

Externalities of Climate Change on Urban Flooding of Agartala City, India



Saptarshi Mitra, Stabak Roy, and Samrat Hore

Abstract Urban flooding has been a crucial issue of urban India for an extended period. According to the 2011 Census of India, the second-largest and fastest-growing city of Northeast India is Agartala, the capital city of the State of Tripura. They are located on the right bank of river Haora, with a total population of 404,004 persons. Due to micro-level climate change and its geophysical location, Agartala has witnessed seasonal urban flooding, which has become a regular event every year. With the increasing effects of climate change, the flood occurrences in Agartala city may likely increase shortly. In order to safeguard from the pluvial hazard of Agartala focus should be on the city drainage system and to prevent the city from flooding. The main objective of this study is to be identifying water logging areas and different factors for water-logging in the city. Also, assess the socio-economic impact of the flood on local communities and draft alternative strategies for strengthening the city drainage system against urban flooding. The study is based on primary and secondary data. Primary data was collected from the city dwellers by door-to-door household survey and stake holder consultation. Secondary data has been collected from the office of Agartala Municipal Corporation, Census operation of India, Agartala etc. To understand the city topography and identify areas prone to water-logging and flooding, satellite imagery has been analysed. The study reveals that the central part of the city located between river Haora and Kata Khal is more vulnerable than any other place of the city. In order to devise a coping mechanism for Agartala city, stakeholders from different sectors were identified to mitigate and understand the strategies to prevent urban flooding. Strategies may help Agartala city as an urban flood-resilient city and safeguard its citizen.

S. Mitra (✉) · S. Roy

Department of Geography and Disaster Management, Tripura University, Agartala, India

e-mail: saptarshigeotu2000@gmail.com

S. Roy

Institute of Socio-Economic Geography and Spatial Management, University of Gdansk, Gdansk, Poland

S. Hore

Department of Statistics, Tripura University, Agartala, India

Keywords Urban water system · Resilient · Water logging · Geo-physical

1 Introduction

Climate change and urbanisation pose remarkable threats to flooding and degradation of water quality in urban areas [42]. Urban flooding is the greatest challenge to human safety and sustained economic growth [25]. Climate change is a concerning factor in changing the precipitation patterns worldwide. Every year, rainstorms and related urban flooding issues are exaggerated in terms of frequency and severity. The main reason for urban flooding is the accumulation of local rainfall runoff due to inadequate drainage and buffer capacity, known as Pluvial flooding [20]. Pluvial flooding is a new approach that updates the current urban drainage models to urban flood models [9]. The externalities of urban flooding can be triggered by intensified rainfall, long-duration precipitation, close repetition of precipitations or a combination of externalities create a full-scale urban crisis by electrical failure, road congestion, interruption in business and influx of polluted water. These are the major problems which can impact heavily in the city dwellers. In order to adapt and mitigate climate change, the local urban body has critical roles. But, local urban bodies in low and middle-income countries cannot reduce climate change impacts [62]. Flood protection is one of the traditional functions of any drainage system and it remains a significant issue in many cities because of economic and health impacts [13]. The main challenges to implementing a sustainable urban drainage system and developing an urban flood resilience model [24]. There has been considerable research and tools developed to analyse fluvial and coastal flooding, but models for pluvial flooding are less advanced. Therefore, modelling and a better understanding of the risk of stormwater flooding is needed urgently for flood risk management [12].

Climate change has varied consequences in different parts of the world [36]. North-East India can be considered a distinct macro-region within the Indian landmass [49, 71]. The Northeast has a diversified climate, with extremely cold winters and semi-humid summers, particularly in the south. The region has a monsoon climate, which gets high or extremely heavy rainfall only during the summer months of June to September. The primary source of rain is the south-west monsoon, with June being the wettest month. There are three seasons in the area, i.e., winter, summer and rainy season. Between valleys and mountains, there is a climate variation. In January, the average temperature in the Assam Valley region is around 16 °C. In contrast, the maximum temperature in the hilly parts of Arunachal Pradesh and Nagaland is 14 °C and the minimum temperature is below freezing. Summer temperatures in the lowlands range from 30 to 33 °C, while in the hills, the average summer temperature is 20 °C and the average lowest is 15 °C [18]. The average annual rainfall is 2000 mm with local variations (1500–12,000 mm). North East India's climate has drastically changed over the last couple of years. Rainfall patterns over the region in the last century have considerably changed, resulting in its overall drying up [60].

This region had been treated as a backward region because of its rurality. However, but in the second half of the twentieth century, the urbanisation process blooms up in the northeastern region [35]. Agartala is the -growing and second-largest city in Northeast India, located in Tripura [16]. Due to the rapid unplanned urbanisation of Agartala. The city faces urban issues like road congestion, solid waste management, development of slums, sanitation and urban flooding [22–46]. Urban flooding is the most crucial issue in cities with significant impacts on the man-environment relationships [24, 26, 30]. The degree and intensity of urban flooding have increased in many Indian cities, as has been reported in the past two decades [1, 5–7, 15, 17, 23, 32, 37, 45, 51, 53, 72]. The spatiality of urban units plays an essential role in urban flooding along with meteorological, hydrological and anthropogenic factors [42, 67]. Due to those inevitable factors, the city's drainage system is facing delinquency. As a result, urban flooding has taken place, especially during the monsoon season [22, 28, 29]. Infrastructure planning is required to improve the city's drainage system, especially for sewage and stormwater [3, 11, 48, 73]. The cities are expanding and growing exponentially, simultaneously the natural drainage systems are traumatised due to development activities in the city [32, 33]. The capacity of water retention and surface runoff of the city has a negative relationship, increasing flood potentiality [38–40, 64, 69]. Unplanned urban infrastructure consequences urban flooding where environment and resource conservation are least prioritised in the development process of urbanisation, through such relationship between urbanisation and development is a vital policy concern [68]. But in micro-level planning, some important parameters such as city slope and its topography, watershed and its catchment areas are needed to be given prior attention which is eventually not being paid.

Agartala is frequently affected by floods during monsoon after heavy rainfall [4, 59]. The present scenario of the city drainage infrastructure system in terms of coping up with urban flooding is not up to the mark. Therefore, the study aims to identify the causal interference of urban flooding in the city of Agartala and explore technical strategies for managing urban flooding in Agartala and minimising the damages due to floods for mankind.

2 Study Area

Agartala, the capital city of Tripura, is located in between 23°45' to 23°55' N latitudes and 91°15' to 91°20' E longitudes (Fig. 1). The city is located on the flood plain of the Rivers Haora and Kata Khal. The physiographic structure of Agartala City is just like saucer-shaped and characterised by Tilla (relatively high land) and Lunga (low land) topography [63]. Maharaja Krishna Manikya built the old Agartala City in the year of 1748. That city was situated in between two uplands, Kunjaban tilla (23°51' N and 91°16' E) in the northern side and college tilla (23°49' N and 91°17' E) in the southern side. Due to the regular water logging situation, Maharaja Krishna Kishore Manikya had shifted his capital from old Agartala to present Agartala (our study area) in 1849. After 25 years of its establishment, in 1874, the Agartala Municipal

Council was formed to provide better services to the city dwellers [61]. In 2014, it became upgraded into Agartala Municipal Corporation (AMC) which represents the local urban governance of the Agartala City [16]. Since its statehood in 1972, the city has become the nerve centre of all administrative, political, cultural and commercial activities of the state. The city has emerged as an essential border-trading centre with international linkage with Bangladesh. National Highway (NH-8 is passing through the city (Fig. 1. Maharaja Bir Bikram Airport [23°53'33.96" N and 91°14'37.81" E] is located about 11.75 km north-west from the Central Business District (CBD) of Agartala City. Agartala railway station is [23°47'35.83" N and 91°16'42.92" E] located in the south-eastern part of the city. The city consists of 49 wards which are broadly divided into four planning zones (North, Central, East and South and shares. An international border with Bangladesh on the western side, and Jirania Rural Development (RD Block, Mohanpur R.D. Block and Dukli R.D. Block are situated in the east, north, and south of the city. The total area of AMC is almost 76.150 km² with 5,26,292 population.

The city holds on important international significance due to its strategic location with Bangladesh. Integrated Check Post (ICP) for trans-border trading is located only about 3 km west of the CBD of Agartala City. Agartala serves good regional connectivity with all the nearby cities of North East India as well as with other cities of India as the city has good connectivity through Roadways, Railways and Airways [27–55, 63]. The recent construction of a broad-gauge railway line in 2016 have also strengthened railway connectivity [57].

The city population varies from the inner to the outer part of the city. High population distribution can be observed in the central part of Agartala, whereas a sparse population is observed in the peripheral region of the city. So, most city people started to live in the central part of the city to avail the basic services and infrastructure facilities. From 1971 to 2011, there has been an upward trend of population density in the city. The highest rate of increase in population density has been observed from 1971 to 1981 due to political migration [16]. However, in 2016 when the city was expanded from 35 to 49 wards by accumulating more than 17.31 km² area.

3 Methodology and Database

In order to identify the flooding areas, the general slope of the city has been analysed through the Digital Elevation Model (DEM). SRTM DEM has been collected from the USGS earth explorer platform and United States Geospatial Server (USGS). Drainage dynamics have been analysed through stream order and the watershed map has been depicted to identify the flow of the water's direction. In the next step, the land use map has been overlaid to analyse the relationship between catchment areas to see whether the urbanisations are swallowing those or not. Triangular irregular networks (TIN) map has been prepared to understand the overall physiographic structure of the city. Simultaneously, satellite-based Tropical Rainfall Measuring Mission (TRMM) data from 1989 to 2019 has also been collected and analysed. A drainage network

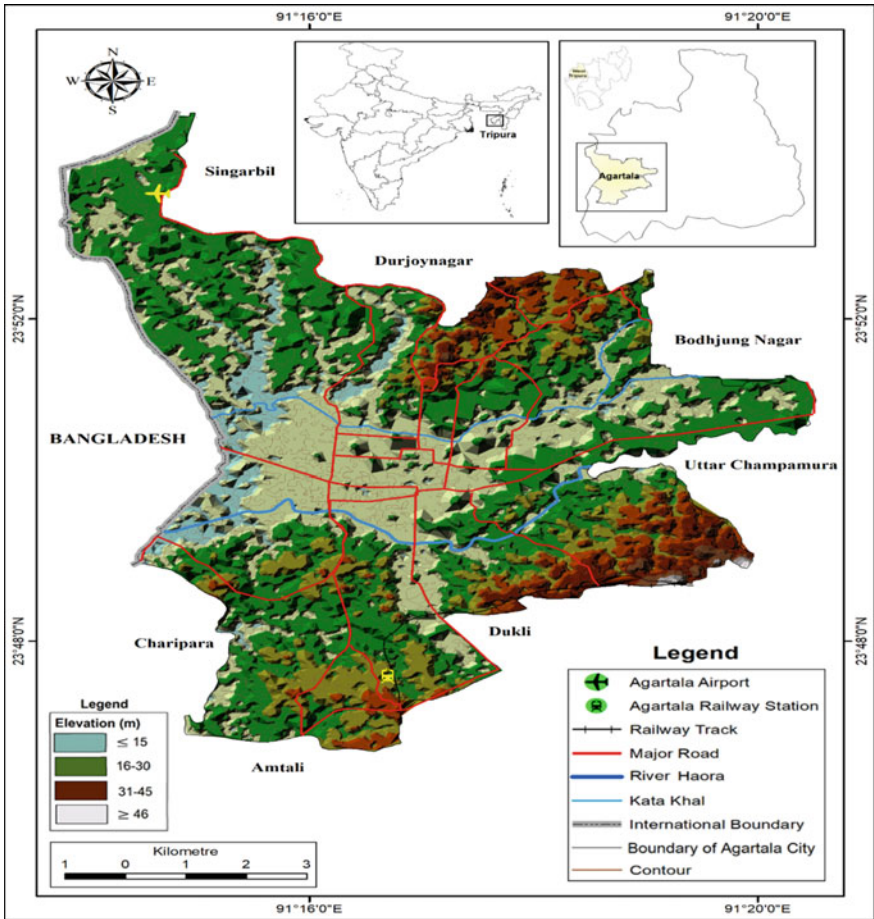


Fig. 1 Location map of the study area (*Source* Prepared by the authors, 2021; *Data* extracted from SRTM DEM, Google Earth and Hand-held GPS Receiver, 2021)

map based on SRTM DEM has prepared to identify urban flooding and respective flood vulnerable areas. According to the duration of waterlogging, the city has been classified into four different vulnerable zones, very high, high, low and very low (Fig. 2). In the very high zone the duration of water logging is more than 72 h. Between 48 and 72 h water logging situated areas are demarketed as high zone. Wherever, 24–48 h and less than 24 h water logging areas of the city are classified as low and very low vulnerable zone, respectively. The Spatio-temporal changes of the urban areas have been monitored through Landsat Satellite Imageries of different years and respective data have been collected from USGS earth explorer. The detailed data summary between (2000–2021) is reported in Table 1.

To represent the LULC for change detection and analysis of urban land use with respect to urban flooding, a series of processes have been done like data acquisition,

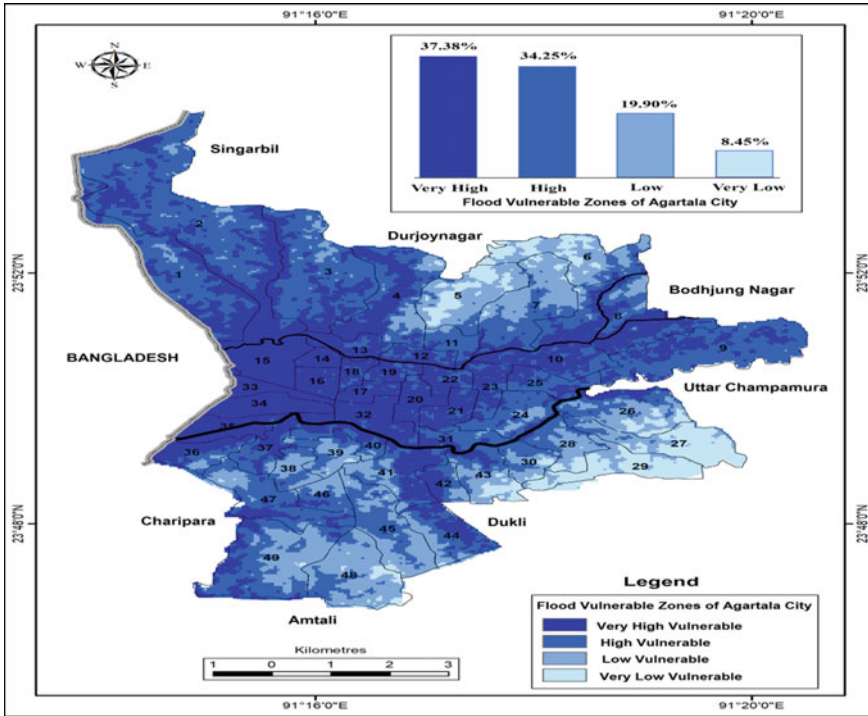


Fig. 2 Flood zonation map of Agartala city (Source Prepared by the authors, 2021 using ArcGIS v.10.8, 2021; Data extracted from TRMM and SRTM DEM)

geometric correction, image extraction, training site collection and supervised classification using the Maximum Likelihood Estimation (MLE) method. The Images are processed by the GIS and RS software like ArcGIS v.10.8 and Map Info v.17 to analyze the Agartala urban area change detection. The Maximum Likelihood (ML) classification algorithm is a well-known parametric classification used for supervised classification [47]. Handheld GPS receiver used for ground verification. A rainfall zonation map has been prepared based on TRMM data (1989–2019) using Inverse Distance Weightage (IDW) method in ArcGIS v.10.8 and Global Mapper v.22 software. Geospatial techniques like GIS and RS have represented the correlation between flooded areas, population density and road density of Agartala City.

Table 1 Sources of the data set^a

Data	Product details	Date of acquisition	No of bands	WRS path/raw	UTM zone	Datum	Scale/resolution
Landsat 8 OLI	LC08_L1TP_13644_20210222_20210303_02_T1	22.02.2021	11	136/44	46	WGS84	30 m
Landsat 8 OLI	LC08_L1TP_136044_20141118_20200910_02_T1	18.11.2014	11	136/44	46	WGS84	30 m
Landsat 7	LE07_L1TP_136044_20070312_20200913_02_T1	12.03.2007	8	136/44	46	WGS84	30 m
Landsat 7	LE07_L1TP_137043_20000228_20200918_02_T1	22.08.2000	7	137/43	46	WGS84	30 m
Shuttle radar topography mission (SRTM) DEM	SRTM1N23E091V3	2015	1	–	46	WGS84	90 m
Ground verification	Garmin eTrex 30x	2019–2021	–	–	–	–	N/A

^a USGS: United States of Geological Survey

4 Results and Discussion

4.1 Characteristics of Urban Flooding in Agartala City

Agartala receives a huge amount of rainfall during the monsoon from May to September [14] in the effect of south-west monsoon wind flowing over the Bay of Bengal. The city receives an average annual rainfall of 211.7 cm with 95 rainy days. The city receives maximum rainfall during the monsoon period [41]. During post-monsoon to pre-monsoon seasons (dry period), the city's groundwater level dries up because of the massive extraction of groundwater by the city to meet the water supply demand for the city dwellers [31]. The main reason, the fluctuation of ground water levels in the city is that there are no recharge techniques in the city and individual household levels and river water lifting from Haora River [10]. Therefore, the city needs to take long term measures to tap the excess rainfall during the monsoon in order to reduce the dependency on groundwater during the dry period. In previous flooding events of Agartala City, critical flood zone is located in the low-lying areas. Where around 4–5 days are required to drain out the water because the city does not have any high-tech water lifting stations to drain out the floodwater

from those low-lying areas [8, 29, 65, 66]. As a result, urban flooding has become a regular event in the low-lying areas of Agartala City in every monsoon (Fig. 2).

In Agartala, about 37.38% area has been identified where water logging extends more than three days especially ward numbers 4, 15, 16, 17, 18, 22, 23, 24, 32, 33, 34, 35, 36 and 42. Maximum wards (16.48%) of AMC characterised with very high flood vulnerability are located in the central-west part of the city. About 34.32% of Agartala City falls under a high flood vulnerability zone where water has been logged for 2 to 3 days (Fig. 2). It has been observed that 19.90% and 8.45% of the area have low and very low flood vulnerability, respectively. Those areas are located in northern, south-eastern and southern parts of the city and the relative height of those areas is comparatively higher than the central and central-western parts of the city (Fig. 1). Vegetation cover is a commonly used indicator to evaluate terrestrial environmental conditions [34, 70]. The cumulative consequences of climate change and urbanisation on surface runoff get measure of the impact of climate change on urban flooding [2]. Enhanced green infrastructure (GI) in urban areas, such as green roofs, parks and green spaces, can significantly enhance the provision of fundamental ecosystem services through nature-based solutions, prevention of urban flooding one of that [75]. Due to climate change and anthropogenic activities, vegetation degradation has taken place in Agartala city significantly (Fig. 3). This change impacts urban flooding. Because GI always acts as a sponge that absorbs a huge amount of Strome water during monsoon. The drainage system is the most crucial factor for urban flooding [19]. A natural drainage system has been identified through the process of stream order. Strahler suggested an ordering technique, still is considered as most reliable method to categories the stream segments into different classes based on their significance and contribution to the drainage pattern [21, 27, 50, 52, 74].

Agartala City had well natural drain network to move out the flooded water from the city (Fig. 4). However, due to rapid urbanisation, the natural stream network has been changed. By using the Strahler method, about 56.20% were a first-order stream, 24.05% second-order stream, 11.46% third-order stream, 5.44% fourth-order stream and 2.69% fifth order stream are found in Agartala City (Fig. 4). The lower order stream takes a longer time (more than 72 h) to subside the flood situation wherever the higher-order stream takes a longer time to develop the flood situation by reducing flood with quicker time (less than 24 h) flood level. In Agartala City, only 0.16% of higher-order streams are observed. As a result, having immense pressure on higher-order streams required more time to subside the flood situation.

This morphometric pattern is one among the response to hydrologic and anthropogenic conditions. However, due to rapid urbanisation since 1991, the maximum first, the second and third-order stream has been either wiped out or the stream has been converted into the respective lower-order stream. Surface runoff in those drainage networks has been obstructed and causes the water to be logged in the city for a couple of hours to a few days and creates a situation of urban flooding. Due to lack of water retention points, in few wards of Agartala City were severely flooded during every monsoon (see Table 2).

The average rainfall intensity of Agartala city is more than 204.5 mm, which is considered as extremely heavy rain [41]. The average annual rainfall of Agartala is

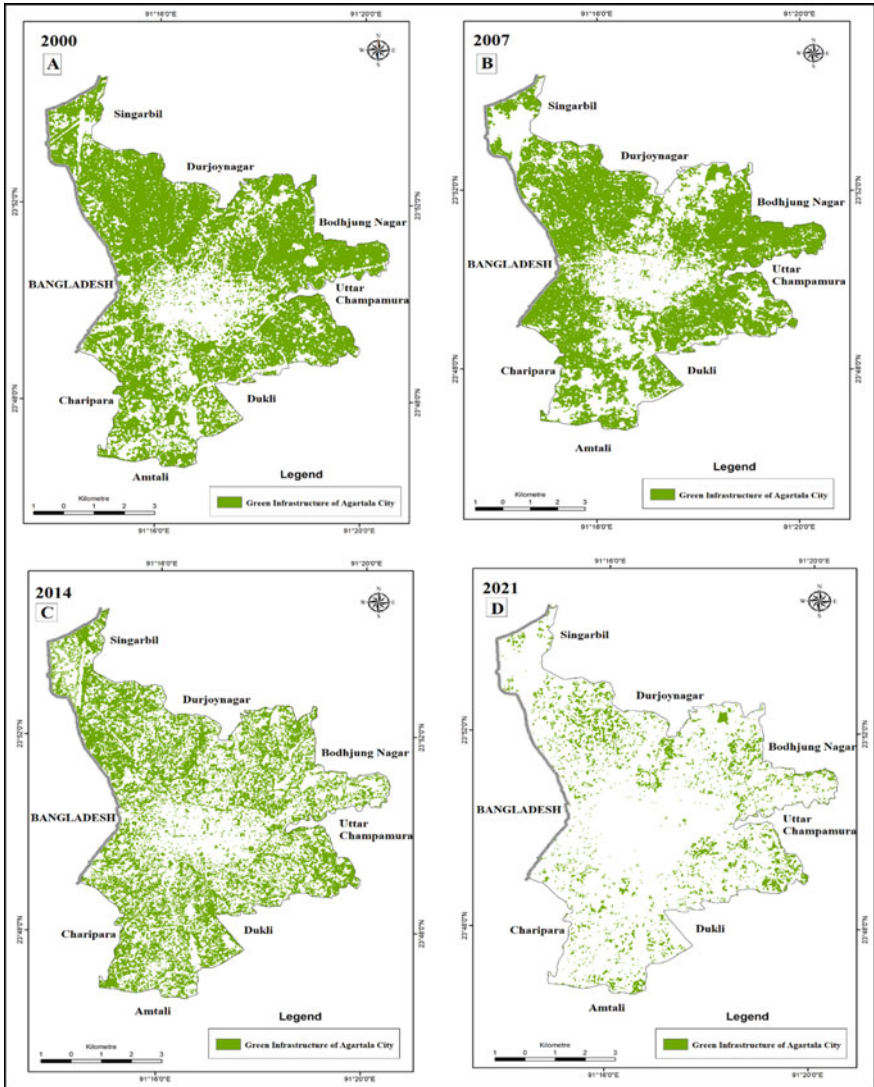


Fig. 3 Green infrastructure of Agartala city [A. 2000, B. 2007, C. 2014 and D. 2021] (Source Prepared by the authors, 2021 using ArcGIS v.10.8, 2021; Data extracted from LANDSAT Series)

about 2146 mm. The seasonal rainfall varied from 68% (monsoon) to 1.4% (post-monsoon). It has been recorded that floods in Agartala city due to intense rainfall over just two days point to immediate attention required towards building urban climate resilience [66].

Due to flooding in Agartala, almost more than half of the city, that is 65% of people, have to struggle with their days without having any alternative occupation

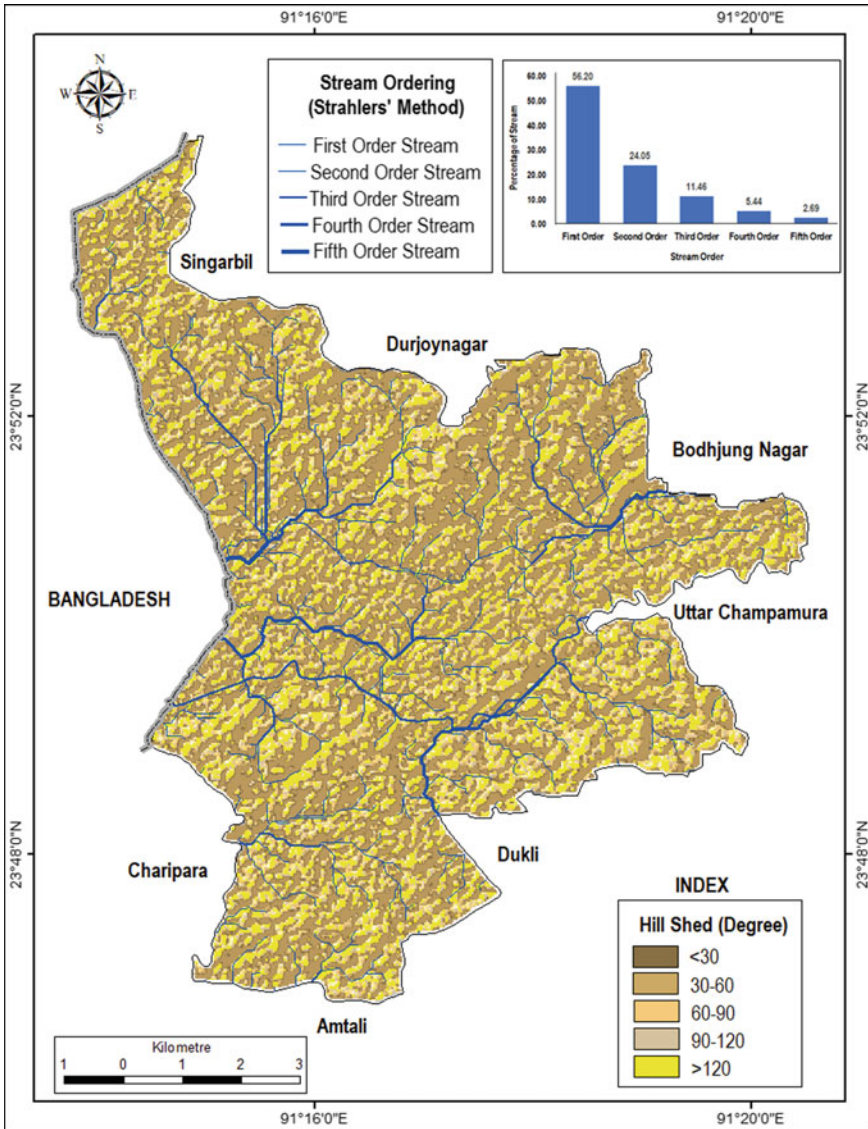


Fig. 4 Hill shed map with stream ordering (*Source* Prepared by the authors, 2021; Data extracted from SRTM DEM through Hydrological Modelling)

Table 2 Externalities of urban flooding

Nature of flooding	Climate change	Urbanisation	Combination
Pluvial features	Rainfall intensity Rainfall amount Rainfall frequency	Green infrastructure Population Surface runoff	Flooding Population affected

and cannot meet the demand of their daily basic needs. During flood time people have to take shelters in schools, colleges, or even on the rooftop as there are no proper flood shelters in Agartala city. Therefore, the socio-economic analysis of Agartala city have been categorised into four parts. The flood can be categorised in the following physical characteristics such as floodwater height, frequency and duration of the flood. The longer period of floodwater stagnation in the city rises the level of vulnerability impact upon the people. Surveys have been done for analysing the communities affected during a flood. Through which it is being observed most vulnerable communities are farmers, daily labours, rickshaw pullers and small business holders in the city. From the above chart, it is seen that the most vulnerable community during flood time is the farmer community because most of the farmers agricultural land are in a low lying region which gets waterlogged very frequently resulting in damage to agricultural crops. Whereas during flood causes death and leads to miseries to the communities like labours and rickshaw pullers as they become homeless, jobless and suffer from starvation. Poor household communities have to face great difficulty in balancing the loss of income than the non-poor community. Similarly, during flood time, the small business holder community faces the problem in storing and carrying their goods in godowns as half of the city goes under the water and most of their goods get damaged, and they have face loss in their income.

Agricultural crops and the damage of shelters are severely damaged due to floods as livelihood assets and property are closely related to each other. When property assets are affected, it directly impacts change of livelihoods. The survey shows that 60 and 44% properties are being damaged in terms of Houses and Agricultural lands. Due to intense flooding in Agartala, the agricultural lands and houses are being submerged severely, and most of the houses are made through local materials like bamboo, muds so, during flood time, the entire houses get washed away along with households furniture. The agricultural lands located near the river yearly lose a huge amount of agricultural crops due to heavy river bank silt erosion due to heavy siltation during flood have made the agricultural land more infertile and have decreased the productivity of the land. Financial losses depend on the city's intensity, duration and frequency of flooding; the average financial loss is 20,000–25,000 rupees per flood per family belonging to a poor, vulnerable community. Apart from the direct income loss, there are loss of retail goods and loss of working days, there is a direct economic loss of 5% of the monthly income due to flooding, with major loss of working days is about 3–5 days due to intense water logging in the city. Most of the community affected by the flood come from middle to lower-income groups. As a result, most people suffer from water-born and vector born diseases such as diarrhea, dysentery, cholera, malaria and respiratory problems. As the people belong to lower-middle-class communities, a result, they are more vulnerable to flood than that person living who live in high-class communities. Therefore it can be said that there is a significant correlation between the people's income and the impact of flood, where the poor people fails to maintain the balance in terms of living standards during the time of the flood. Hence these people can afford neither medicine nor medical check-up during the time of the disaster, which results in death and chronic suffering from the water and vector born diseases.

5 Findings

From the above analysis following are the significant findings-

- Urban flooding intensity in the city is very high due to high population density and poor drainage infrastructure.
- The city's natural drainage system has been choked due to the unscientific construction.
- The city has a mayhem flood due to the degradation of the drainage network and pluvial activities.
- The rapid change in the change in green infrastructure of Agartala results in the increase of surface runoff in the city.
- The pluvial flooding of Agartala city mainly affected the poor and people living in low-lying areas.
- Financial and property losses are common phenomena of urban flooding, mostly depending on the intensity, duration and frequency of flooding in the city.

6 Conclusion

Pluvial events change nature due to climate change. Spatial prioritisation based on urban flood analysis of Agartala City has been spotted. To resolve the issue of urban flooding, sustainable strategic city drainage network planning is needed for making the plan. As Agartala City has grown up in an unexpected way, like unfollowing the city development control rules, regulations and guidelines, the city is frequently facing urban flooding. Along with pluvial events, anthropogeomorphic factors are also responsible for hazards impacting human lives and livelihood.

Acknowledgements This publication results (in part) from the research project supported by the Department of Science and Technology (DST), Ministry of Science and Technology, Government of India. The project entitled “**Identification, Assessment and Model Building of Urban Morphology using Geospatial Techniques: A Study of Border City Agartala**” (File No. NRDMS/UG/S.Mitra/Tripura/e-10/2019 (G) dated 15.05.2019). The content is solely the authors' responsibility and does not necessarily represent the official views of the DST, New Delhi.

References

1. Ahmed Z, Rao RM, Reddy RM, Raj EY (2016) Integrated storm water management—an approach for urban flooding in Hyderabad, India. *Am J Eng Res* 5(10):102–110. Retrieved from https://www.academia.edu/29121344/Integrated_Storm_Water_Management_An_Approach_for_Urban_Flooding_In_Hyderabad_India
2. Alam MS, Willems P, Alam MM (2014) Comparative assessment of urban flood risks due to urbanization and climate change in the turnhout valley of Belgium. *ABC J Adv Reseach* 3:15–24

3. Arisz H, Burrell CB (2006) Urban drainage infrastructure planning and design considering climate change. In: EIC climate change technology, 2006. IEEE, pp 1–9. IEEE. <https://doi.org/10.1109/EICCCC.2006.277251>
4. Asian News International (ANI) (2019, July 14) Heavy rain hits normal life in Agartala. Agartala, Tripura, India. Retrieved from <https://www.aninews.in/news/national/general-news/heavy-rain-hits-normal-life-in-wbs-agartala20190714195753/>
5. Avinash S (2014) Flood related disasters: concerned to urban flooding in Bangalore, India. Int J Res Eng Technol 1–9. Retrieved from https://www.academia.edu/49317657/Flood_Related_Disasters_Concerned_to_Urban_Flooding_in_Bangalore_India
6. Baghel A (2016) Causes of urban floods in India: study of Mumbai in 2006 and Chennai in 2015. In: International Conference on Disaster and Risk Management, Sohna, Haryana. Retrieved from https://www.researchgate.net/publication/332696866_Causes_of_Urban_Floods_in_India_Study_of_Mumbai_in_2006_and_Chennai_in_2015
7. Banerjee S (2018) An analysis of urban flooding scenario in the city of Kolkata, West Bengal. Int J Innov Knowl Concepts 6(5):1–9. Retrieved from <https://core.ac.uk/download/pdf/233155235.pdf>
8. Bhattacharjee B (2018) Tripura floods displace 23,000 people. Times of India, Agartala. <https://timesofindia.indiatimes.com/city/agartala/tripura-floods-displace-23000-people/articleshow/64266838.cms>
9. Cedo M, Dusan P, Surajate BA, Joao PL, Slobodan D, Richard A (2009) Overland flow and pathway analysis for modelling of urban pluvial flooding. J Hydraul Res 47(4):512–523. <https://doi.org/10.1080/00221686.2009.9522027>
10. Central Ground Water Board (2020) Master plan for artificial recharge to ground water-2020. Ministry of Water Resource, Government of India, New Delhi. <http://cgwb.gov.in/Master%20Plan%20to%20GW%20Recharge%202020.pdf>
11. Central Public Health & Environmental Engineering Organisation (CPHEEO) (2019) Manual on storm water drainage systems. Ministry of Housing and Urban Affairs, Government of India, New Delhi. Retrieved from [http://mohua.gov.in/upload/uploadfiles/files/Volume%20I%20Engineering\(3\).pdf](http://mohua.gov.in/upload/uploadfiles/files/Volume%20I%20Engineering(3).pdf)
12. Chen H, Xu CY, Guo S (2012) Comparison and evaluation of multiple GCMs, statistical downscaling and hydrological models in the study of climate change impacts on runoff. J Hydrol 434–435:36–45. <https://doi.org/10.1016/j.jhydrol.2012.02.040>
13. Cherqui F, Belmeziti A, Granger D, Sourdriil A, Gauffre PL (2015) Assessing urban potential flooding risk and identifying effective. Sci Total Environ 514:418–425. <https://doi.org/10.1016/j.scitotenv.2015.02.027>
14. Das R, Purkayastha N, Phukan R, Saha D (2020) Performance of monsoon 2020 in Tripura—a report. India Meteorological Department, Government of India, Agartala. https://agartala.imd.gov.in/special_report/Monsoon%20Report%20Tripura%202020.pdf
15. De US, Singh GP, Rose DM (2013) Urban flooding in recent decades in four mega cities of India. J Indian Geophys Union 17(2):153–165. Retrieved from http://iguonline.in/journal/Arc_hives/17-2/4usde.pdf
16. Debbarma D, Roy S, Santra A, Mitra S (2018) A spatial analysis of population distribution, density and growth in Agartala city. Asian J Spat Sci 6(1):24–36. https://www.researchgate.net/publication/330578562_A_Spatial_Analysis_of_Population_Distribution_Density_and_Growth_in_Agartala_City
17. Dhiman R, VishnuRadhan R, Eldho TI, Inamdar A (2019) Flood risk and adaptation in Indian coastal cities: recent scenarios. Appl Water Sci 9(5):1–16. <https://doi.org/10.1007/s13201-018-0881-9>
18. Dikshit KR, Dikshit JK (2014) North-East India: land, people and economy. Springer, New York. <https://doi.org/10.1007/978-94-007-7055-3>

19. Eldho TI, Zope PE, Kulkarni AT (2018) Urban flood management in coastal regions using numerical simulation and geographic information system. In: Samui P, Kim D, Ghosh C (eds) *Integrating disaster science and management*. Elsevier, Amsterdam, pp 205–219. <https://doi.org/10.1016/C2016-0-02482-8>
20. Falconer RH, Cobby D, Smyth P, Astle G, Golding DB (2009) Pluvial flooding: new approaches in flood warning, mapping and risk management. *J Flood Risk Manag* 2(3):198–208. <https://doi.org/10.1111/j.1753-318X.2009.01034.x>
21. Fenta AA, Yasuda H, Shimizu K, Haregeweyn N, Woldearegay K (2017) Quantitative analysis and implications of drainage morphometry of the Agula watershed in the semi-arid northern Ethiopia. *Appl Water Sci* 7:3825–3840. <https://doi.org/10.1007/s13201-017-0534-4>
22. Firstpost (2021) Explainer: what makes Mumbai flood every monsoon? Clogged drains, rivers and receding mangroves likely reasons. Mumbai: The Network 18. Retrieved from <https://www.firstpost.com/india/explainer-what-makes-mumbai-flood-every-monsoon-clogged-drains-rivers-and-receding-mangroves-likely-reasons-9700391.html>
23. Goswami D (2020) Urban flood risk reduction, case area: Bhopal. *Int J Archit* 6(2):9–18. Retrieved from <http://www.iaeme.com/IJA/issues.asp?JType=IJA&VType=6&ITType=2>
24. Gupta K (2007) Urban flood resilience planning and management and lessons for the future: a case study of Mumbai, India. *Urban Water J* 4(3):183–194. <https://doi.org/10.1080/15730620701464141>
25. Hall JW, Sayers PB, Dawson RJ (2005) National-scale assessment of current and future flood risk in England and Wales. *Nat Hazard* 36:147–164. <https://doi.org/10.1007/s11069-004-4546-7>
26. Hammond MJ, Chen SA, Djordjević S, Butler D, Mark O (2015) Urban flood impact assessment: a state-of-the-art review. *Urban Water J* 12(1):14–29. <https://doi.org/10.1080/1573062X.2013.857421>
27. Hughes RM, Kaufmann PR, Weber MH (2011) National and regional comparisons between Strahler order and stream size. *J N Am Benthol Soc* 30(1):103–121. <https://doi.org/10.1899/09-174.1>
28. Indo-Asian News Service (2017, September 11) Poor drainage and sewage system is the real cause of urban flooding: experts. New Delhi, India
29. Jainer S, Rohilla SK, Pasricha D (2020) An every monsoon affair: how to tackle urban flooding. Down to Earth, New Delhi. <https://www.downtoearth.org.in/blog/urbanisation/an-every-monsoon-affair-how-to-tackle-urban-flooding-72558>
30. Jang JH, Hsieh CT, Chang TH (2019) The importance of gully flow modelling to urban flood simulation. *Urban Water J* 16(4):1–12. <https://doi.org/10.1080/1573062X.2019.1669198>
31. Jha BM, Sinha SK (2020) Towards better management of ground water resources in India. Central Ground Water Board, Ne Delhi
32. Jha SK (2018) Urban floods—a case study of Araria, Bihar. Ambedkar University, Delhi. Retrieved from https://www.researchgate.net/publication/326655201_Urban_Floods-A_Case_Study_of_Araria_Bihar
33. Jia N, Sitzenfrie R, Rauch W, Liang S, Liu Y (2019) Effects of urban forms on separate drainage systems: a virtual city perspective. *Water* 1–18. <https://doi.org/10.3390/w11040758>
34. Jiang L, Jiapaer G, Bao A, Guo H, Ndayisaba F (2017) Vegetation dynamics and responses to climate change and human activities in Central Asia. *Sci Total Environ* 599–600(1):967–980. <https://doi.org/10.1016/j.scitotenv.2017.05.012>
35. Khawas V (2005) Urbanisation in the North-East: patterns, trends, and policy prongs. *Soc Chang* 35(2):47–69. <https://doi.org/10.1177/004908570503500204>
36. Klingelhofer D, Muller R, Braun M, Bruggmann D, Groneberg DA (2020) Climate change: does international research fulfill global demands and necessities? *Environmental Sci Eur* 32(137):1–21. <https://doi.org/10.1186/s12302-020-00419-1>
37. Lavanya K (2012) Urban flood management—a case study of Chennai city. *Archit Res* 2(6):115–121

38. Li C, Liu M, Hu Y, Shi T, Zong M, Walter MT (2018) Assessing the impact of urbanization on direct runoff using improved composite CN method in a large urban area. *Int J Environ Res Public Health* 15(775):1–14. <https://doi.org/10.3390/ijerph15040775>
39. Ligtenberg J (2017) Runoff changes due to urbanization: a review. Umea University, Umea. Retrieved from <https://www.divaportal.org/smash/get/diva2:1067287/FULLTEXT01.pdf>
40. McGrane SJ (2016) Impacts of urbanisation on hydrological and water quality dynamics, and urban water management: a review. *Hydrol Sci J* 61(13):2295–2311. <https://doi.org/10.1080/02626667.2015.1128084>
41. Meteorological Centre, Agartala (2020) Climate of Tripura. Indian Meteorological Department, Government of India, Agartala. Retrieved from <https://agartala.imd.gov.in/Tripura-Climateology/>
42. 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>
43. Mitra S, Roy S (2020) Infrastructural development and future scope of railway transport system in Tripura: a spatial analysis. In: Mukherjee D, Saha M (eds) *Purvottaran-the rise of North East: paradigms of development in the VUCA world*. Bloomsbury, New Delhi, pp 500–531. <https://www.bloomsbury.com/in/purvottaran-9789390513017/>
44. Mitra S, Debbarma D, Santra A, Roy S (2018) Road network system in Agartala municipal corporation: a geographical analysis. *Indian J Reg Sci*, 66–77. https://www.researchgate.net/publication/333246169_Road_Network_System_in_Agartala_Municipal_Corporation_A_Geographical_Analysis
45. Nath S (2014) *Addressing*. Guru Gobind Singh Indraprastha University, New Delhi. Retrieved from https://www.academia.edu/7076587/Addressing_Delhis_Urban_Flooding_Problem
46. Neog R (2021) Evaluation of temporal dynamics of land use and land surface temperature (LST) in Agartala city of India. *Environ Dev Sustain*, 1–21. <https://doi.org/10.1007/s10668-021-01572-0>
47. Otukei JR, Blaschke T (2010) Land cover change assessment using decision trees, support vector machines and maximum likelihood classification algorithms. *Int J Appl Earth Observ Geoinf* 12(Special):27–31. <https://doi.org/10.1016/j.jag.2009.11.002>
48. Parkinson J (2003) Drainage and stormwater management strategies for ow-income urban communities. *Environ Urbanization* 15(2):115–126. Retrieved from <https://doi.org/10.1177/095624780301500203>
49. Parthasarathy B, Sontakke NA, Munot AA, Kothawale DR (1987) Droughts/floods in the summer monsoon season over different meteorological subdivisions of India for period 1871–1984. *J Climatol* 7:57–70. <https://doi.org/10.1002/joc.3370070106>
50. Pradhan MP, Ghose MK, Kharka YR (2012) Automatic association of strahler's order and attributes with the drainage system. *Int J Adv Comput Sci Appl*, 30–34. https://www.researchgate.net/publication/236868521_Automatic_Association_of_Strahler's_Order_and_Attributes_with_the_Drainage_System
51. Rafiq F, Ahmed S, Ahmed S, Khan AA (2016) Urban floods in India. *Int J Sci Eng Res* 7(1):721–735. <https://www.ijser.org/researchpaper/Urban-Floods-in-India.pdf>
52. Rai PK, Mohan K, Mishra S, Ahmad A, Mishra VN (2017) A GIS-based approach in drainage morphometric analysis of Kanhar River Basin, India. *Appl Water Sci* 217–232. <https://doi.org/10.1007/s13201-014-0238-y>
53. Ray K, Pandey P, Pandey C, Dimri AP, Kishore K (2021) On the recent floods in India. *Curr Sci* 117(2):204–218. <https://doi.org/10.18520/cs/v117/i2/204-218>
54. Roy S, Mitra S (2016) Railway transport system in Tripura, India: an geographical analysis. *Geogr Rev India* 78(1):40–57
55. Roy S, Mitra S (2020) Railway stations of Tripura, India: an assessment of infrastructural conditions. In: Bandyopadhyay S, Pathak CR, Dentinho TP (eds) *Urbanization and regional sustainability in South Asia*. Springer, Belgium, pp 177–200

56. Roy S, Mitra S (2016) Infrastructural status of railway transport system in Northeast India: a geographical analysis. *Asian J Spat Sci* 4:89–100. https://www.researchgate.net/publication/318909107_Infrastructural_Status_of_Railway_Transport_System_in_Northeast_India_A_Geographical_Analysis
57. Roy S, Mitra S (2021) Rail freight transport system in Tripura: an analysis of performances and prospects. In: Mitra S, Bandyopadhyay S, Roy S, Dentinho TP (eds) *Railway transportation in South Asia*. Springer, Cham, pp 103–130. <https://doi.org/10.1007/978-3-030-76878-2>
58. Roy S, Mitra S (2018) Intra state mobility pattern of railway passengers in Tripura, India. In: Gogoi L (ed) *Land, people and environment*. Suprava Publication, Guwahati, pp 70–92
59. Sangomla A (2020) Extreme weather in North East: floods in some districts, others stay dry. *Down to Earth*, New Delhi. <https://www.downtoearth.org.in/news/climate-change/extreme-weather-in-north-east-floods-in-some-districts-others-stay-dry-71950>
60. Sangomla A (2021) Climate crisis in North East India: why are rainfall patterns changing? *Down to Earth*, New Delhi. <https://www.downtoearth.org.in/news/climate-change/climate-crisis-in-north-east-india-why-are-rainfall-patterns-changing--78879>
61. Santra A, Mitra S, Debbarma D (2018) Impact of urbanisation on land use changes in Agartala city, India. *Res J HumIties Soc Sci* 9(2):1–8. https://www.researchgate.net/publication/327144012_Impact_of_urbanization_on_land_use_changes_in_Agartala_City_India
62. Satterthwaite D (2008) *Climate change and urbanisation: effects and implications for urban governance*. United Nations Secretariat, New York. https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/unpd_egm_200801_climate_change_and_urbanization_effects_and_implications_for_urban_governance_satterthwaite.pdf
63. Sen S, Santra A, Debbarma D, Mitra S, De SK (2015) Morphology of Tilla-Lunga topography in West Tripura District, Tripura, India. *Ann NAGI* 35(2):77–93. Retrieved from https://www.researchgate.net/publication/316668526_Morphology_of_Tilla-Lunga_Topography_in_West_Tripura_District_Tripura_India
64. Shinde S, Pande CB, Barai VN, Gorantiwar SD, Atre AA (2023) Flood impact and damage assessment based on the Sentinel-1 SAR data using google earth engine. In: Pande CB, Moharir KN, Singh SK, Pham QB, Elbeltagi A (eds) *Climate change impacts on natural resources, ecosystems and agricultural systems*. Springer Climate. Springer, Cham. https://doi.org/10.1007/978-3-031-19059-9_20
65. Sinha B (2017) Lessons from Agartala's flood fury. *Agartala: India climate dialogue*. <https://indiaclimatedialogue.net/2017/08/18/lessons-agartalas-flood-fury/>
66. The Hindu (2019) Heavy rain in Agartala city in Tripura. N. Ravi, Chennai
67. Tucci CE (2007) *Urban flood management*. World Meteorological Organisation, Geneva. Retrieved from <https://www.floodmanagement.info/floodmanagement/wpcontent/uploads/2020/06/Cap-Net-WMO-Urban-Flood-Management.pdf>
68. Turok I, McGranahan G (2013) Urbanization and economic growth: the arguments and evidence for Africa and Asia. *Environ Urbanization* 25(2):465–482. <https://doi.org/10.1177/0956247813490908>
69. Wakode HB, Baier K, Jha R, Azzam R (2018) Impact of urbanization on groundwater recharge and urban water balance for the city of Hyderabad, India. *Int Soil Water Conserv Res* 6(1):51–62. <https://doi.org/10.1016/j.iswcr.2017.10.003>
70. Wang J, Wang K, Zhang M, Zhang C (2015) Impacts of climate change and human activities on vegetation cover in hilly southern China. *Ecol Eng* 81:451–461. <https://doi.org/10.1016/j.ecoleng.2015.04.022>
71. Winstanley D (1973) Recent rainfall trends in Africa, the Middle East and India. *Nature* 243:464–465. <https://doi.org/10.1038/243464a0>
72. World Resources Institute (2019) *Urban flooding: insights from Hyderabad*. WRI India Ross Center, Delhi
73. Yazdanfar Z, Sharma A (2015) Urban drainage system planning and design—challenges with climate change and urbanization: a review. *Water Sci Technol* 72(2):165–179. <https://doi.org/10.2166/wst.2015.207>

74. Zhang L, Guilbert E (2012) A study of variables characterising drainage patterns in river networks. In: International archives of the photogrammetry, remote sensing and spatial information sciences. XXII ISPRS Congress, Melbourne, Australia, pp 29–34. <https://www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XXXIX-B2/29/2012/isprsarchives-XXXIX-B2-29-2012.pdf>
75. Zimmermann E, Bracalenti L, Piacentini R, Inostroza L (2016) Urban flood risk reduction by increasing green areas for adaptation to climate change. *Procedia Eng* 161:2241–2246. <https://doi.org/10.1016/j.proeng.2016.08.822>