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EDITORIAL

Challenges in predicting floods

Flood is said to have occurred when a piece of land that is usually dry is submerged under water. It is the foremost cause of natural disaster-related fatalities. Delving into the past would unveil evidences of devastating great flood disasters. In the recent years, there is a surprising increase in the frequency and severity of floods in different parts of the world, which affected lives, properties, social and mental health of millions of people. This trend is speculated to further intensify in the coming years. Currently, there is a debate in the scientific community on attribution of the same to human-induced climate and/or land-use/land-cover (LULC) changes, and efforts are on to develop robust procedures for accurate flood prediction.

Often, the words forecast, prediction and projection are used interchangeably due to confusion. In the context of floods, prediction is a probabilistic statement that there is a certain chance (probability) for flood of specified magnitude or severity to happen at the target location over a longer time (e.g. next 100 years) in future. Projection of flood is a similar statement, but conditional on development of a scenario such as climate or LULC change. On the other hand, forecast is a much more specific statement about when (i.e. date(s) or time) and with what magnitude the flood would occur at the target location or area in the near future. Currently, many flood forecasting centres are issuing probabilistic forecasts for floods. However, the uncertainties involved in forecasting are much less when compared to those in prediction and projection. Prediction of floods is essential in studies related to risk evaluation of existing water control (e.g. dams, barrages, levees) and conveyance structures (e.g. culverts, storm sewers, spillways) in river basins, and for planning and design/retrofitting of such structures for flood mitigation, assessment and zoning of flood prone areas for land-use planning and management, and flood insurance assessment. Flood zoning is recommended, but has not been done in several flood-prone states of India.

Prediction of floods requires insight into nuances of the types of flood encountered. Floods could be classified as riverine/fluvial, urban/pluvial, coastal and groundwater floods based on the underlying processes which trigger them. Riverine floods could be triggered by (i) extreme high intensity rainfall (possibly due to cloud burst), which could sometimes occur in combination with high baseflow (groundwater flow) and/or snowmelt, (ii) reduction in flow carrying capacity of rivers and storage capacity of water detention facilities (e.g. lakes, reservoirs) due to their siltation and/or encroachment; (iii) breaches to flood defence infrastructure (e.g. dams, levees, flood walls), (iv) outburst of nonglacial/glacial lakes, or of temporary landslide lakes which are formed when river flows are blocked by major landslides following earthquakes or extreme rainfall, (v) alteration of terrain and reduced infiltration due to deforestation or hydrophobic nature of catchment's soil following wildfires, and (vi) blockage of river flow in colder parts of the world when chunks of ice clump together to form ice jam causing upstream inundation, or sudden release of river water downstream when the ice jam breaches. Urban floods occur when capacity or condition of storm water drain network is inadequate to drain away the excess rain water. The flooding may get exacerbated when urban floods occur in combination with riverine and/or coastal floods. Coastal flooding could be in the form of tsunami due to earthquakes in ocean, or in the form of high tides in combination with strong winds (e.g. during cyclones), and it affects areas adjoining sea coast, ocean, or any other large open water body. Groundwater flooding occurs due to rise in groundwater table above the ground surface. This could be triggered when underlying hydro-geologic formation cannot quickly drain away rain water, or when underground structures (e.g. metro rail tunnel) create barriers to groundwater flow.

Challenges in developing an effective model for flood prediction include identification of explanatory variables (predictors) influencing the flood (predictand), and procurement of past observations on the predictand and predictors. Rainfall is an important predictor for urban/riverine flood prediction and its spatial-temporal data are necessary for the entire catchment which contributes flow to the target location. A catchment size could typically vary from few hundreds to lakhs of square kilometers. It is a challenge to procure data at the required spatial resolution, as (i) many areas have sparse density of gauges possibly due to lack of accessibility in setting-up gauges owing to nature of the terrain and/or economic constraints in establishing adequate number of gauges, and (ii) there are limitations in gauging procedures considered for data procurement. Even for many gauged locations, records are short/limited and unavailable at required finer (sub-daily/hourly) temporal resolution, or they have many discontinuities possibly due to occasional gauge-related defects. More recently, modern technology (e.g. radar, drones, remote sensing) is proving effective in gathering the essential information over areas which are either sparsely gauged or have complex terrain. However, this has just begun gaining momentum in India.

Another important issue is that flows unaffected by human interventions (e.g. diversions, impoundments) are supposed to be considered in riverine flood prediction studies, but such data are usually unavailable. Impacts of human interventions could be removed from flow records to derive uncontrolled flows, but the additional information required for this purpose cannot be procured for several major river basins in India from state/central water resources departments, as it is deemed classified information due to interstate and/or international river water disputes. Restriction on disbursement of essential gauged data on hydro-meteorological variables (e.g. rainfall) is another hurdle. For example, India Meteorological Department currently disburses rainfall data over large area at only daily scale in grid (spatial average) format. In contrast, many developed countries put-up enormous amount of gauged observations on web for use by researchers. Characteristics of extreme rainfall estimated using gridded products could be significantly different from those of the original gauged data. Hence, use of those estimates for flood prediction could result in large errors.

Methods in vogue for riverine flood prediction include empirical methods, rainfall-runoff methods, unit hydrograph methods and regional frequency analysis methods. None of those is established to be universally superior. Hence it is necessary to quantify uncertainty in flood prediction due to choice of method, but this is often ignored. Empirical methods have inherent shortcomings, as they consider very few predictor variables for predicting flood. However, they are still used in India perhaps due to ease in application. Rainfall-runoff methods involve estimation of flood frequency from rainfall frequency using a hydrological model which links rainfall to resultant runoff in the catchment of target location. Relationships between rainfall and flood frequency are not yet established for river basins in India. Often, modellers assume frequency of rainfall and flood to be the same in flood prediction, which is debatable. On the other hand, unit hydrograph methods involve construction of synthetic pulse response functions for sub-catchments (typically area $<5000\ km^2$) in the catchment of target location. For this purpose, regression relationships which relate parameters of the function to time invariant physiographic characteristics of sub-catchment are available for 7 zones and 26 sub-zones delineated in India (Flood estimation report, Directorate of Hydrology (Small Catchments), Central Water Commission, New Delhi, 1983). The relationships are being adopted/adapted in risk assessment studies on about 257 large dams in India as part of Dam Rehabilitation and Improvement Project (DRIP). Currently, there is a need to validate the relationships which were advocated for use in 1983, as pulse response function of sub-catchments (obtained using the relationships) cannot be considered time invariant, owing to LULC and other anthropogenic changes in river basins. This is of significance, as such studies would be extended to about another 5000 large dams in the near future. Another issue is that many of the zones are heterogeneous for use in flood prediction, and this necessitates need for fresh investigations to prepare effective zones.

Prediction of riverine flood by regional frequency analysis (RFA) method requires past observations of peak flows (instantaneous maxima) and other flood-related characteristics at the target location and at other locations whose catchments resemble that of the target location. Extraction of instantaneous maxima and other information is not possible when flow data are available only at daily scale. Consequently, modellers base their analysis on information extracted from daily values and this has adverse effects. Another challenge encountered by researchers is to develop theory/framework to perform RFA in non-stationary scenario.

Flood in an urban catchment is often predicted using rainfall-runoff model for synthetic rainfall events (of different feasible durations and frequencies), which are designed to be more critical than those observed in the catchment. Observations on rainfall and flows in storm drains are required at sub-hourly scale, as response time of urban catchments is small. Rainfall records are usually available at daily scale, and they are disaggregated to sub-hourly scale by making several assumptions. Further, drains are usually not gauged in many urban localities. This poses a major hurdle in model development. Another issue is that conventional rainfall-runoff models cannot account for dynamic LULC changes which are witnessed in many urban catchments. Currently there is a need to improvize the models by adding this feature, and also modernize hydrometric networks to gather information on rainfall and flows at the required finer temporal and spatial scales. Besides this, practitioners should ensure quantification of uncertainty in flood estimates with regard to (i) rainfall disaggregation, (ii) synthetic rainfall estimation, (iii) rainfall-runoff modelling, and (iv) regional/global climate change. This should be emphasized in Indian design manual for urban storm water drainage, which is over-due for revision.

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