooding and urban water quality: a review of the evidence concerning the United Kingdom. J Hydrol Reg Stud 12:345–362. https://doi.org/10.1016/j.ejrh.2017.06.006
Mimura N (2013)Sea-level rise caused by climate change and its implications for society. Proc Jpn Acad Ser B Phys Biol Sci 89:281–301. https://doi.org/10.2183/pjab.89.281
Mishra A (2015) A study on the occurrence of flood events over Jammu and Kashmir during September 2014 using satellite remote sensing. Nat Hazards 78:1463–1467. https://doi.org/10.1007/s11069-015-1768-9
Morita M (2014) Flood risk impact factor for comparatively evaluating the main causes that contribute to flood risk in urban drainage areas. Water 6:253–270. https://doi.org/10.3390/w6020253
Moses LAB, Guogping X, John LCL (2017) Causes and consequences of rural-urban migration: the case of Juba Metropolitan, Republic of South Sudan. IOP Conf Ser Earth Environ Sci 81. https://doi.org/10.1088/1755-1315/81/1/012130
Mujumdar M, Bhaskar P, Ramarao MVS, Uppara U, Goswami M, Borgaonkar H, Chakraborty S, Ram S, Mishra V, Rajeevan M, Niyogi D (2020) Droughts and floods. In: Krishnan R, Sanjay J, Gnanaseelan C (eds) Assessment of climate change over the Indian region: a report of the Ministry of Earth Sciences (MoES), Government of India. Springer Singapore, Singapore, pp 117–141
Notaro V, Fontanazza CM, Freni G, La Loggia G (2014) Assessment of modelling structure and data availability influence on urban flood damage modelling uncertainty. Procedia Eng 89:788–795. https://doi.org/10.1016/j.proeng.2014.11.508
Ole M, Chusit A, Mostafa KM, Guna P (2021) Modelling of urban flooding in Dhaka City. Urban Drain Model 333–343. https://doi.org/10.1061/40583(275)32
Ouyang W, Guo B, Hao F, Huang H, Li J, Gong Y (2012) Modeling urban storm rainfall runoff from diverse underlying surfaces and application for control design in Beijing. J Environ Manag 113:467–473. https://doi.org/10.1016/j.jenvman.2012.10.017
Paquier A, Mignot E, Bazin P-H(2015) From hydraulic modelling to urban flood risk. Procedia Eng 115:37–44. https://doi.org/10.1016/j.proeng.2015.07.352
Parida Y, Saini S, Chowdhury JR (2021) Economic growth in the aftermath of floods in Indian states. Environ Dev Sustain 23:535–561. https://doi.org/10.1007/s10668-020-00595-3
Prawiranegara M (2014) Spatial multi-criteria analysis (SMCA) for basin-wide flood risk assessment as a tool in improving spatial planning and urban resilience policy making: a case study of Marikina River Basin, Metro Manila—Philippines. Procedia Soc Behav Sci 135:18–24. https://doi.org/10.1016/j.sbspro.2014.07.319
Prütz R, Månsson P (2021) A GIS-based approach to compare economic damages of fluvial flooding in the Neckar River basin under current conditions and future scenarios. Nat Hazards 108:1807–1834. https://doi.org/10.1007/s11069-021-04757-y
Qi Y, Chan FKS, Thorne C, O'Donnell E, Quagliolo C, Comino E, Pezzoli A, Li L, Griffiths J, Sang Y, Feng M (2020) Addressing challenges of urban water management in Chinese sponge cities via nature-based solutions. Water 12. https://doi.org/10.3390/w12102788
Rahman A, Shaw R, Surjan A, Parvin GA (2016) Urban disasters and approaches to resilience. In: Shaw R, Atta-ur-Rahman, Surjan A, Parvin GABT-UD and R in A (eds) Urban disaster and resilience in Asia. Butterworth-Heinemann, pp 1–19
Ramlal B, Baban SMJ (2008) Developing a GIS based integrated approach to flood management in Trinidad, West Indies. J Environ Manag 88:1131–1140. https://doi.org/10.1016/j.jenvman.2007.06.010
Ranger N, Hallegatte S, Bhattacharya S, Bachu M, Priya S, Dhore K, Rafique F, Mathur P, Naville N, Henriet F, Herweijer C, Pohit S, Corfee-Morlot J (2011) An assessment of the potential impact of climate change on flood risk in Mumbai. Clim Chang 104:139–167. https://doi.org/10.1007/s10584-010-9979-2
Reddy KR, Devaraj S, Biradar S et al (2019) Spatial distribution of land use/ land cover analysis in Hanamkonda taluk, Telangana—a case study. Indian J Geo-Marine Sci 48:1761–1768
Revilla-Romero B, Hirpa FA, Pozo JT, Salamon P, Brakenridge R, Pappenberger F, de Groeve T (2015) On the use of global flood forecasts and satellite-derived inundation maps for flood monitoring in data-sparse regions. Remote Sens 7:15702–15728. https://doi.org/10.3390/rs71115702
Rubinato M, Nichols A, Peng Y, Zhang JM, Lashford C, Cai YP, Lin PZ, Tait S (2019) Urban and river flooding: comparison of flood risk management approaches in the UK and China and an assessment of future knowledge needs. Water Sci Eng 12:274–283. https://doi.org/10.1016/j.wse.2019.12.004
Rufat S, Tate E, Burton CG, Maroof AS (2015) Social vulnerability to floods: review of case studies and implications for measurement. Int J Disaster Risk Reduct 14:470–486. https://doi.org/10.1016/j.ijdrr.2015.09.013
Safiah Yusmah MY, Bracken LJ, Sahdan Z, Norhaslina H, Melasutra MD, Ghaffarianhoseini A, Sumiliana S, Shereen Farisha AS (2020) Understanding urban flood vulnerability and resilience: a

case study of Kuantan, Pahang, Malaysia. Nat Hazards 101:551–571. https://doi.org/10.1007/s11069-020-03885-1
Samarasinghea SMJS, Nandalalb HK, Weliwitiyac DP et al (2010) Application of remote sensing and GIS for flood risk analysis: a case study at Kalu-Ganga River, Sri Lanka. Int Arch Photogramm Remote Sens Spat Inf Sci 38:110–115
Satterthwaite D, McGranahan G, Tacoli C (2010) Urbanization and its implications for food and farming. Philos Trans R Soc Lond Ser B Biol Sci 365:2809–2820. https://doi.org/10.1098/rstb.2010.0136
Seenirajan M, Natarajan M, Thangaraj R, Bagyaraj M (2017) Study and analysis of Chennai flood 2015 using GIS and multicriteria technique. J Geogr Inf Syst 09:126–140. https://doi.org/10.4236/jgis.2017.92009
Shimokawa S, Fukahori H, Gao W (2016)Wide-area disaster prevention of storm or flood damage and its improvement by using urban planning information system. Procedia Soc Behav Sci 216:481–491. https://doi.org/10.1016/j.sbspro.2015.12.065
Shrestha S, Lohpaisankrit W (2017) Flood hazard assessment under climate change scenarios in the Yang River Basin, Thailand. Int J Sustain Built Environ 6:285–298. https://doi.org/10.1016/j.ijsbe.2016.09.006
Simoes NE, Ochoa-Rodríguez S, Wang L-P et al (2015) Stochastic urban pluvial flood hazard maps based upon a spatial-temporal rainfall generator. Water 7:3396–3406. https://doi.org/10.3390/w7073396
Simonovic SP, Kundzewicz ZW, Wright N (2021) Floods and the COVID-19pandemic—a new double hazard problem. WIREs Water 8:e1509. https://doi.org/10.1002/wat2.1509
Singh BR, Singh O (2012) Study of impacts of global warming on climate change: rise in sea level and disaster frequency. In: Singh BR (ed) Global warming—impacts and future perspective. IntechOpen, Rijeka
Singh RK, Kumar Villuri VG, Pasupuleti S, Nune R (2020) Hydrodynamic modeling for identifying flood vulnerability zones in lower Damodar river of eastern India. Ain Shams Eng J 11:1035–1046. https://doi.org/10.1016/j.asej.2020.01.011
Sivalingam S, Murugesan GP, Dhulipala K, Kulkarni AV, Devaraj S (2021) Temporal fluctuations of Siachen Glacier velocity: a repeat pass SAR interferometry based approach. Geocarto Int 0:1–22. https://doi.org/10.1080/10106049.2021.1899306
Solaimani K (2009) Flood forecasting based on geographical information system. Afr J Agric Res 4:950–956
Srivastava RK (2012) Disaster management of India, disaster risk reduction programme (2009–2012), Ministry of Home Affairs, Government of India. https://www1.undp.org/content/dam/india/docs/disaster_management_in_india.pdf
Suarez P, Anderson W, Mahal V, Lakshmanan TR (2005) Impacts of flooding and climate change on urban transportation: a systemwide performance assessment of the Boston Metro Area. Transp Res Part D Transp Environ 10:231–244. https://doi.org/10.1016/j.trd.2005.04.007
Sukhwani V, Shaw R, Deshkar S, Mitra BK, Yan W (2020) Role of smart cities in optimizing water-energy-food nexus: opportunities in Nagpur, India. Smart Cities 3:1266–1292. https://doi.org/10.3390/smartcities3040062
Sun AY, Scanlon BR (2019) How can Big Data and machine learning benefit environment and water management: a survey of methods, applications, and future directions. Environ Res Lett 14. https://doi.org/10.1088/1748-9326/ab1b7d
Sun L, Chen J, Li Q, Huang D (2020) Dramatic uneven urbanization of large cities throughout the world in recent decades. Nat Commun 11:5366. https://doi.org/10.1038/s41467-020-19158-1
Sundaram S, Yarrakula K (2017)Multi-temporal analysis of sentinel-1 SAR data for urban flood inundation mapping—case study of Chennai Metropolitan City. Ind J Ecol 44(Special Issue 5):564–568
Supriya P, Krishnaveni M, Subbulakshmi M (2015) Regression analysis of annual maximum daily rainfall and stream flow for flood forecasting in Vellar River Basin. Aquat Procedia 4:957–963. https://doi.org/10.1016/j.aqpro.2015.02.120
Surampudi S, Yarrakula K (2020) Mapping and assessing spatial extent of floods from multitemporal synthetic aperture radar images: a case study on Brahmaputra River in Assam State, India. Environ Sci Pollut Res 27:1521–1532. https://doi.org/10.1007/s11356-019-06849-6
Suresh D, Yarrakula K (2020) Assessment of topographical and atmospheric errors in Sentinel 1 derived DInSAR. Geocarto Int:1–20. https://doi.org/10.1080/10106049.2020.1822926
Suresh D, Collins Johnny J, Jayaprasad BK et al (2018) Morphometric analysis for identification of groundwater recharge zones: a case study of Neyyar river basin. Indian J Geo-Marine Sci 47:1969–1979
Suroso DSA, Kombaitan B, Setiawan B (2013) Exploring the use of risk assessment approach for climate change adaptation in Indonesia: case study of flood risk and adaptation assessment in the South Sumatra Province. Procedia Environ Sci 17:372–381. https://doi.org/10.1016/j.proenv.2013.02.050
Syme WJ, Pinnell MG, Wicks JM (2004) Modelling flood inundation of urban areas in the UK using 2D/1D hydraulic models. In: 8th National Conference on Hydraulics in Water Engineering, pp 1–8. https://www.tuflow.com/media/4988/2004-modelling-flood-inundation-of-urban-areas-in-the-uk-using-2d-1dhydraulic-models-syme-et-al.pdf
Szypuła B (2019) Quality assessment of DEM derived from topographic maps for geomorphometric purposes. Open Geosci 11:843–865. https://doi.org/10.1515/geo-2019-0066
Tabari H (2020) Climate change impact on flood and extreme precipitation increases with water availability. Sci Rep 10:13768. https://doi.org/10.1038/s41598-020-70816-2
Talbot CJ, Bennett EM, Cassell K, Hanes DM, Minor EC, Paerl H, Raymond PA, Vargas R, Vidon PG, Wollheim W, Xenopoulos MA (2018) The impact of flooding on aquatic ecosystem services. Biogeochemistry 141:439–461. https://doi.org/10.1007/s10533-018-0449-7
Tanoue M, Taguchi R, Nakata S, Watanabe S, Fujimori S, Hirabayashi Y (2020) Estimation of direct and indirect economic losses caused by a flood with long-lasting inundation: application to the 2011 Thailand flood. Water Resour Res 56:e2019WR026092. https://doi.org/10.1029/2019WR026092
Tarekegn TH, Haile AT, Rientjes T, Reggiani P, Alkema D (2010) Assessment of an ASTER-generated DEM for 2D hydrodynamic flood modeling. Int J Appl Earth Obs Geoinf 12:457–465. https://doi.org/10.1016/j.jag.2010.05.007
Tazyeen S, Nyamathi SJ (2015) Flood routing in the catchment of urbanized lakes. Aquat Procedia 4:1173–1180. https://doi.org/10.1016/j.aqpro.2015.02.149
Timbadiya PV, Patel PL, Porey P (2014)One-dimensional hydrodynamic modelling of flooding and stage hydrographs in the lower Tapi River in India. Curr Sci 106:708–716
Turner AB, Colby JD, Csontos RM, Batten M (2013) Flood modeling using a synthesis of multi-platform LiDAR data. Water 5:1533–1560. https://doi.org/10.3390/w5041533
Vercruysse K, Dawson DA, Glenis V, Bertsch R, Wright N, Kilsby C (2019) Developing spatial prioritization criteria for integrated urban flood management based on a source-to-impact flood analysis. J Hydrol 578:124038. https://doi.org/10.1016/j.jhydrol.2019.124038
Vorobevskii I, Al Janabi F, Schneebeck F et al (2020) Urban floods: linking the overloading of a storm water sewer system to precipitation parameters. Hydrology 7:1–23. https://doi.org/10.3390/hydrology7020035
Wang Y (2015) Advances in remote sensing of flooding. Water 7:6404–6410. https://doi.org/10.3390/w7116404
Wang X, Gu X, Wu Z, Wang C (2008) Simulation of flood inundation of Guiyang City using remote sensing, GIS and hydrologic model. Int Arch Photogramm Remote Sens Spat Inf Sci 37:775–778

Wu X, Lu Y, Zhou S, Chen L, Xu B (2016) Impact of climate change on human infectious diseases: empirical evidence and human adaptation. Environ Int 86:14–23. https://doi.org/10.1016/j.envint.2015.09.007

Xing Y, Liang Q, Wang G, Ming X, Xia X (2019)City-scale hydrodynamic modelling of urban flash floods: the issues of scale and resolution. Nat Hazards 96:473–496. https://doi.org/10.1007/s11069-018-3553-z

Yan J, Zhang Y, Zhang J, Yang X (2011) The method of urban rain-flood utilization based on environmental protection. Energy Procedia 5: 403–407. https://doi.org/10.1016/j.egypro.2011.03.069

Zeng C, Bird S, Luce JJ, Wang J (2015) A natural-rule-based-connection(NRBC) method for river network extraction from high-resolution imagery. Remote Sens 7:14055–14078. https://doi.org/10.3390/rs71014055

Zhang D, Chen X, Yao H, Lin B (2015) Improved calibration scheme of SWAT by separating wet and dry seasons. Ecol Model 301:54–61. https://doi.org/10.1016/j.ecolmodel.2015.01.018

Zhou Q (2014) A review of sustainable urban drainage systems considering the climate change and urbanization impacts. Water 6:976–992. https://doi.org/10.3390/w6040976