Rapid assessment of the October 2020 Hyderabad urban flood and risk analysis using geospatial data

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The present study looks into the Hyderabad urban floods of October 2020 from a geospatial perspective. The spatial extent and severity of the flooding event for a part of the urban catchment (Zone-12) of Hyderabad city are modelled using HEC-RAS 1D–2D considering 13 October 2020 rainfall event. The study compares the present flooding to the previous flooding incidence which impacted Hyderabad, almost a decade back on 24 August 2000. The study shows that rapid unplanned urbanization ignoring the regional and local hydrological landscape has aggravated the flooding severity. The study highlights the fact that rapid, uncontrolled urbanization (16.5% increase) over the last two decades have substantially influenced the urban hydrology producing higher flood volumes for comparatively small rainfall event. Thus regulating urbanization, providing enhanced drain capacity, rejuvenating the water bodies and streams is need of an hour to check and reduce the spatial flooding extent.

Keywords: Geospatial extent, HEC-RAS, mapping, modelling, urban floods.

NATURAL hazards and extreme climatic events are becoming more frequent as a result of climate change[1–3]. The problem is further aggravated due to migration of the rural population to urban areas[4]. Such migration is estimated to be 70% of the world's population by 2050 (ref. 5). Urbanization and climate change have a major impact on watershed hydrology by inducing uncertainty in rainfall and run-off patterns[1,6,7]. Rapid unplanned urbanization and increased climate variability pose a serious threat in the form of urban floods across the globe[8]. India is no exception to the growing threat of extreme climatic events and urbanization problems, whose impacts have started becoming visible on the ground in the form of urban flooding events in the last few decades. The recurrent incidences of catastrophic urban flooding, viz. the Chennai – 2015, Kerala – 2018, Patna – 2019 and Hyderabad – 2020 floods highlight the seriousness of the situation. Extreme events pose a great challenge towards sustainable town planning and disaster management[9]. Considering the rising urban flood risk, the Government of India (GoI) has now initiated the Atal Mission for Rejuvenation and Urban Transformation (AMRUT), programme that focuses on the provision of water supply, sewerage, stormwater drains, green spaces and public transport in 500 cities[9]. The National Disaster Management Authority (NDMA), GoI, has provided guidelines to tackle urban floods, but many of these are yet to be implemented in the field[10]. The Town and Country Planning Organization, Ministry of Housing and Urban Affairs, GoI, has come out with a standard operating procedure (SOP) for urban flooding. A manual on stormwater drainage was also published in 2019 for planning sustainable drainage systems by the Central Public Health and Environmental Engineering Organization (CPHEEO), Ministry of Housing and Urban Affairs, GoI[11]. Despite various initiatives, urban flooding remains a big challenge due to the rapid urbanization together with hydrologic extremes and climate change, towards implementing flood-resilience measures in many of the cities in India[12]. The extreme rainfall events cannot be regulated, but the advancement in technology allows us to minimize the risk and damage involved by mapping the extent and severity of such likely events. The present study analyses the urban floods of October 2020 in Hyderabad, Telangana, India, from a geospatial perspective.

Hyderabad has witnessed several devastating floods in the past, including the disastrous Musi floods which occurred a century ago in 1908 triggered due to 480.06 mm of rainfall recorded within 48 h, inundating low-lying areas up to almost 3.3 m and causing massive damage to life and property[13]. To tackle floods in the

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Table 1. Recent important flood events in Hyderabad (24-h duration)[18,32]

Event	Rainfall (mm)	Deluge depth (m)	Damage/affected areas			
			Lives	Houses	People (lakh)	Estimated loss (Rs)
October 2020	192.0	2–4	81	>20,500	>1.8	5000 crores
September 2019	133.0	1–2	0	>30,000	>1.2	>10 lakhs (goods)
September 2016	167.2	1–2	8	>17,000	>1	60 crores
August 2008	137.0	2–3	14	>32,000	>1.5	49.2 crores
August 2002	130.0	1–2	0	>12,000	>1	>10 lakhs (goods)
August 2001	127.8	1–2	0	>15,000	>1	>10 lakhs (goods)
August 2000	241.5	2–4	26	>35,693	>2	135 crores
July 1989	187.7	1–3	10	>20,500	>1	30 crores

future and provide drinking water to the city two major reservoirs, i.e. the Osman Sagar and Himayat Sagar were constructed in 1920 and 1927 respectively[14]. However, post-Musi floods Hyderabad has not witnessed similar amounts of rainfall, but the severity of the problem has been increasing ever since. The August floods of 2000 (241.5 mm in 24 h) caused huge property loss and more than 90 residential colonies were submerged (2–4 m water level). Hyderabad witnessed another intense downpour on 13 October 2020, and the event points to the persistent warnings that people chose to overlook over these years. The low-pressure system that formed in the Bay of Bengal while crossing over the Telangana region caused excessive rainfall resulting in massive flooding which impacted more than 120 colonies, 20,500 homes and causing as many as 80 deaths[15].

Many researchers have studied the aspects of urban flood hazard for the Hyderabad region[16–18]. However most of these studies have focused on reasoning and data analysis. Few works implemented modelling techniques using proprietary models and also faced the limitation of raw data for model-building, development and simulation. The present study intends to capture the geospatial flooding extent and severity of the event employing the HEC-RAS 1D–2D flood modelling technique developed for Zone-12 urban catchment of Hyderabad city for the 13 October 2020 event and compare it with the previous 24 August 2000 event.

Hyderabad: October 2020 urban flooding

Hyderabad experienced continuous heavy incessant rainfall during the second week of October 2020, causing massive flooding in most parts of the city. Generally, for Hyderabad July–September is the period of peak rainfall activity, followed by significant decline from October onwards. However, the recent Hyderabad floods of October 2020 witnessed extreme rainfall which was the highest ever in October, and also the second highest on any day in any month since 1891 (ref. 19). The weather monitoring station of India Meteorological Department (IMD) at Begumpet recorded 192 mm of rainfall during 24 h on 13 October 2020. Before this event, the highest recorded rainfall in Hyderabad according to IMD was 241.5 mm on 24 August 2000. Table 1 shows the recent extreme rainfall events that triggered floods in Hyderabad city and the damages incurred.

Method and materials

The methodology for carrying out urban flood modelling in the present study is based on that of Rangari *et al.*[20] adopted for developing a regional-scale urban flood model with HEC-RAS 1D–2D. It involves hydrologic model HEC-HMS and hydraulic model HEC-RAS in integration with ArcGIS 10.1 for Zone-12 of Hyderabad (Figure 1). The key parameters used for model development and simulation were rainfall data, stream–drainage network, catchment characteristics (such as area, imperviousness, roughness coefficient and elevation), sub-catchment outlets, digital elevation model (DEM), 2D flow area and 2D mesh. The 2D model parameterization is described in Rangari *et al.*[21]. Land use/land cover (LULC) for the period 2000–2020 for Zone-12 of Hyderabad was used as base data to perform the model simulation run and assess the flooding extent. The LULC analysis was performed using cloud-free Landsat Thematic Mapper (TM) scene (30 m resolution) acquired on 2 February 2000 and Sentinel-2 (10 m resolution) scene acquired on 28 February 2020, through the USGS Earth-Explorer open portal[22]. Drainage details (i.e. type of drain, length, size and shape as well as depth) were acquired from Greater Hyderabad Municipal Corporation (GHMC). The catchment characteristics were extracted from Cartosat DEM (10 m resolution) by processing in Arc-GIS. To examine flooding severity, the model was simulated using rainfall data of 13 October 2020 and the simulation results were matched with flooding extent of the 22 August 2000 event. The hourly rainfall data for 13 October 2020 were obtained from IMD. Monthly rainfall data and cumulative rainfall depth of extreme events (2000–2019) for the analysis were taken from open online sources. The daily rainfall

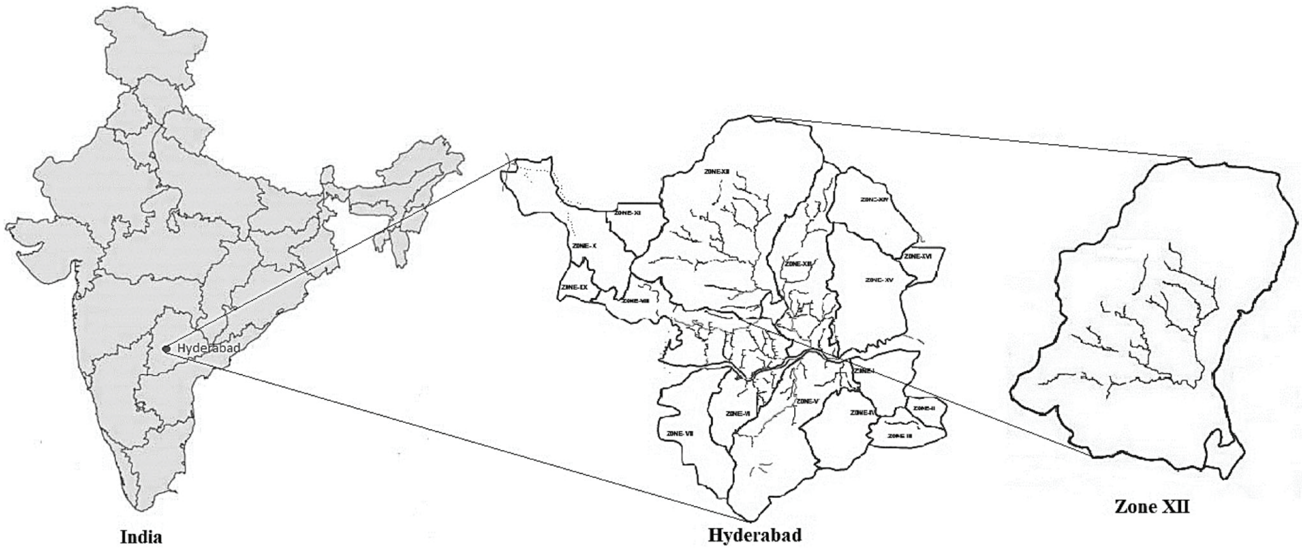

Figure 1. Location map Zone-12, Hyderabad (source: Google Earth).

data of Hyderabad city (2000–2013) were procured from IMD. Figure 2 *a* shows the hyetograph of event rainfalls considered for model simulation. Figure 2 *b* presents the flow chart of the methodology.

Results and discussion

Land-use/land-cover analysis

The satellite imagery was pre-processed to apply the geometric correction, and suppress the atmospheric effect and noise in the raw dataset[23,24]. The nearest neighbourhood data resampling was applied to the dataset to match the spatial resolution of Sentinel-2 and Landsat TM on account of its clarity and ability to keep store original information unchanged. The unsupervised ISODATA technique was employed to classify the land use into four classes (i.e. built-up area, water body, vegetation and others). The LULC output was validated by generating 100 random sample points of the developed LULC in Arc-GIS and exported to Google Earth as a KML layer. The KML layer was superimposed over the historically stored images available with Google Earth and a match accuracy of 87.2% and 88.8% respectively, was observed (kappa coefficient > 0.83). Kappa value > 0.80 indicates precision in the approach with a strong agreement[25]. Figure 3 shows the changes in LULC of Zone-12, Hyderabad for 20 years (2000–2020). In false colour composite satellite images the urban areas appear in steel-grey tone, vegetated areas in reddish tone and water bodies in dark-bluish tone. A significant reduction in open land can be observed with only a few visible pockets of light red tone, and an overall decline in the number of water bodies (dark-bluish tone) and their spread. Zone-12 which had 65% of impervious area in 2000 is now almost 89% covered with impervious surfaces, registering an overall increase of about 23.75%. The increase in imperviousness basically in the form of urban growth which has occurred at the cost of encroachment of vegetative areas, other open lands and water bodies was 0.95%, 15% and 0.65% respectively. The increased imperviousness limits the infiltration process thereby increasing the total runoff from the urbanized catchments up to six times and peak flows up to 1.8–8 times, thus leading to flooding[10].

Flood extent estimation and analysis using HEC-RAS 1D–2D

The HEC-RAS 1D–2D model derives results in the form of flood inundation extent and depth with a stipulated time duration. Figure 4 *a* shows the progressive advancement of flooding extent at an interval of 7 h for the 13 October 2020 event. As seen from the figure, around 7 h interval water started accumulating in the areas along the streamline. The water level started building up with the passing time that caused the spreading of floodwater in adjoining low-lying areas at around 14 h. Most of the localities, including Begumpet, Ameerpet, Madhapur, Tulasi Nagar, Rajiv Gandhi Nagar, Adarsha Nagar, Pragathi Nagar, Laxmi Nagar and Chandra Nagar experienced heavy flooding by the end of 21st hour[26]. A week later, many of these colonies were still under water[27]. To have a comparative analysis of the October 2020 deluge with the other big flood events which occurred two decades ago, the flooding extent of August 2000 was plotted over the flooding extent of October 2020 (Figure 4 *b*). Figure 4 *c*

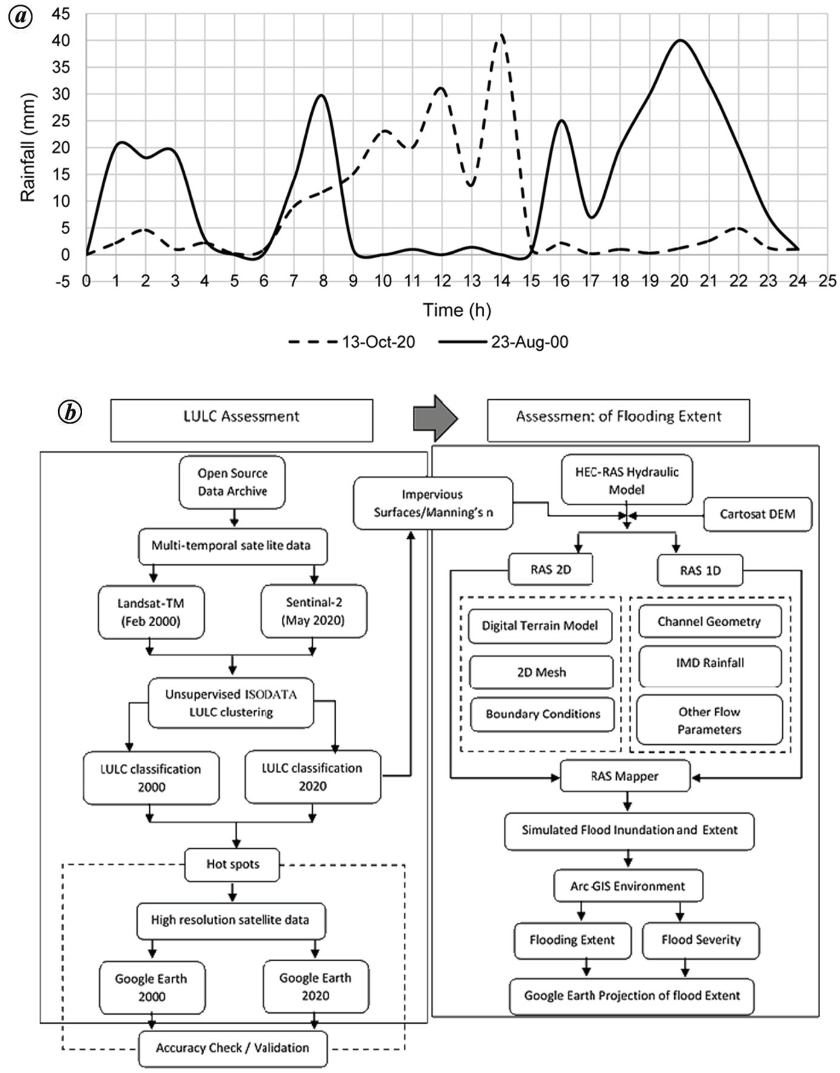

Figure 2. ***a***, Event rainfall hyetograph for model simulation. ***b***, Flow chart of the methodology.

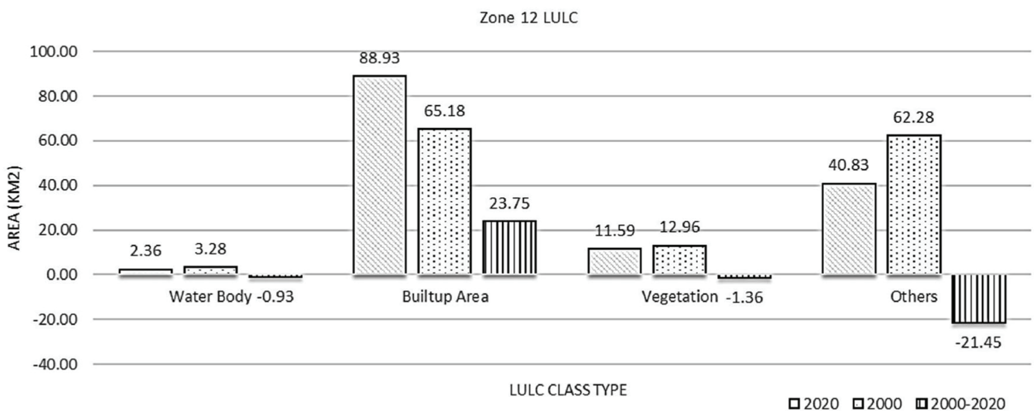

Figure 3. Changes in land use/land cover over the period of 20 years (2000–2020).

shows the October 2020 flood depth over underlined terrain. A maximum of 2–3 m inundation depth was observed at Begumpet, Ameerpet and around Fox-Sagar Lake. The results show that the rainfall event of October 2020 produced inundation over 34.05 km^2 (23.70%), which is 8.42% more severe compared to the August 2000 inundation (15.28%) (Table 2). From Table 2, we can observe a more than 50% rise in high risk for the

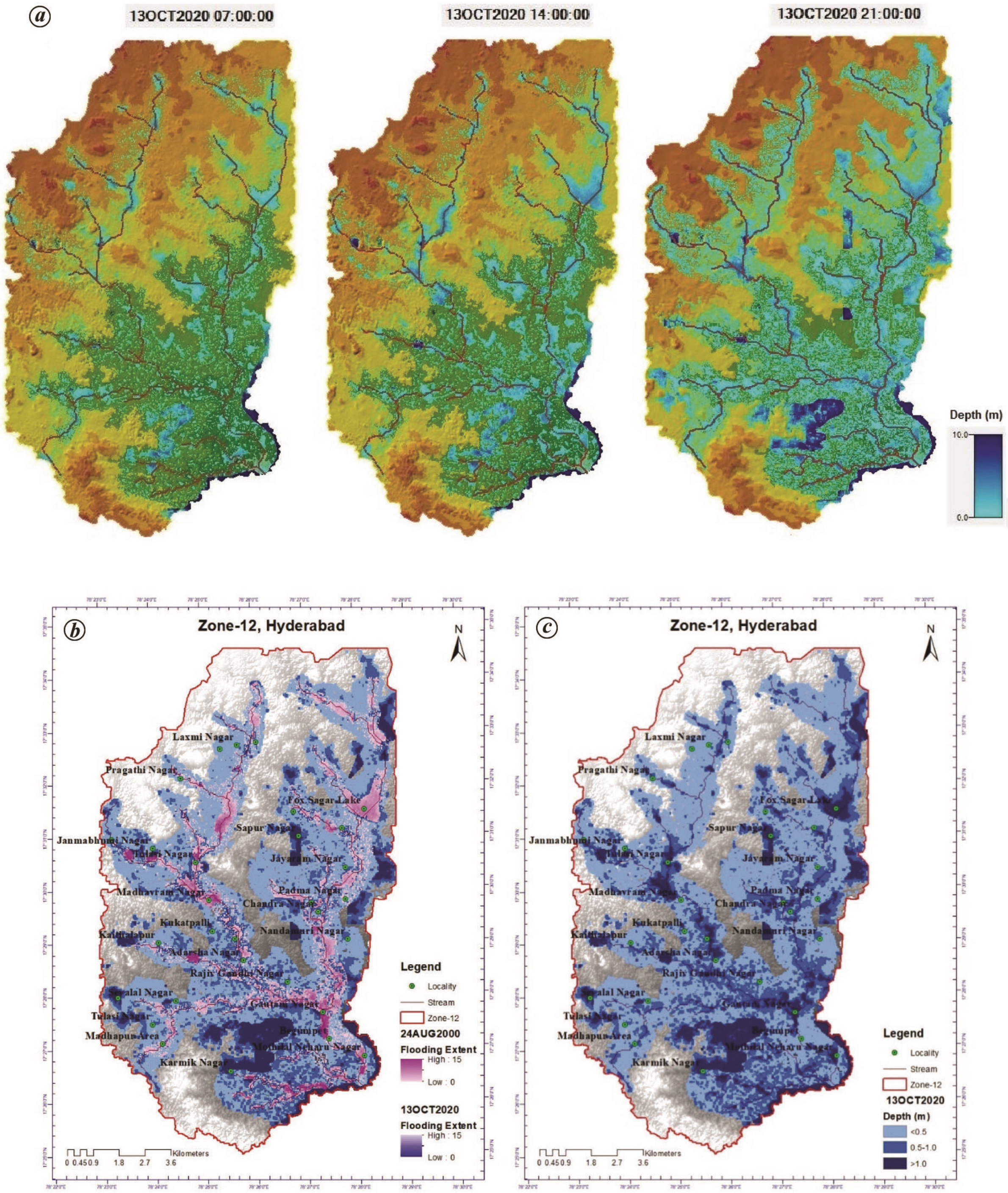

Figure 4. ***a***, Advancement of flood extent with time for the October 2020 event. ***b***, Superimposed flooding extent. ***c***, The October 2020 flood depth.

October 2020 event. Similarly, there is significant rise in low and medium risks compared to the August 2000 event. The major affected areas of Zone 12, Hyderabad, are Begumpet, Ameerpet, Madhapur, Kukatpalli, Rajiv Gandhi Nagar, Chandra Nagar, Tulasi Nagar and Laxmi Nagar. The Google Earth projection of the October 2020 flooding presents the extent of risk class and severity of the event.

Rainfall data analysis

Hyderabad city receives the bulk of its rainfall during the summer monsoon (June–September) with an average annual amount of 136.1 mm. Past studies reported no significant change in the mean monsoon rainfall over the city, but marked a major rising trend in heavy rainfall at the end of the summer monsoon[15]. The vulnerability risk

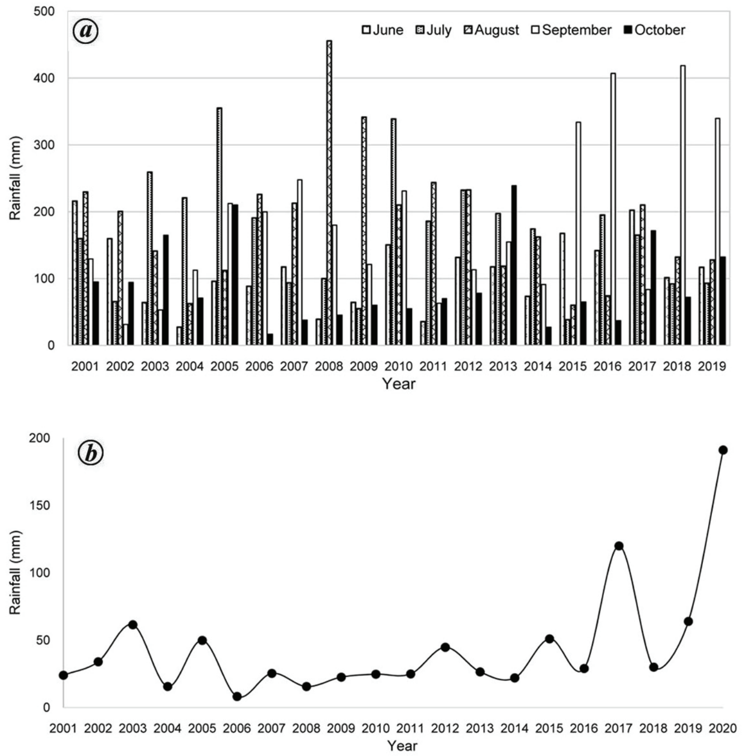

Figure 5. ***a***, Hyderabad rainfall data analysis (2001–2019; Source: IMD, online open data). ***b***, One-day maximum rainfall in October (2001–2020; Source: IMD, online open data).

Table 2. Deluge severity for the flood event

Deluge risk	Flooded area (km^2) 13 October 2020	24 August 2000
Low	22.23	14.19
Medium	7.15	5.63
High	4.67	2.13
Total	34.05	21.95

of extreme rainfall conditions on urban catchments can be addressed by reviewing the severity and seriousness of past rainfall data. However, the availability of basic data, including hourly and sub-hourly rainfall data is a major concern in hydrologic studies. Figure 5 *a* and *b* shows the cumulative monthly rainfall data and one-day maximum values in October (2001–2019) for Hyderabad city. Based on the long-term average monthly data of two decades, it is observed that monsoon is more prominent towards the end of summer after 2015, and Hyderabad is reeling under deficit rainfall during June and July. The monthly rainfall for June and July is observed to be less than the monthly average rainfall 10 times in the past 20 years. However, the October monthly average rainfall (103.6 mm) has been crossed five times in the last 20 years. Further one-day maximum rainfall events show an increasing trend over the last decade. Such abrupt variation in rainfall is seen all over the country, and researchers claim these topical changes in rainfall over the Indian continent as direct implications of urbanization and climate change[17,28].

Impact of urbanization on land-use changes

One of the reasons for urban flooding is the rapid growth in population permitting changes in LULC. Studies have assessed the land-use changes (1972–2013) and the impact of urbanization on rainfall pattern over Hyderabad city[29,30]. The population of Hyderabad city has increased enormously in past 20 years with an average growth rate of 3.46 (ref. 31), which has exerted a huge pressure on land use as unbound settlements and is visible through LULC analysis. Remotely sensed multi-temporal satellite imagery shows that Zone-12 urbanization has transformed the natural landscape bearing waterbodies, drainage paths, fertile and open lands into a built-up environment. This transformation has wiped out the identity of Hyderabad, once known as ‘the City of Lakes’, with the disappearance of many streams and dried lakes. The lakes in Hyderabad were connected by a ‘cascade system’ with a strong natural stream network as the carrier of floodwater from one lake to another. Figure 6 *a* shows the interconnected natural drains that link the series of lakes through a cascade system. Many of these lakes have disappeared from the ground, and natural streams connecting these water bodies are not visible at present

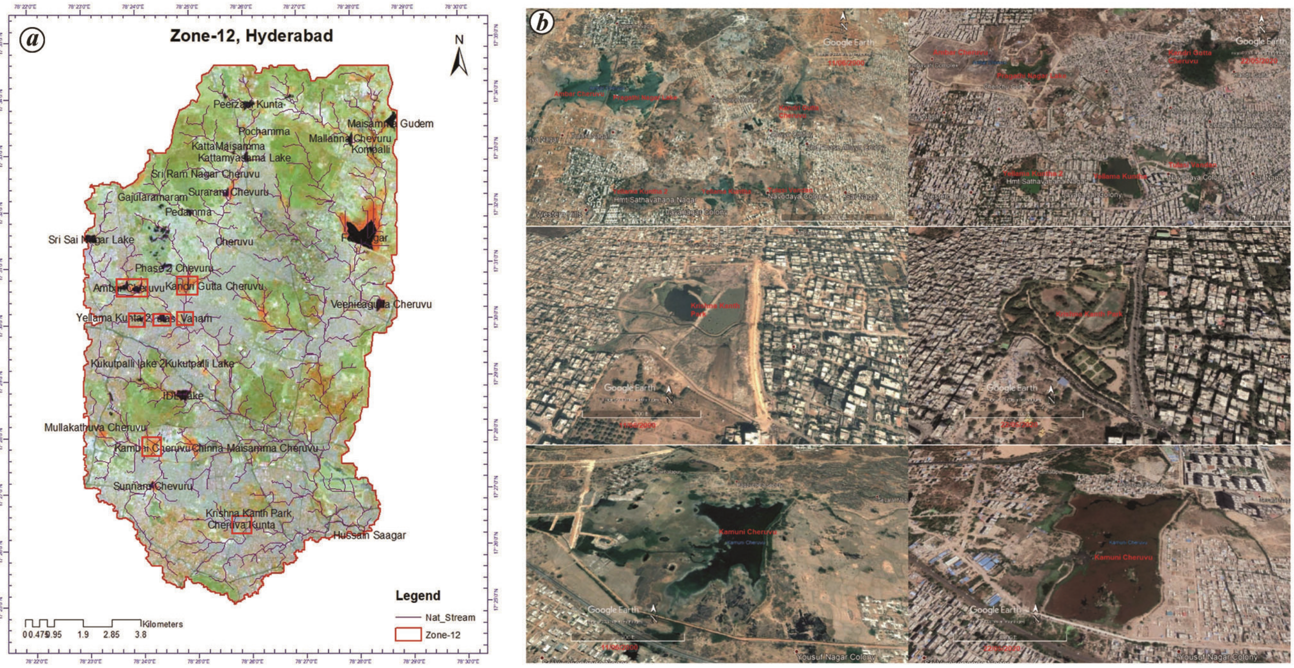

Figure 6. ***a***, Sentinel-2 satellite image of 28 February 2020. ***b***, Encroachment in lake command area from 2001 to 2020 (source: Google Earth).

due to encroachment and urbanization. Figure 6 *b* shows the encroachment in lake command area from 2001 to 2020 (enlarged view of highlighted in Figure 6 *a*). The Google Earth projection of lakes shows their reduced areal extent due to massive encroachments, and its impact were visible in recent events when the stream path was activated causing floods, especially in the basement floors of buildings along natural stream paths and encroached lake territory. The flooding extent of the October 2020 event was critically assessed and analysed to be compared with the August 2000 event. Though the October 2020 event was less critical, it has produced 8.42% more flooding extent and vast damage in terms of property and human life compared to the more severe event of August 2000. Thus, to summarize, the October 2020 Hyderabad flood event and the resulting damage are an aggregation of climate change, changes in rainfall pattern, uncontrolled urbanization and land-use changes induced to anthropogenic activities. Since urbanization and climate change go hand-in-hand together, urban flooding and the subsequent damage will intensify in the near future. Therefore, to make cities resilient to urban flooding, we must adopt flood-mitigation measures, rejuvenate natural wetlands, upgrade the storm sewer drainage in tandem with future population-projected scenarios, adopting nature-friendly engineering solutions as an integral part of the smart-city planning.

Conclusion

The selection of a particular model for urban flood situations is a complex task and needs to be tackled delicately based on the requirement of model input parameters, availability of extensive dataset and output deliverables. This study presents an HEC-RAS 1D–2D urban flood modelling approach to assess geospatial flooding extent and risk analysis. The model simulation results are presented as spatial flood extent and risk maps that show the susceptibility of the study area to flooding events and the associated risks. These maps can be used by the city administration, governing authorities, and common people to identify critical areas during extreme events and find safe places of shelter. The maps will also help the urban planners in sustainable future developments. Further, the study highlights the fact that even though the October 2020 event (191.1 mm) was less severe in terms of rainfall than the August 2000 event which saw higher rainfall, rapid urbanization (16.5% increase) over the last two decades has increased the flood severity. Therefore, urbanization needs to be regulated and equally supported with adequate capacity for stormwater drains to address the increased population. The water bodies and streams need to be rejuvenated so that they can absorb the excess flow during monsoon season. Proper regulations and their strict implementation are necessary against the encroachment of water bodies. Satellite images in conjunction with geospatial technologies and hydrological models can be useful in assessing such events and planning mitigation measures.

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