Development of a flood forecasting system integrating climate information

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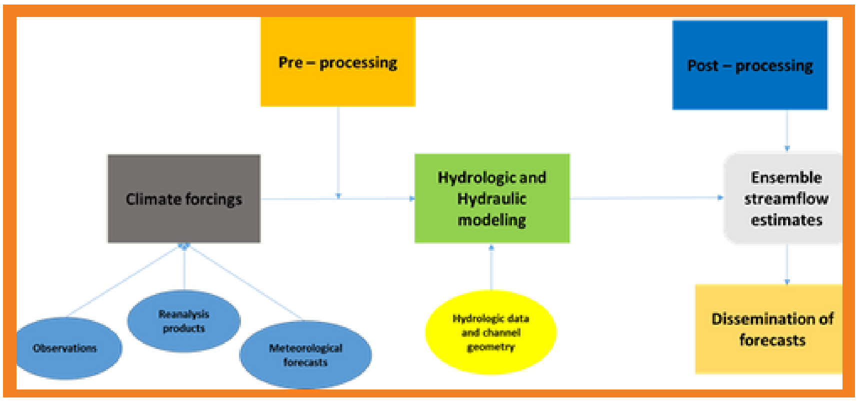
Climate change is easily perceived in rising temperatures at global scale, and it has the capability to alter the hydrological cycle at regional scale. Many studies across the globe have shown the effects of climate change in terms of increased frequency and intensity of extreme precipitation, changes in seasonal precipitation patterns and different aspects of floods. In India, low pressure systems that typically occur during the monsoon cause floods and are influenced by the climate drivers whose association with hydrology may vary because of the climate change. Therefore, it is important to integrate climate information on both short- and long-term scales in flood modeling and management.

Flood modeling including flood forecasting seen as non-structural measure to mitigate flood effects, and having reliable information at advance lead times greatly benefits. In this regard, climate at both short- and long-term scales on a river basin scale must be incorporated into the flood forecasting systems. Streamflow modeling has witnessed great advances but are in the research settings, and the operational mode of streamflow modeling is in its early stages. The current operational flood forecasting system in India is mainly driven by statistical- and empirical-methods and does streamflow estimation including flood forecasts at specific locations. Importantly, it does not provide uncertainty that is associated with forecasts which result from multiple sources including climate.



The efforts addressing the issues have been put together by relevant agencies using models of both open source and commercial, e.g., such as Hydrologic Engineering Center - Hydrologic Modeling System (HEC - HMS) and MIKE.

One important requirement for all these models is availability of significant amounts of data, which has been on the rise in recent years. The other aspect is to modify the model or model elements to reflect the regional processes including changes in land use and land cover - highlights the need to develop indigenous models that are capable of providing ensemble information at desired locations incorporating the climate information.

In this regard, a widely used conceptual model, i.e., Sacramento Soil moisture accounting (SAC-SMA) is employed over the Narmada river basin, India. While the proposed framework is similar to the ensemble streamflow modeling framework that is used elsewhere, we like to explore the physics of processes with model parameters so that models can represent indigenous models with less effort with a goal to bring the methodology on other river basins. We plan to explore methods that integrate climate information, multiple hydrologic and hydraulic models and statistical models so that probabilistic streamflow is estimated - it assists in efficient mitigation measures.

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Climate change, extreme rains and floods - challenges and opportunities

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As a child, I was curious to find a place where rain appears magically. However, this is no longer an intriguing proposition. In the city of Hyderabad, I see rain, heavy in some parts while merely drizzling in others, and no rain at all in other parts still. This aspect i.e., spatial variability of rainfall has always existed, but having it within a small geographical area, such as within Hyderabad city, is relatively new and has been associated as one important effect of anthropogenic climate change. This presents new challenges such as frequent flooding that we have witnessed in major cities and river basins across India and its neighboring countries. This also highlights the need for new various capabilities in the context of rainfall and runoff estimation.

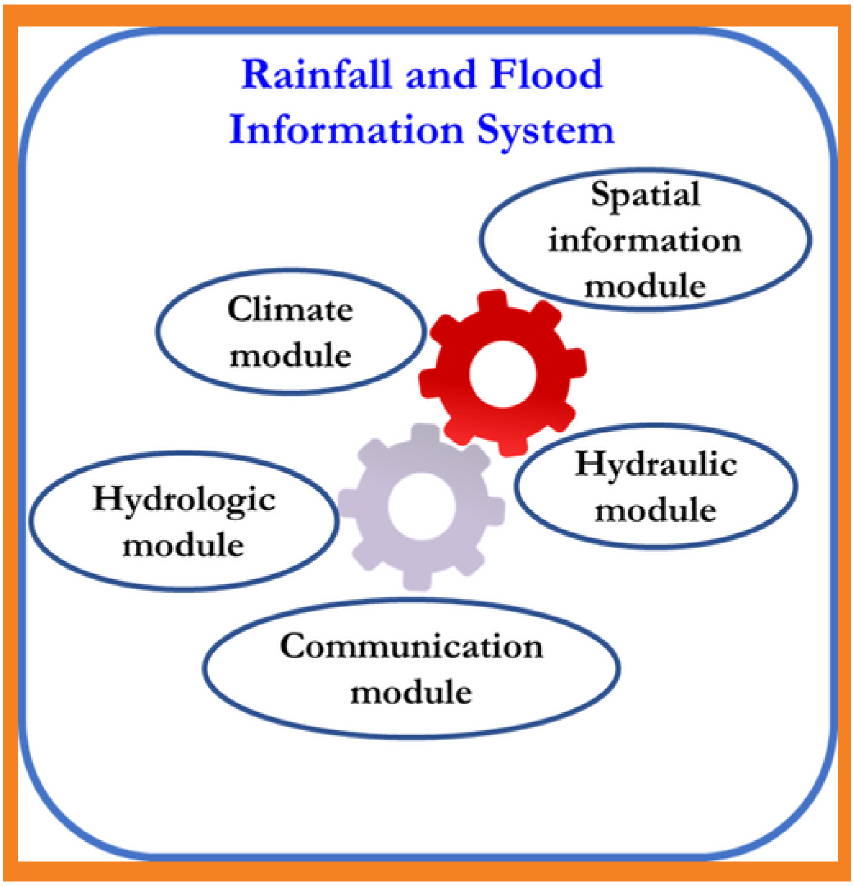
Variability in rainfall manifests in different ways e.g., more rainy days/spells, increased rainfall intensity, shorter rainfall spells, changes in rainfall locations, etc. Therefore, changes are expected in flood aspects as well. These already disrupt conventional engineering approaches to flood planning and are further exacerbated due to changes in land use and land cover (LULC) and urbanization. Extreme rains and floods impact a diverse range of stakeholders, including e.g., street vendors, industries of both small and large scale, and policy makers, necessitating the development of customized information and products that can cater to their needs. This warrants (a) new sets of data of multiple spatial and temporal scales, and (b) new methods that read information, model mechanisms and provide tailored products.

Conventional data sets of basic hydrometeorological variables allowed for quite a few interesting findings, however, as the scale of challenges has increased, monitoring of (new) variables in new ways has become imperative. For example, heat generating sources in cities are of a wide variety, i.e., the city's dominating urban cover (asphalt and cement roads), vehicular traffic and air conditioning. We therefore now require monitoring of temperatures at finer spatial and temporal resolutions. Additionally, concentrated skyscrapers in patches of areas not only contribute to the city's heat islands but modify wind patterns, which need to be monitored as well. Further, monitoring of clouds as well as rainfall and runoff measurements at finer spatial and temporal resolution is also needed as cities start exhibiting significant spatial variability in rainfall. To effectively route the rainfall that contributes to runoff, it is important to understand the drainage patterns. While these patterns do not change frequently in river basins which predominantly comprise rural areas, cityscapes are far more dynamic and require frequent monitoring and updating in this regard. Periodic surveys undertaken with drones and LiDAR systems can be of great use here.

The gauge network to measure various hydrometeorological variables including rain, streamflow and stage has been greatly densified over the last several years. Data from multiple sources, weather radars, satellites and high dense rain gauge networks is also becoming available more readily. Information on many weather variables from high density automatic weather station (AWS) networks assists in improving climate model's reliability and accuracy and allows for the development of regional- and local- as small as city-level climate models.

While issues of data quality, storage, and resolution persist, there is nonetheless a clear opportunity for developing new methods that improve understanding of regional hydroclimatology andallow development of new products such as high resolution rainfall information and flood maps.

Against this background, we are currently working to address rainfall and runoff estimation aspects comprehensively for the city of Hyderabad and a few river basins in India. We analyzed high density hourly rain-gauge data for the city of Hyderabad and understood the climatological aspects of the rainfall at



different space- and time- scales (Mohammed et al., 2022). Further, we explored the usability of information content in weather radar- and satellite-based rainfall estimates. Additionally, development of hybrid methods i.e., combination of physically based and statistical methods is underway. Similarly, flood modeling efforts on river basin scale addressing uncertainty information are pursued (Sharma and Regonda, 2021a, 2021b), and methods capable of integrating climate information and multiple models are underway. Thus, we envision a system with following key components, i.e., climate-, spatial information-, hydrologic, hydraulic- and communication- modules (Figure).

We have initiated collaborations with multiple institutes, and started steps from data collection (weather and rain gauge stations and drone) data archiving and database development to modeling including prediction. We believe that these types of information systems need to be city- as well as river basin-specific for a prosperous society.

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