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A REVIEW OF ADVANCES IN RIVER BASIN FLOOD EARLY WARNING SYSTEM THROUGH MORPHOMETRY ANALYSIS

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Abstract

The following review paper explores and details the concepts of flash floods, working of a flash flood warning system, the concept of morphometry and the integration of morphometric analysis into the flash flood warning system by assessing the correlation between morphometric parameters and studies conducted on areas affected by flash floods.

Introduction

Flash floods are defined by the American Meteorological Society as "A flood that rises and falls quite rapidly with little or no advance warning, usually as the result of intense rainfall over a relatively small area". Early warning systems are crucial to saving lives. Flash flood early warning systems can be particularly effective at reducing fatalities, notably due to the effectiveness and low cost of evacuating for a flash flood.[1] The distinguishing characteristic of a flash flood is its short-lived nature. Traditionally, any flood that occurs at a certain location within a few hours after the causative event (e.g., rainfall, dam break) is classified as a flash flood for that location.[2] Flash floods are typically caused by torrential rainfall and efficient runoff production because of a variety of hydrologic characteristics (such as antecedent soil moisture conditions, soil type and depth, terrain slope, land use and vegetation), which leads to short time lags between the rainfall occurrence and peak discharge.[3] Flash-flood warning systems face a very challenging task for providing timely and effective warnings for improved community preparedness about flood risk.[4]

Flooding is one of the major disasters occurring in various parts of the world. Every year, they cause loss of lives and damage to infrastructure, agriculture and severely affect economic development. The 2010 Pakistan floods began in late July 2010, because of heavy monsoon rains. The floods directly affected about 20 million people, mostly via destruction of property, livelihood, and infrastructure. About 2,000 people died and the total economic impact was $US40 billion.[5] Hence, there is a need for effective modelling to understand the problems and minimize the severity of the disastrous effect of flash foods.[6] The magnitude and severity of a flash flood is determined by a number of natural and human influenced factors including: rainfall duration and intensity, antecedent soil moisture conditions, land cover and soil type, watershed characteristics, and land use. Implementation of flood warning systems and community self-help programs is one of the most effective ways to mitigate the flash-flood risk. In many instances, these are the only affordable and sustainable mitigation approaches.[4]

Basin morphometric parameters play an important role in hydrological processes, as they largely control a catchment's hydrologic response. Their analysis becomes even more significant when studying runoff reaction to intense rainfall, especially in the case of ungauged, flash flood prone basins.[7] Drainage characteristics of hydrographic basins and sub-basins in many areas of the world have been studied using conventional geomorphologic approaches (HORTON 1945, STRAHLER 1964, RUDRIAIAH, M. et. al. 2008; NAGESWARARAO, K. et. al. 2010 and A L SAUD 2009). GARDINER (1990) indicated that in some studies, the morphometric characteristics of basins have been used to predict and describe flood peaks and estimation of erosion rate, underling the importance of such studies. [8]

Why is a flash flood warning system required?

Flash flood early warning systems can be particularly effective at reducing fatalities, notably due to the effectiveness and low cost of evacuating for a flash flood. Fast responding catchments are most prone to flash floods[10]. Although flash foods are not new phenomena to the district, recently problems related to flooding have been greatly increased. Human interference into the catchments in the form of settlement construction, deforestation and mining has aggravated the problems and encroaching of settlement into the flood plain further increases the severity of the flash flood hazard. However, the devastating nature of the hazard can be reduced by adopting management strategies (Bisht et al. 2018). Hence, there is a need for effective modelling to understand the problems and minimize the severity of the disastrous effect of flash foods (Youssef et al. 2011). The magnitude and severity of a flash flood is determined by a number of natural and human influenced factors including rainfall duration and intensity, antecedent soil moisture conditions, land cover and soil type, watershed characteristics, and land use. While land use impacts, particularly urban development, can increase the severity of a flash flooding event (Leopold, 1968), Martinez-Mena et al. (1998) and Castillo et al. (2003) suggested that rainfall intensity and antecedent soil moisture, respectively, play the most important roles. The complex and intertwined properties of these determining factors allude to flash flood forecasting and warning systems.[11]

Working of a flash flood system

The system uses rainfall intensity data from terrestrial microwave communication links and the geostationary Meteosat Second Generation satellite, i.e., two systems that are already in place and operational. Flash flood early warnings are based on a combination of the Flash Flood Guidance method and a hydrological model. The system will be maintained and operated through a public-private partnership, which includes a mobile telephone operator, a national meteorological service, and an emergency relief service. The mobile telephone operator acts as both the supplier of raw input data and the disseminator of early warnings. The early warning system could significantly reduce the number of fatalities due to flash floods, improve the efficiency of disaster risk reduction efforts and play an important role in strengthening the resilience to climate change of developing countries.[10]

Flood Sensing Methods [12]

1) Ultrasonic Sensor

2) Water Level Indicator

3) Camera

4) Optical Remote Sensing

5) Lagrangian Sensor

6) Radar Systems in Flood Monitoring

Steps to follow for morphometric analysis of flash flood risk assessment [13]

1) Delineation of drainage network and watershed boundary from DEM and subsequent calculation of different morphometric parameters. According to morphometric attributes and their contribution to the possible risk of a flash flood, the morphometric parameters can be classified into two groups. Group 1 includes all the parameters; Group 2 comprises only two parameters which are indirectly proportional to the degree of flash flood.

2) Determination of maximum (Xmax) and minimum (Xmin) value of each parameter of each watershed.

3) This provides the standardized factors that reflect the degree of risk for each morphometric parameter compared with the same parameter in the other sub-basins.

4) The ranking score of the parameters of each basin is summed up and grouped into three classes, i.e., low flooding susceptibility (27–35), moderate flooding susceptibility (36–44), and high flooding susceptibility (45+).

5) Flash flood susceptibility map of river watershed is then prepared.

Flash flood modelling methods [14]

There are many methods of flash flood susceptibility mapping; traditional bases hydrological methods, statistical, and machine learning based methods. Rule-based and automated modelling methods have outperformed outdated traditional flood models due to their more suitable for hazard analyses. In recent times, researchers have coupled many methods with GIS to increase the accuracy prediction of flooded areas (flood susceptibility). These methods are including qualitative method such as analytical hierarchy process (AHP), quantitative techniques such as weight of evidence (WoE) and frequency ratio (FR), and machine learning method such as artificial neural networks (ANN). However, there are still lack of studies have been carried out for flash flood susceptibility modelling.

Morphometry

River morphology and stream morphology are terms used to describe the geometries of river channels and how they evolve over time.

The composition and erodibility of the bed and banks (e.g., sand, clay, bedrock) influence the morphology of a river channel. Erosion is caused by the power and consistency of the stream and can affect the evolution of the river's path. Additionally, vegetation and the rate of plant growth; sediment availability; the size and composition of the sediment moving through the channel; the rate of sediment transport through the channel and the rate of deposition on the floodplain, banks, bars, and bed; and regional aggravation or degradation due to subsidence or uplift.

Morphometry is the measurement and mathematical analysis of the configuration of the earth’s surface and of the shape and dimension of its landforms. The form and structure of drainage basins and their associated drainage networks are described by their morphometric parameters. Morphometric properties of a drainage basin are quantitative attributes of the landscape that are derived from the terrain or elevation surface and drainage network within a drainage basin. [15]

Many researchers have looked at drainage basin morphometric properties as markers of structural effect on drainage development and geomorphologic activity. Several studies have employed morphometric analysis to analyse the basins' groundwater potentiality and to determine acceptable places for check dams and artificial recharge projects.

The unpredictable nature of seasonal rain in India's Monsoons can encourage diverse river flow behaviour, altering channel or basin characteristics and resulting in floods, changes in drainage patterns, and sediment deposition.

River basins are the primary source of irrigation in a flood-prone country like ours, where land is mostly used for agriculture, so studies on river behaviour are extremely important.

In India, early studies on river morphology were mostly conducted by hydraulic engineers who attempted to understand river characteristics in terms of flow pattern.

Even though recent investigations continue to seek to understand river morphology in terms of the unpredictability of river systems, the emphasis has shifted in recent years to process-based research in river morphology. This reflects a shift away from studies of basin morphometry and drainage networks and toward studies of the processes at work in terms of the unique characteristics of monsoon-influenced river systems in India (Kale, 2002). River morphology research in the modern era employs a wide range of technological tools, including field instruments and the use of satellite technology via remote sensing.

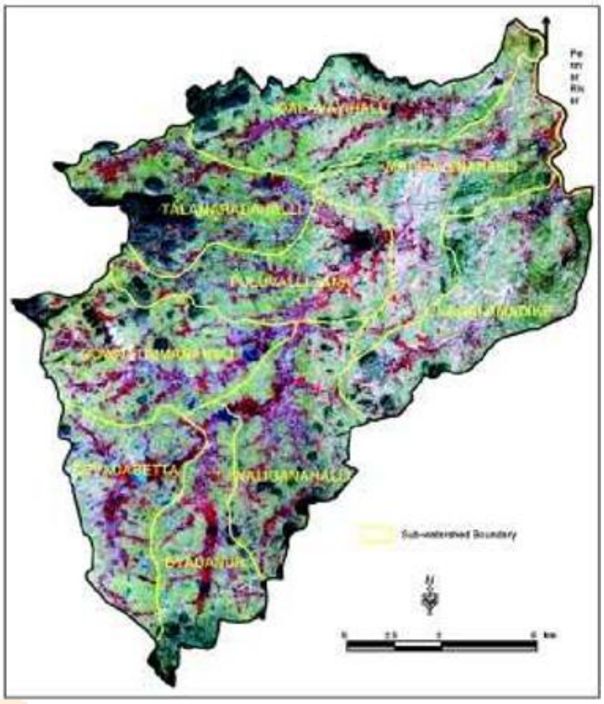
River morphology studies first try to identify the order of streams and river reaches, or stretches, that run the length of the rivers. In this case, the demarcation of cross-section lines in river basins is critical for identifying flow areas. The second step is data collection, which can be accomplished through field surveys or through data collected using remote sensing. Both methods may necessitate the use of highly sophisticated technology. Remote sensing can provide a wealth of data on both temporal and spatial scales. The results of both methods can be used to validate and calibrate mathematical and/or hydraulic models. On the basis of this analysis, qualitative or quantitative studies can be conducted to better understand river behaviour. The qualitative aspects of river morphology studies include structure analysis, the stage of landform development in terms of drainage pattern, and process-based studies in terms of stage of landform development and its relationships to river discharges.

Technological methods

The data collected from analyzing satellite data using IRS 1A LISS-I and IRS-P6 LISS-III satellite images related not only to data on river channel configuration but also to significant other findings in terms of river morphology in the Brahmaputra. The RS-GIS-based assessment, for example, was able to identify changes in river morphology in the Brahmaputra, such as changes in the main channel and stable or unstable reaches in the riverbanks. The assessment was able to provide up-to-date information in terms of both precise temporal and large spatial scales, which can be used to replace time-consuming field measurements.

In a study conducted in the Pavagada area of Tumkur district for the morphology using GIS technology.

The maps showing drainage details have been prepared from digital data of IRS 1 C and 1 D of both LISS III and PAN (PAN data of March 15 and 18, March 2001 and LISS III data of March 18, 2001). These satellite images have been geo-referenced and merged using Image Processing software ERDAS IMAGINE (V 8.5) and the thus merged data (Fig. 2) were used in the study. In the present study, the maps showing drainage details have been prepared from digital data of IRS 1 C and 1 D of both LISS III and PAN (PAN data of March 15 and 18, March 2001 and LISS III data of March 18, 2001). These satellite images have been geo-referenced and merged using Image Processing software ERDAS IMAGINE (V 8.5) and the thus merged data (Fig. 2) were used in the study. [16]



Overlay of sub-watersheds on satellite image of study area

Morphometric analysis method

The Indian Remote Sensing (IRS)-ID Satellite Linear Image Self Scanning (LISS)-III sensor data is collected and registered to Survey Of India (SOI) topographical sheets at 1:50,000 scale in the Engineering Analysis and Scientific Interface/ Picture Analysis, Correction and Enhancement (EASI/ PACE) image analysis system ver. 7.0 (PCI, 2000). Delineation based on the water divide line concept is to be performed. The drainage network of the basin is traced on transparency and digitized as available on toposheets (1:50,000 scale) and some of the first order streams are updated with the help of satellite sensor data. The basin is divided into sub basins and morphometric analysis is carried out at sub basin level in the Spatial Analysis System (SPANS) GIS system. Based on the drainage order, the drainage channels are classified into different orders (Strahler, 1964). In GIS, drainage channel segments are ordered numerically as order number 1 from a stream's headwaters to a point downstream. The stream segment that results from the joining of two first order streams is assigned order 2. Two second order streams formed a third order stream and so on. [17]

The measurement of various morphometric parameters namely – stream order, stream length (Lu), mean stream length (Lsm), stream length ratio (RL), bifurcation ratio (Rb) mean bifurcation ratio (Rbm), relief ratio (Rh) drainage density (D), stream frequency (Fs) drainage fexture (Rt), form factor (Rf), circulatory ratio (Rc), elongation ratio (Re) length of overland flow (Lg) is carried out and the data are to be presented. [18]

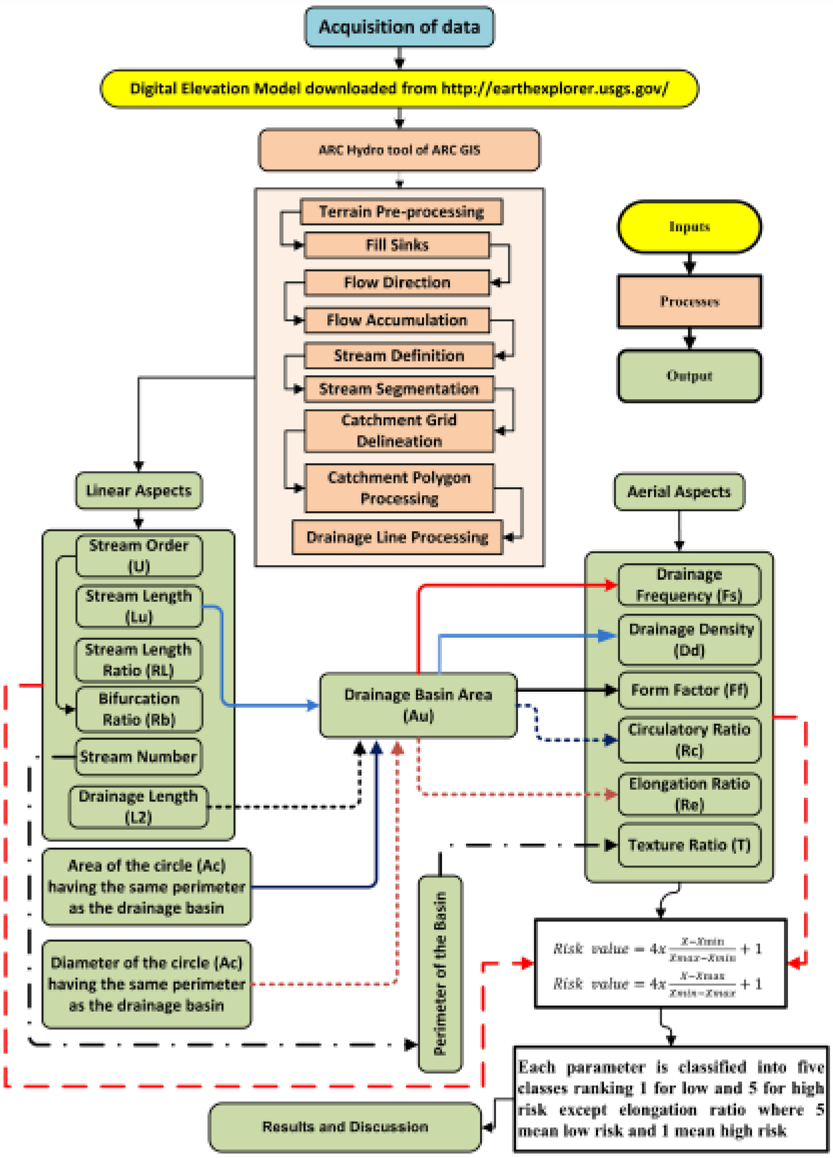
The evaluated morphometric parameters are grouped as linear, relief and areal parameters. Subsequently detailed landform analysis is carried out based on their genesis, relief and their morphometric characteristics. The soil depth, drainage, texture and AWC maps of the study area are generated based on the delineated geomorphic units from satellite sensor data and available soil survey information. The eroded lands of the basin are delineated and characterized based on the characteristics of satellite imagery in conjunction with landforms, drainage morphometry, broad soil physical characteristics, vegetation cover and ground data. Using the 'Area Cross Tabulation' option in GIS, the area and per cent area are calculated for considered themes at sub basin level to analyse the relationships between the basin morphometry on the one hand and slope, landforms, soil depth, soil drainage, soil AWC and degraded lands characteristics on the other. The derived results are to be checked in the field at selected random sample sites. [17]

Morphometric Analysis method for parabolic regions (hills and valleys). [19]

Geospatial analyst tool in ArcGIS software is used for morphometric analysis of parabolic regions. Detailed methodology is conducted using the following steps-

- GIS database creation—GIS database of different thematic layers was created through onscreen digitisation of satellite images.
- 2D/3D analysis of dunes—Digital elevation model (DEM) of Cartosat-1 stereo pair is used for multiple tasks like generation of orthoimage, generating slope map of the area, generation of contour line and to find out the elevation of an area.
- Retrieving the area of sand dunes—Area of the parabolic region is represented by the area of the land surface formed by sand accumulation.
- Estimation of the volume of sand accumulation—It is estimated by delineating the outer boundary of the parabolic region, extraction of DEM of every sand dune by using the tool (extract by mask) of ArcGIS and 3D analysis tool.
- Morphometric data analysis
- Wind speed data analysis—Monthly wind speed data in km grid, are downloaded and interpolated.

- Estimation of sand migration—it is done by using temporal data sets from SRTM DEM.

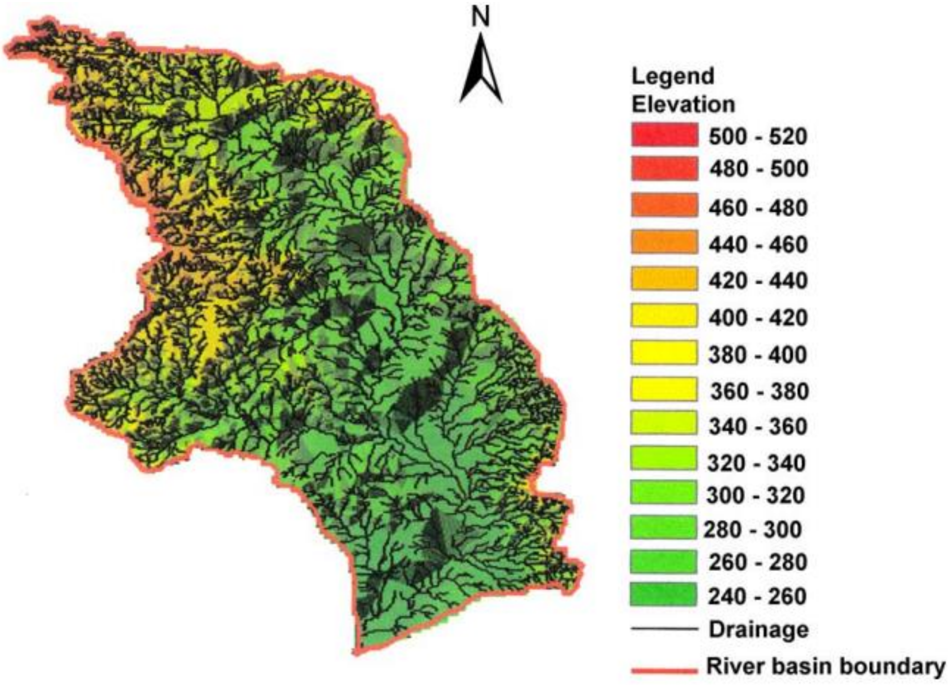


Flowchart of the morphometry guided flood warning system

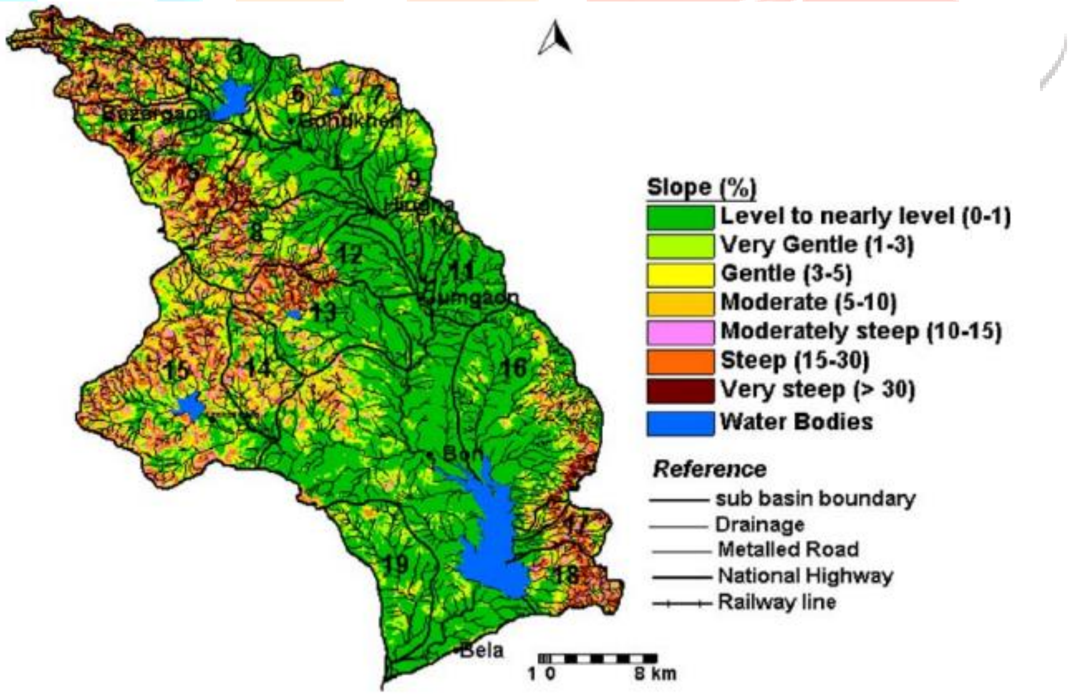
Results [17]

The following results are to be found:

1) Elevation



2) Slope



As found, there are mainly 7 types of observable slopes-

- Level to nearly level slope
- Very gentle slope
- Gentle slope
- Moderate slope
- Moderately steep slope
- Steep slope
- Very steep slope

3) Geological features of the land

4) Evaluation of morphometric parameters is then conducted, such as

- Linear parameters
- Relief parameters
- Areal parameters

Conclusion

The findings from the above studies gives an indication about how the topographical features of a land area, specifically expressed through morphometric parameters, allows one to assess the susceptibility of an area to the phenomenon of flash flood, through correlation between studies conducted on areas affected by flash floods and morphometry practices.

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