13 Application of Geospatial Techniques for Urban Flood Management: A Review

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Abstract

The present world is fond of urbanization and the rapid urban growth often gave birth to so many new problems, like urban flood and that leads to several other challenges which can be managed with the use of geospatial technology. The urban communities in most of the urban areas of the world are often exposed to vulnerable condition to a greater risk by witnessing urban flood as it has amplified its incidence and magnitude in the current era and India is not an exception. As a consequence, the spatial distribution, extensive mapping, zonation of flood, vulnerability, risk proneness, and risk zonation have now become popular, irrespective of boundaries to deal with the question of urban flood monitoring and management. In this context, the geospatial technology coupled with the Remote Sensing (RS), Geographic Information System (GIS), and Global Positioning System (GPS) has become the powerful and key tool for urban flood management and thus gaining attention in both developed and developing countries. The Optical to Microwave remote sensing have provided the data of flood mapping analysis in all weather conditions and GIS helps to map the flood hazard, potential areas, vulnerable areas, core attention areas, etc.; therefore, both become vigorously imperative. The remotely sensed hydrological data, geomorphological information, weather information, and Digital Elevation Model (DEM) have becoming more effective, and they furnish the high accuracy of flood estimation derived from the high-resolution remote sensing data and they are powerfully employed to manage urban flood more efficiently and effectively. The current effort is an attempt to highlight the reviews which already worked in various cities of the world, addressing the diverse issues of urban flood management with the application of geospatial techniques, to provide scientific information for the city planners and policy-makers to formulate the resilient urban flood management strategy.

Keywords

Urban · Geospatial techniques · Urban flood · Flood management · Resilient · Strategy

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13.1 Introduction

Flood occurs worldwide in var locations and in diverse magnitude, and thus this widespread hazard plays a marked and significant role in shaping the environment, economy, and society. Heavy rainfall, uneven distribution of rainfall, improper drainage system, decreasing and decaying of wetlands, etc. are often get aggravated together with the uncontrolled urban population growth and density leads to urban flood. Flood is a widespread devastating phenomenon as it affected more than 2 billion people worldwide between 1998 and 2017; loss of life, damages of property, and health hazards are the immediate effects of such incidences. Worldwide, people belong to low-lying areas and floodplains are the most vulnerable, but the urban areas are not an exception to fetch such incidences for diverse reasons. Urban flooding is considered as a type of pluvial flooding caused by surface run-off, and thus this concept is different from fluvial or coastal flooding. The physical characteristics and concrete infrastructure of the urban area and the rate of urbanization are the factors that increase the chances of water logging problem in a larger scale and enhance the occurrences flood. The flood management especially in urban areas is often becoming very challenging and a tough mission for the urban planners and policy-makers because it must enclose the wellbeing of the inhabited people, maximize the use of resources along with the minimization of human and economic loss and damages caused by the flood. Recently, the geospatial technology coupled with the Remote Sensing (RS), Geographic Information System (GIS) and Global Positioning System (GPS) has become the dominant and solution tool for flood mitigation and management. The vulnerability, risk proneness, flood-affected zones, and attainable areas could easily be found out and mapped through the GIS. Moreover, the advancement from optical to microwave remote sensing has developed in this field, which provides the all-weather capable data for mapping and analysis of flood hazard. The quantification and reduction of the damages, precaution and assessment of flood, identification of vulnerable areas and prediction of such events through the RS and GIS helps to minimize the harmful effects of flood and superior management can be provided with the diverse applicable ways by geospatial technology. Furthermore, the troubles of socio-economic motion together with transport and communication, contamination of drinking water, unavailability of food and loss of property, aftermath illness along with the structural damages are the consequences of urban flood (Hewitt and Burton 1971). The urban area located in the flat surface or low-lying terrain often have to adjust with the poorly build drainage and sewerage system which often have been blocked by disposed municipal waste. The unplanned or poorly planned urbanization makes the densely concentrated inhabitants vulnerable to urban flood, and therefore the damages become extrapassionate and complex to manage (Jha et al. 2011). Urbanization often found in turn of the switch of wetland, natural vegetation, agricultural land to build up setting, structure and infrastructural enlargement (Adoeye et al. 2009), which has a strong connection with the occurrence of urban flood. Thus, many factors are responsible for the occurrence of urban flood, such as duration and intensity of precipitation, clearance of natural vegetation, land use pattern, natural, quasi-natural and man-made impediments. All of these enhances the occurrence of flood, its frequency, duration of stay, magnitude, inundation and areal expand which are needed to judge for the mitigation and management, and the application of geospatial technology is the key apparatus for such effort. Different statistical and geospatial techniques have been successfully used for qualitative and quantitative analysis of urban flood to uncover the vulnerable and risk proneness, and thus it contributes a lot in the planning and formulation of appropriate flood management strategies. The magnitude of urban flood can be reduced if adequate emergency prevention, preparedness, response,and sustainable recovery measures are implemented in a timely manner.

Some important studies have been found describing the collision of urbanization and meteorological changes and its connection with the increasement of rainfall in urban area (Guhathakurata et al. 2011; Ghosh et al. 2009; De et al. 2005; De Roo 2000; Rao et al. 2004; Khole and Dey 2001; Roy et al. 2001; De and Rao 2004; Goswami et al. 2006; Sinha et al. 1999); rapport between urbanization and hydrological features like decrease in infiltration, incensement of runoff, increase the number and height of flood occurrence (Alaghmand et al. 2010). Some studies have found RS and GIS as very effectual in identifying the spatial section of flood management as it supplies adequate geographical information (Lowery et al. 1995; Smith 2001); GIS made the flood hazard identification, vulnerability assessment, monitoring and forecasting easier (Roy et al. 2001); while RS intended a synoptic attitude of spatial information, allocation and dynamism of hydrological episode employed to determine and monitor the flood, and quantification of the areal extend easily (Izinyon and Ehiorobo 2011). Currently, greater than 50% population of the world live in the urban area and this is going to accomplish two-thirds by 2050 (IFRC 2010; WHO 2010) and this could be very alarming so far the management of urban flood is concern. Furthermore, the urban flood is considered as dangerous catastrophic events across the globe and ranked as the commonest event with some serious consequences ranging from trivial to foremost accidental (Liu and Li 2017; Gharagozlou et al. 2011; Clement 2013; Ramlal and Baban 2008; Mark et al. 2004). Moreover, the flood risk is increasing with an escalation of hydrological and climatic variables (Masser 2001; Mathew et al. 2012;Messner and Meyer 2006; Mohit and Aktar 1998; Yi et al. 2010; Heywood et al. 1993; Huong and Pathiran 2013), thus and need of the hour is to reduce such urban flood risk in urban areas of the world. In most of the urban areas, the harsh nature of urban flood is exasperated by the predominantly occurred heavy rainfall; stumpy infiltration due to impervious facade, poor and unmaintained prior urban drainage infrastructure, accelerated surface runoff, and related inundation of low-lying areas (Liu and Li 2017; Few 2003; Chen et al. 2009; Fernandez and Lutz 2010). Such urban flood events are often amplified by the consequences of climate change and unplanned and extensive urban expansion, and therefore diverse techniques have to be employed for effective and efficient management. In this regard, the prologue exercise of geographical information systems (GIS) has improved the estimation of urban floods, identifying poor zones, finding risk-prone zones using diverse analysis and modelling of flood-causing essentials like precipitation, river discharge, drainage systems, depth of groundwater table, and slope to deal the perilous nature of urban floods for resilient management. Different aspects of urban flood elements have been analyzed using multi-criteria spatial analysis, overlay analysis, employment of different models using GIS techniques, and with the help of systematic integration of structural and non-structural events with the community level, flood risk can be lessened to some extent or to an acceptable level.

13.2 Common Concepts in Flood and Flood Management

The relevant and important terms that are closely associated with the urban flood and its management are mentioned in the form of a flowchart (Fig. 13.1).

Flood hazard: In a specific time within an area, the occurrence of an urban flood event showing its potentiality and magnitude and the several factors dependent on it (Crichton 2002; Kron 2005; Dang et al. 2010). The frequency of occurrence, warning time, rate, and increase of water levels, flood depth, duration, velocity, etc. are very important in flood management.

Flood vulnerability: The physical, economic, social, environmental conditions that make the population more susceptible to urban flood hazard is known as flood vulnerability, which has been judged in numerous studies (Alcantara-Ayala 2002; Pelling 2003; ISDR 2004; Barroca et al. 2006; Adelekan 2011). This vulnerability should be studied as vulnerability indicators,

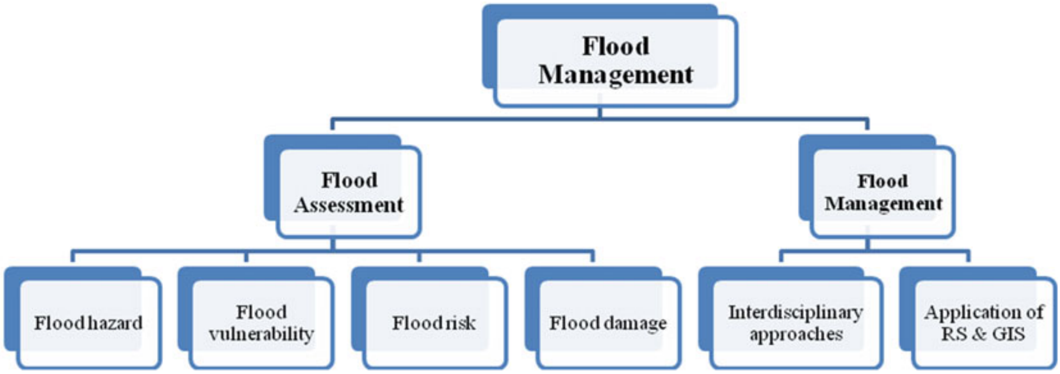

Fig. 13.1 Flowchart of concepts of flood management

susceptibility, exposer, and coping indicators (Weichselgartner 2001; Adelekan 2011) and such kind of information is paramount in determining the flood risk.

Flood risk: The hazards and its potential loss is generally amounted by the flood risk (Crichton 2002; Kron 2005) which signifies the overall effects of urban flooding including the treats of life, danger, evacuating of people, potential damages to the structure, buildings, social disruption, loss of production and community belongings, etc. Thus the flood risk is often expressed by the formula: Flood Risk = Flood hazard x Flood vulnerability (Dang et al. 2010; Karim et al. 2005; Kron 2005; Apel et al. 2009).

Flood damage: The impact of flood damage can be assessed by the amount of flood damage both in tangible and intangible form, which includes agricultural and environmental damages, business interruption, health, etc. (Pielke and Downton 2000; Munich and Topics 2005; Dutta et al. 2003).

Flood management: Urban flood has been gaining increased attention over the years because of the increased rate of urbanization and its connections with the hazards, and significant damages caused to populace, livestock, health, assets, bridges, buildings, communication, homes, and business (Ramlal and Baban 2008; Chen et al. 2009; Few 2003; Mark et al. 2004). In the developed countries, these hazards are devastating to the cities in diverse ways mostly due to notably extreme precipitation events coupled with dilapidated drainage system generated by over urbanization. The urban flood management reducing its potentiality includes proper and timely analysis of risk assessment employing interdisciplinary approaches with the help of RS and GIS (Barbosa et al. 2012; Chen et al. 2009). The application of RS and GIS techniques in all the four stages (Prediction, Preparation, Prevention and Mitigation and Damage Assessment) of flood management is incredibly effective and fruitful as it has updated and potential appliances.

13.3 Flood Management with the Application of RS and GIS

RS and GIS can provide information about predicted flood events in order to facilitate early prediction and planning and to build up an improved management system. Thus, effective and efficient planning with the help of some models and methods by using geospatial techniques for urban flood management was well adopted in some urban areas of the world. Some of the models like, WetSpa, HYDROTEL, LISFLOOD, TOPMODEL, SWAT, (Wang et al. 2011; De Smedt et al. 2000; Fortin et al. 2001; De Roo et al. 2000; Quinn et al. 1991; Arnold et al. 1998; De Smedt et al. 2002); Digital Elevation Model (DEM) and hydrological models were increasing popularity as these models include the data of land use and land cover, river discharge, rainfall amount, rainfall frequency, surface roughness, spatial and temporal information, etc. Some have used multispectral RS data for employing GIS-based models like Normalized Difference Vegetation Index (NVDI), DEM (Townsend and Walsh 1998; Konadu and Fosu 2009); while several studies worked on different GIS-based hydrological models (De Roo et al. 2000; De Smedt et al. 2000; Usul and Tarun 2006; Batelaan et al. 2007; Chormanski et al. 2008; Stancalie et al. 2009; Kabir et al. 2011) in a more simplified manner to predict flood. The application of geospatial technology in urban flood management is grouped into a single frame (Fig. 13.2).

13.3.1 Flood Hazard Mapping

The identification of potential urban flood-prone area, risk-prone area and probable threat area is very essential in flood management, and this helps the planner, government, and even Non-Governmental Organizations (NGOs) to concentrate on the priority areas, allocating resources in proper areas. In this regard, the application of geospatial technology have proved powerful in predicting potential flood risk, vulnerability, and hazard (Islam and Sado 2000; Brivio et al. 2002; Hardmeyer and Spencer 2007; Singh and Sharma 2009; Stancalie et al. 2009; Konadu and Foshu 2009; Davor et al. 2016; Farnandez and Lutz 2010; Joy et al. 2019; Patel and Srivastava 2013; Singh and Kanga 2017; Sowmya et al. 2015) as the maps provide simplified information on the flood depth, velocity, direction of flow, inundated area, etc. The season wise (dry and wet) analysis of remote sensing-based satellite data can easily be comparable with the flood inundation models (Samarasinghea et al. 2010) and hydrological models, and helps to validate the accurate information of flood simulation and flood risk mapping in any urban area. The application of recent RS data like Landsat Enhanced Thematic Mapper Plus (ETM +) and ERS (European Space Agency) SAR(Synthetic Aperture Radar) imageries to recognize and categorize the flood depth, flooded zones, and non-flooded areas (Sanyal and Lu 2004; 2005; Solheim et al. 2001) helps to predict floods (Ramlal and Baban 2008; Correia et al. 1999) and build up urban flood resilient strategies.

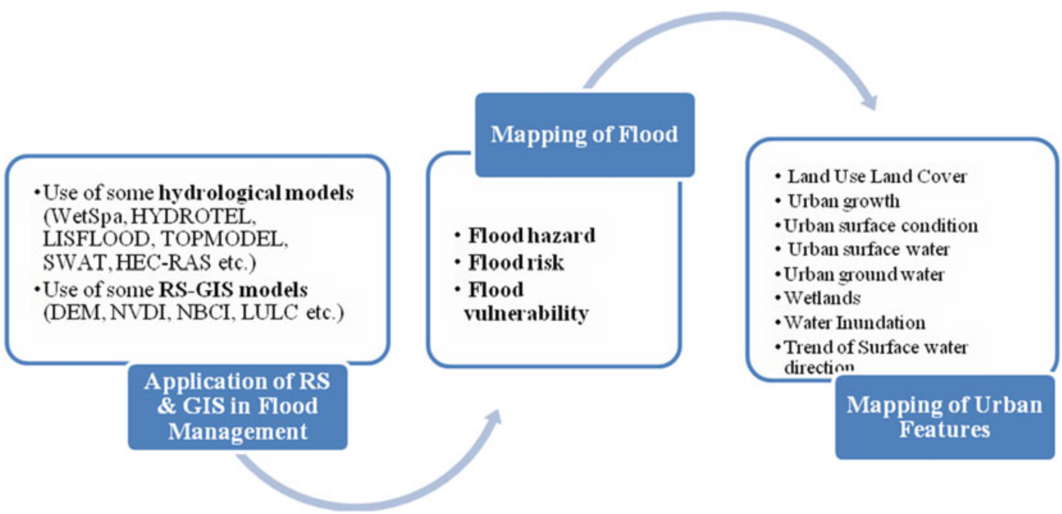

Fig. 13.2 Application of geospatial techniques for flood management

13.3.2 Mapping of Urban Features

As the anthropogenic inputs are very prompt in urban areas and have a larger contribution in occurrence of flood, various factors including urban growth scenarios are needed to consider, and this is the importance of geospatial technology. Urbanization enhances the trend of urban flood and it is anticipated that more than five billion people athwart the globe will inhabit the mega urban areas by the year 2025, which could aggravate the occurrences of urban flood (Masser 2001; Sorensen et al. 2016; Fernandez and Lutz 2010). Therefore, worldwide urban planner, civil engineers, architects, scientist, and environmentalist come forward together for updated and sustainable city planning to reduce the diverse effects of dissimilar hazards like urban flood and other issues. In this context, the geospatial technology easily pointed out the complex network of urban infrastructure, both natural and man-made features using various RS-GIS methods. Similarly, the changes of Land Use Land Cover (LULC) have some serious and valuable non-stop and indirect contributions in the discrepancy and disruption of hydrological cycle and which awkwardly later causes urban flood (Dai et al. 2001; Correia et al. 1999; Betel and Moghanm 2011; Weng 2001; DeVantier and Feldman 1993), and this could be addressed by the application of geospatial technology. Moreover, the spatio-temporal changes of urban expansion can be studied using this technology, which is very effective and necessary to formulate resilient flood management plans. Moreover, it is imperative to note that geospatial technology helps in site selection for waste disposal, location of wetlands, concentration of build up areas and ground water assessment (Dai et al. 2001; Chen et al. 2009; Correia et al. 1999) and facilitate new avenues in building 3D urban mapping models (Esri 2014) for appropriate urban ecosystems environment, urban land use planning, natural hazards identification, etc.

13.3.3 Preparation of Hydrological Models

In most of the urban areas, the developmental works affect the hydrological setting and water system, and the parameters like rainfall amount, duration, frequency, infiltration, surface runoff, water discharge, water stagnation, inundation, water balance, etc. can effectively be incorporated in building hydrological models for urban flood management with the application of geospatial technology. Thus, with employment of advanced, affordable, available RS and GIS software, the planner can fruitfully develop the proficiency to manage, manipulate, analyze, and display spatial information of urban flood (Sample et al. 2001; Mark et al. 2001; Lekuthai and Vongvisessomjai 2001; Meyer et al. 1993; Tsihrintzis et al. 1996; Lee and Heaney 2003; Diaz-Nieto et al. 2008). The employment of such models helps to attenuate urban flood, quick assessment of sinks, and probable areas of urban flooding for building sustainable resilient strategies. In this regard, the open-source RS data, like Google Earth permits to be updated by the users which could be greatly applied in urban planning, land use planning, infrastructural planning, and fed into an integrated urban flood management plan as it depicts the ground-level scenario (Penanowski et al. 2007; Patterson 2007; Schumann et al. 2007; Liu et al. 2005; Smith and Lakshmanan 2006; Sheppard and Cizek, 2009; Whitmeyer 2012; Yu et al. 2008; Chien and Tan 2011; Yu and Gong 2012). Moreover, despite some challenges in the utilization of geospatial technology, many researchers, planners, and government officials are using this sophisticated technology, and thus it gained sombre attention from the users to analyze the

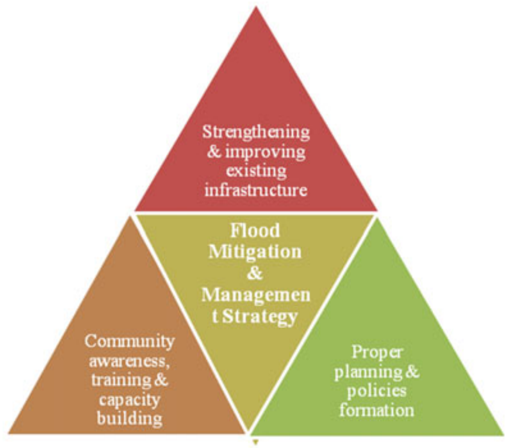

Fig. 13.3 Strategies of urban flood management

miscellaneous and imperative spatial and geo-referenced datasets for the superior urban flood management integrating the local plans, diverse systems, and framework.

13.3.4 Flood Management Strategies

The flood management strategies, especially for the urban area has some solemn methodological consequences and steps to be followed. In this process, strengthening and improving the existing flood management infrastructure, proper planning, policies formation and community awareness, training, capacity building are considered as the pillars (Fig. 13.3).

It is also imperative to collect the historical records, secondary data, and information from various sources and websites about the flood occurrences; and for the minute observation of the flood scenario, primary survey needs to be completed for the statistical analysis of the ground level urban flood scenario of an urban area. The groundwater data have to be acquired from different sources, and groundwater zonation map, identification of the low-lying areas using Digital Elevation Model (DEM), flow direction map of running water, zonation of water inundation level, Land Use Land Cover (LULC) maps, etc. should be analyzed and mapped and finally statistical methods have been applied for hazard and risk zonation map of urban flood. Moreover, the post-incidence part is also important and the employment of geospatial techniques in all phases is becoming powerful for the formation of proper mitigation and to build

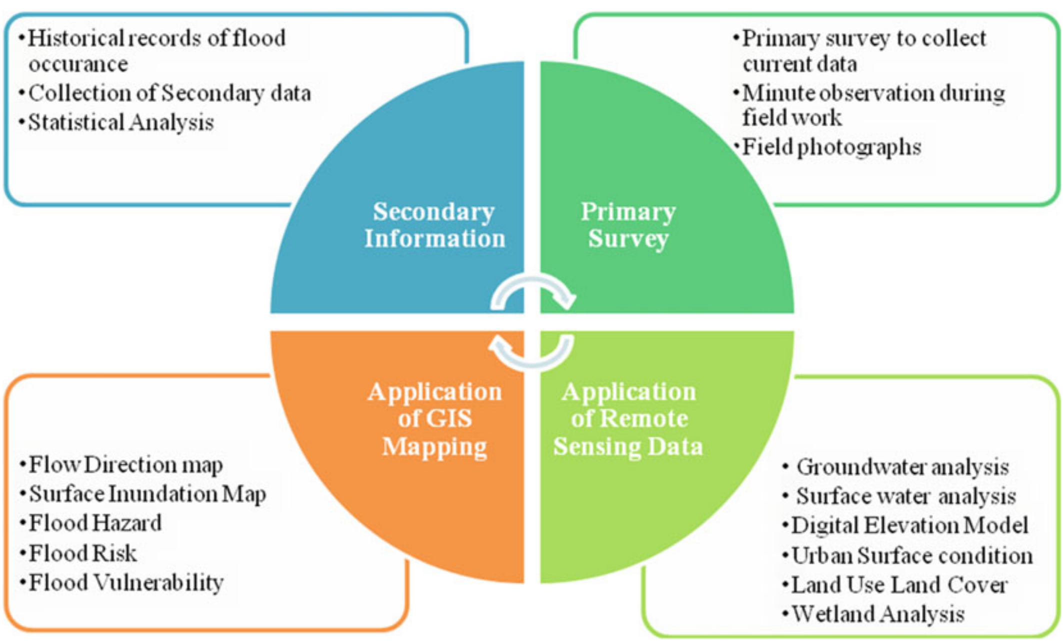

Fig. 13.4 Application of geospatial technology in flood risk assessment for monitoring management

up resilient strategies for superior management. The methodological steps that usually follows in the application of geospatial technology in urban flood risk assessment and monitoring the management is mentioned systematically in the form of a diagram (Fig. 13.4).

A number of recommended measures for the formulation of flood management strategies as recognized in various studies in the context of Indian cities, in combination of the National Disaster Management Guidelines (2010) are grouped into a single window (Fig. 13.5).

13.4 Conclusion

The urban flood occurred primarily due to long-term anthropological reasons and natural situation, still everywhere the anthropological causes are largely highlighted; but the physical settings, climatic conditions, geological, and geomorphological characteristics of the area is also responsible to large extent. The existing review works demonstrate how the urban flood be triggered according to the location, physical setting, and anthropogenic upshots, and all these are

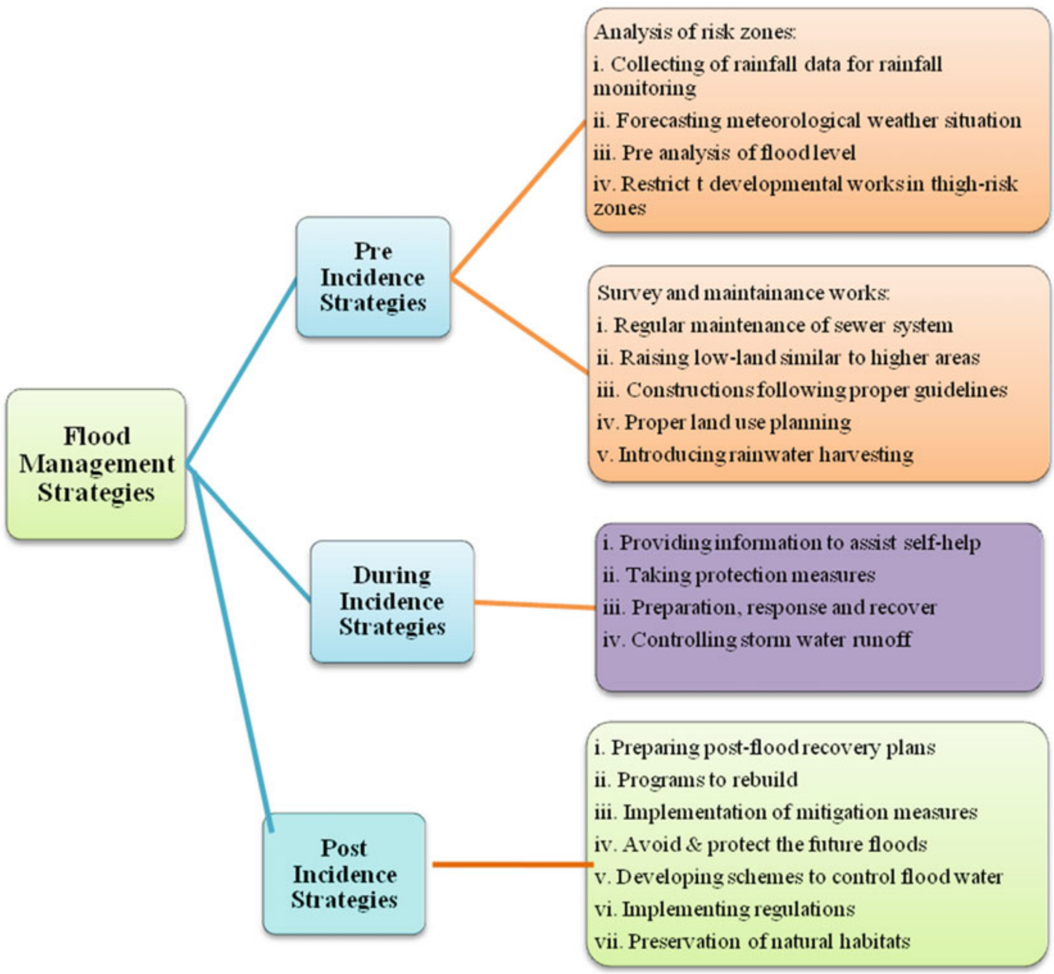

Fig. 13.5 Flood Management Strategies

efficiently explained with the application of geospatial technology. This geospatial technology with the combination of RS and GIS techniques deals with the various aspects of flood issues and holds best to manage the urban flood by prevention, preparedness, and relief management. It also helps to take the appropriate, location-specific flood management strategies, and policies, and if the remedial measures are taken accurately, the effect of such disaster can straight forwardly be reduced and confined into a reduced amount of valuable hazard in near future. Furthermore, this geospatial technology is capable to update and amend the existing flood management system by supplementing or complementing with the combination of various mapping and employment of hydrological (WetSpa, HYDROTEL, LISFLOOD, TOPMODEL, SWAT, HEC-RAS etc.) and RS based models/methods (DEM, NVDI, NBCI, LULC etc.), and thus, this technology has enormous prospect in preparedness in flood proneness, risk assessment, and relief management of every urban spot. Finally, it reveals that the current review effort definitely helps to sketch future research on flood risk analysis and management matters, strategy building, and finding innovative approaches in any urban vicinity employing the geospatial technology.

References

Adelekan OI (2011) Vulnerability assessment of an urban flood in Nigeria: Abeokuta flood 2007. Nat Hazards 56:215–231

Adeoye NO, Ayanlade A, Babatimehin O (2009) Climate change and menace of floods in Nigerian Cities: socio-economic implications. Adv Nat Appl Sci 3(3):369–377

Alaghmand S, Bin Abdullah R, Abustan I, Vosoogh B (2010) GIS-based river flood hazard mapping in urban area (a case study in Kayu Ara River Basin, Malaysia). Int J Eng Technol 2(6):488–500

Alcantara-Ayala I (2002) Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries. Geomorphology 47:107–124

Apel H, Aronica GT, Kreibich H, Thieken A (2009) Flood risk assessments: How detailed do we need to be? Nat. Hazards 49:79–98

Arnold JG, Srinivasan S, Muttaih RS, Williams JR (1998) Large area hydrologic modeling and assessment. Part 1: Model development. J Am Water Res Assoc 34: 73–87

Barbosa AE, Fernandes JN, David LM (2012) Key issues for sustainable urban stormwater management. Water Res 46(20):6787–6798

Barroca B, Bernardara P, Mouchel JM, Hubert G (2006) Indicators for identification of urban flooding vulnerability. Nat Hazards Earth Syst Sci 6:553–561

Batelaan O, Chormanski J, Canters F, Van de Voorde T (2007) Improved distributed runoff modelling of urbanised catchments by integration of multi-resolution remote sensing. Proceeding of the geoscience and remote sensing symposium, IGARSS, IEEE 23–28 July 2007, pp 5021–5024

Belal AA, Moghanm FS (2011) Detecting urban growth using remote sensing and GIS techniques in Al Gharbiya governorate. Egypt Egyptian J Remote Sens Space Sci 14(2):73–79

Brivio PA, Colombo R, Maggi M, Tomas R (2002) Integration of remote sensing data and GIS for accurate mapping of flooded areas. Int J Remote Sens 23:429–441

Chen J, Hill AA, Urbano LD (2009) A GIS-based model for urban flood inundation. Journal ofHydrology 373 (1):184–192

Chien NQ, Tan SK (2011) Google Earth as a tool in 2-D hydrodynamic modeling. Comput Geosci 37(1):38–46

Chormanski J, Van de Voorde T, Deroeck T, Batelaan O, Canters F (2008) Improving distributed runoff prediction in urbanized catchments with remote sensing based estimates of impervious surface cover. Sensors 8:910–932

Clement AR (2013) An application of Geographic Information System in mapping flood risk zones in a north central city in Nigeria. Afr J Environ Sci Technol 7(6):365–371

Correia FN, da Graca Saraiva M, Da Silva FN, Ramos I (1999) Floodplain management in urban developing areas. Part II. GIS-based flood analysis and urban growth modelling. Water Resour Manag 13(1):23–37

Crichton D (2002) UK and global insurance responses to flood hazard. Water Int 27:119–131

Dai FC, Lee CF, Zhang XH (2001) GIS-based geo-environmental evaluation for urban land-use planning: a case study. Eng Geol 61(4):257–271

Dang NM, Babel MS, Luong HT (2010) Evaluation of food risk parameters in the day river flood diversion area, Red River Delta. Vietnam. Nat Hazards 56:169–194. https://doi.org/10.1007/s11069-010-9558-x

Davor KV, Roger AF, Michaela B (2016) Flood Hazard assessment for extreme flood events. Nat Hazards 84:1569–1599. https://doi.org/10.1007/s11069-016-2501-z

De Roo APJ, Wesseling CG, Van Deursen WPA (2000) Physically based river basin modeling within a GIS: the LISFLOOD model. Hydrol Process 14:1981–1992

De Smedt F, Liu YB, Gebremeskel S (2000) Hydrologic Modeling on a catchment scale using gis and remote sensed land use information. In: Brebbia CA (ed) Risk Analysis II. WTI Press, Southampton, Boston, pp 295–304

De Smedt F, Liu YB, Qiao Y (2002) Prediction of floods with the WetSpa model. Ann Warsaw Agric. Univ SGGW Land Reclam 33:71–80

De US, Rao PGS (2004) Urban climate trends—the Indian scenario. J Indian Geophys Union 8(3):199–203

De US, Dube RK, Prakasa RGS (2005) Extreme weather events over India in the last 100 years. J Indian Geophys Union 9(3):173–188

DeVantier BA, Feldman AD (1993) Review of GIS applications in hydrologic modeling. J Water Resour Plann Manag 119(2):246–261

Diaz-Nieto J, Blanksby J, Lerner DN, Saul AJ (2008) A GIS approach to explore urban flood risk management. In: Proceedings of the 11th international conference on urban drainage, Edinburgh, UK (Vol 31)

EM-DAT (Emergency Events Database) (2006) Disaster profile for floods. International Disaster Database, Retrieved from: http://www.em-dat.net/disasters/profiles.php. Retrieved February 16, 2021

ESRI (2014) 3D urban mapping: from pretty pictures to 3D GIS,An Esri® White Paper. [online] New York, USA: esri. Available at: https://www.esri.com/library/whitepapers/pdfs/3d-urban-mapping.pdf. Retrieved May 7, 2021

Fernández DS, Lutz MA (2010) Urban flood hazard zoning in Tucumán Province, Argentina, using GIS and multicriteria decision analysis. Eng Geol 111 (1):90–98

Few R (2003) Flooding, vulnerability and coping strategies: local responses to a global threat. Progr Dev Stud 3(1):43–58

Gharagozlou A, Nazari H, Seddighi M (2011) Spatial analysis for flood control by using environmental modeling. J Geogr Inf Syst 3(4):367

Ghosh S, Luniya V, Gupta A (2009) Trend analysis of Indian summer monsoon rainfall at different spatial scales. Atmos Sci Lett 10(4):285–290

Goswami BN, Venugopal V, Sengupta D (2006) Increasing trend of extreme rain events over India in a warming environment. Science 314:1442. https://doi.org/10.1126/science.1132027

Guhathakurta P, Sreejith OP, Menon PA (2011) Impact of climate change on extreme rainfall events and flood risk in India. J Earth Syst Sci 120(3):359–373

Hardmeyer K, Spencer MA (2007) Using risk-based analysis and geographic information systems to assess flooding problems in an urban watershed in rhode island. Environ Manag 39:563–574

Hewitt K, Burton I (1971) The hazardousness of a place: a regional geology of damaging events. Department of Geography Research Publication, University of Toronto, Toronto

Heywood I, Oliver J, Tomlinson S (1993) Building an exploratory multi-criteria modeling environment for spatial decision support. Int J Geogr Inform Sci. http://libraries.maine.edu/Spatial/gisweb/spatdb/egis/eg94072.html

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

IFRC (2010) World Disaster Report 2010: Focus on urban risk. International federation of red cross & red crescent societies, Retrieved February 16, 2021, from: https://www.ifrc.org/Global/Publications/disasters/WDR/WDR2010-full.pdf

ISDR (International Strategy for Disaster Reduction) (2004) A global review of disaster reduction initiatives. Retrieved February 16, 2021, from: http://www.unisdr.org/eng/about_isdr/bd-lwr-2004-eng.htm

Islam MM, Sado K (2000) Satellite remote sensing data analysis for flood damaged zoning with GIS for flood management. Ann J Hydraul Eng JSCE 44. Retrieved February 16, 2021, from: http://www.un-spider.org/content/4461/satellite-remote-sensing-data-analysis-flood-damaged-zoning-gis-flood-management

Izinyon O, Ehiorobo J (2011) Measurements and documentation for flood and erosion monitoring and control in the Niger Delta states of Nigeria. TS07E. Engineering Survey, Marrakech, Morocco, Retrieved February 16, 2021, from: https://www.fig.net/resources/proceedings/fig_proceedings/fig2011/papers/ts07e/ts07e_ ehiorobo_izinyon_5126.pdf

Jha A, Lamond J, Bloch R, Bhattacharya N, Lopez A, Papachristodoulou N, Bird A, Proverbs D, Davies J, Barker R (2011) Five feet high and rising: cities and flooding in the 21st century, policy research working paper 5648, The World Bank, East Asia and Pacific Region, Transport, Energy and Urban Sustainable Development Unit

Joy J, Kanga S, Singh SK (2019) Kerala flood 2018: flood mapping by participatory GIS approach. Meloor Panchayat Int J Emer Technol 10(1):197–205

Kabir A, Mahdavi M, Bahremand A, Noora N (2011) Application of a geographical information system (GIS) based hydrological model for flow prediction in Gorganrood river basin. Iran. Afr J Agric Res 6:35–45

Karim MF, Minura N, Nobuoka H (2005) Management of storm surge flood risk in the coastal region of Bangladesh. In: Proceedings of the 1st international conference on coastal zone management and engineering in the Middle East.

Khole M, De US (2001) Socio-economic impacts of natural disasters. WMO Bull 50:35–40

Konadu DD, Fosu C (2009) Digital elevation models and gis for watershed modelling and flood prediction—a case study of Accra Ghana. Appropriate technologies for environmental protection in the developing world, pp 325–332. Retrieved February 16, 2021, from: books.google.com/ books?isbn=1402091397

Kron W (2005) Flood Risk = Hazard · Values · Vulnerability. Water Int 30(1):58–68

Lee JG, Heaney JP (2003) Estimation of urban imperviousness and its impacts on storm water systems. J Water Resour Plan Manag 129(5):419–426

Lekuthai A, Vongvisessomjai S (2001) Intangible flood damage quantification. Water Resour Manag 15 (5):343–362

Liu C, Li Y (2017) GIS-based dynamic modelling and analysis of flash floods considering land-use planning. Int J Geogr Inf Sci 31(3):481–498

Liu YB, De Smedt F, Hoffmann L, Pfister L (2005) Assessing land use impacts on flood processes in complex terrain by using GIS and modelling approach. J Environ Model Assess 9(4):227–235

Lowry JH, Miller HJ, Hepner G (1995) A GIS-based sensitivity analysis of community vulnerability to hazardous contaminants on the Mexico/US Border. Photogrammic Eng Remote Sens 61(11):1347–1359

Mark O, Apirumanekul C, Kamal MM, Praydal G (2001) Modelling of urban flooding in Dhaka City. In: Urban drainage modeling, 333–343

Mark O, Weesakul S, Apirumanekul C, Aroonnet SB, Djordjević S (2004) Potential and limitations of 1D modelling of urban flooding. J Hydrol 299(3):284–299

Masser I (2001) Managing our urban future: the role of remote sensing and geographic information systems. Habitat Int 25(4):503–512

Mathew S, Truck S, Henderson-Sellers A (2012) Kochi, India case study of climate adaptation to floods. Glob Environ Change 22:308–319

Messner F, Meyer V (2006) Flood damage, vulnerability and risk perception-challenges for flood damage research. In: Schanze J, Zeman E, Marsalek J (Eds), Flood risk management-hazards, Vulnerability, Mitigation Measures. NATO Special Series, Springer, Berlin, Heidelberg, New York, pp 149–167

Meyer SP, Salem TH, Labadie JW (1993) Geographic information systems in urban storm-water management. J Water Resour Plan Manag 119(2):206–228

Mohit MA, Akther S (1998) delineation of flood damaged zones of Dhaka city based on the 1998 flood by using GIS. In: Ali MA, Seraj SM, Ahmad S (Eds), ISBN: 984–823–002–5

Patel DP, Srivastava PK (2013) Flood hazards mitigation analysis using remote sensing and GIS: Correspondence with town planning scheme. Water Resour Manag 27:2353–2368

Patterson TC (2007) Google Earth as a (not just) geography education tool. J Geogr 106(4):145–152

Pelling M (2003) The vulnerability of cities: natural disasters and social resilience. Earthscan Publications, London

Pezanowski S, Tomaszewski B, d MacEachren AM (2007) An open geospatial standards-enabled google earth application to support crisis management. Geomatics Solutions for DisasterManagement. Springer, Berlin Heidelberg, pp 225–238

Quinn P, Beven K, Chevallier P, Planchon O (1991) The prediction of hillslope flow paths for distributed hydrological modeling using digital terrain models. Hydrol Process 5:59–79

Ramlal B, Baban SM (2008) Developing a GIS based integrated approach to flood management in Trinidad, West Indies. J Environ Manage 88(4):1131–1140

Rao GSP, Jaswal AK, Kumar MS (2004) Effects of urbanization on meteorological parameters. Mausam 55:429–440

Roy L, Leconte R, Brissette F, Marche C (2001) The impact of climate change on seasonal floods of a southern Quebec River basin. Hydrol Processes 15:3167–3179

Roy AH, Wenger SJ, Fletcher TD, Walsh CJ, Ladson AR, Shuster WD, Thurston HW, Brown RR (2008) Impediments and solutions to sustainable, watershed-scale urban stormwater management: lessons from Australia and the United States. Environ Manage 42 (2):344–359

Samarasinghea SMJS, Nandalalb HK, Weliwitiyac DP, Fowzed JSM, Hazarikad MK, Samarakoond L (2010) Application of remote sensing and GIS for flood risk analysis: a case study at Kalu-Ganga River, Sri Lanka. Int Arch Photogr Remote Sens Spatial Inform Sci 38 (8), Kyoto Japan

Sample DJ, Heaney JP, Wright LT, Koustas R (2001) Geographic information systems, decision support systems, and urban storm-water management. J Water Resour Plann Manag 127(3):155–161

Sanyal J, Lu XX (2004) Application of remote sensing in flood management with special reference to Monsoon Asia: a review. Nat Hazards 33:283–301

Sanyal J, Lu XX (2005) Remote sensing and GIS-based flood vulnerability assessment of human settlements: A case study of Gangetic West Bengal, India. Hydrol Process 19:3699–3716

Schumann G, Hostache R, Puech C, Hoffmann L, Matgen P, Pappenberger F, Pfister L (2007) High-resolution 3-D flood information from radar imagery for flood hazard management. IEEE T Geosci Remote Sens 45(6)

Sheppard SR, Cizek P (2009) The ethics of Google Earth: crossing thresholds from spatial data to landscape visualisation. J Environ Manage 90(6):2102–2117

Singh AK, Sharma AK (2009) GIS and a remote sensing based approach for urban flood-plain mapping for the Tapi catchment, India. Hydroinformatics in hydrology, hydrogeology and water resources. Proceeding of the symposium of JS.4 at the Joint IAHS and IAH Convention, Hyderabad, India

Singh SK, Kanga S (2017) Mapping of salt affected and waterlogged areas using geospatial technique. Int J Recent Innov Trends Comput Commun 5(5):1298–1305

Sinha Ray KC, Mukhopadhyay RK, De US (1999) Meteorological disasters during last twenty two years. Natural disasters some issues and concerns. Natural disaster management cell. VisvaBharati, Santiniketan, 10–23

Smith K (2001) Environmental hazards: assessing risk and reducing hazards. Third Edition. Routledge (Taylor & Francis Group), New York, USA

Smith TM, Lakshmanan V (2006) Utilizing google earth as a GIS platform for weather applications. In: 22nd international conference on interactive information processing systems for meteorology, oceanography, and hydrology

Solheim I, Solbo S, Indregard M, Lauknes I (2001) User requirements and SAR-solutions for flood mapping. In: 4th international symposium on retrieval of bio- and geophysical parameters from SAR data for land applications, Innsbruck, Austria

Sorensen J, Persson A, Sternudd C, Aspegren H, Nilsson J, Nordström J, Jönsson K, Mottaghi M, Becker P, Pilesjö P, Larsson R (2016) Re-thinking urban flood management—time for a regime shift. Water 8(8):332

Sowmya K, John CM, Shrivasthava NK (2015) Urban flood vulnerability zoning of Cochin City, southwest coast of India, using remote sensing and GIS. Nat Hazards 75:1271–1286

Stancalie GH, Craciunescu V, Irimescu A (2009) Spatial data integration for emergency services of flood management. In: Jones JAA et al (Eds), threats to global water security, pp 155–165

Townsend PA, Walsh SJ (1998) Modeling floodplain inundation using an integrated GIS with radar and optical remote sensing. Geomorphology 21:295–312

Tsihrintzis VA, Hamid R, Fuentes HR (1996) Use of geographic information systems (GIS) in water resources: a review. Water Resour Manage 10(4):251–277

Usul N, Turan B (2006) Flood forecasting and analysis within the Ulus Basin, Turkey, using geographic information systems. Nat Hazards 39:213–229

Wang Y, Li Z, Tang Z, Zeng G (2011) A GIS-based spatial multi-criteria approach for flood risk assessment in the Dongting Lake Region, Hunan. Central China. Water Resour Manag 25:3465–3484

Weichselgartner J (2001) Disaster mitigation: The concept of vulnerability revisited. Disaster Prevent. Manag. 10:85–94

Weng Q (2001) Modeling urban growth effects on surface runoff with the integration of remote sensing and GIS. Environ Manage 28(6):737–748

Whitmeyer SJ (2012) Google Earth and virtual visualizations in geoscience education and research (ed. vol 492). Geological Society of America

WHO (2010) World Disasters Report. Chapter 2 and 6: Focus on Urban Risk. Retrieved from: http://www.ifrc.org/Docs/pubs/disasters/wdr2010/WDR2010-English-2.pdf. Retrieved May 7, 2021.

Yi CS, Lee JH, Shim MP (2010) GIS-based distributed technique for assessing economic loss from flood damage: Pre -feasibility study for the Anyang Stream Basin in Korea. Nat Hazards 55:251–272

Yu L, Gong P (2012) Google Earth as a virtual globe tool for Earth science applications at the global scale: progress and perspectives. Int J Remote Sens 33 (12):3966–3986