Abstract

Estimates of design flood are necessary at locations of hydrologic structures (e.g., flood control dams, barrages) in studies related to their planning, design and risk assessment. In situations, where failure of hydrologic structures could have catastrophic consequences on environment and mankind owing to the presence of thickly populated areas and/or nuclear facilities downstream, the design flood estimate is considered to be the probable maximum flood (PMF). The PMF could be estimated by convoluting probable maximum precipitation (PMP) for catchment contributing flow to the target location with Unit hydrograph (UH) of the catchment. For the purpose of convoluting PMP with UH, their effective durations should be the same.

Geomorphological Instantaneous Unit Hydrograph (GIUH) could form the basis to arrive at UH of any required effective duration. There is ambiguity in GIUH constructed for gauged locations, as parameters of GIUH are sensitive to (i) scale of map and support/threshold area for initiation of the first order streams, and (ii) the position of outlet of catchment. To address this, recently a strategy based on the hypothesis of self-similarity of stream networks was proposed by Moussa (2009) to estimate GIUH parameters and the resulting GIUH is referred to as equivalent GIUH (E-GIUH). Previous studies on the self-similarity hypothesis were confined to a few French catchments, and did not examine digital elevation model (DEM) based uncertainty. In this perspective, hypothesis of self-similarity‖ was tested on 200 catchments in four Indian river basins (Mahanadi, Godavari, Krishna and Cauvery) having wide range in their areas (19 km2 to 3,00,870 km2) by using the Shuttle Radar Topography Mission (SRTM) DEM data. Results indicated that the self-similarity hypothesis is valid for all the 200 catchments. Parameters required to construct E-GIUH for each of the catchments are provided. In addition, investigations were carried out on 42 gauges in two river basins (Mahanadi and Cauvery) to examine (i) validity of the hypothesis of "self-similarity" with change in DEM source, and (ii) the effect of DEM source (30m resolution Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and 90m resolution SRTM) on morphometric properties of the channel networks, equivalent H-S ratios and the corresponding equivalent GIUH constructed for the catchments. The results indicated that the hypothesis of "self-similarity" was valid for all the 42 catchments irrespective of the DEM source considered for the analysis. Further, SRTM DEM was found to be reliable (when compared to ASTER DEM) for extracting morphometric descriptors for the catchments. Overall the results indicated that uncertainty associated with DEM source cannot be ignored in hydrological studies involving E-GIUHs.

To account for spatial variability in extreme rainfall, catchment of a target location (e.g., dam) is often delineated into sub-catchments, many of which could be ungauged. There is dearth of studies to predict E-GIUH for ungauged catchments. To address this, entropy based regionalization approach is proposed which utilizes catchment geomorphological descriptors suggested by Moussa (2008a). Effectiveness of the approach was evaluated by application to 55 catchments of reasonable size (< 5200 km2) in four Indian river basins (Mahanadi, Godavari,

Krishna and Cauvery). The analysis yielded three regions, which were shown to be effective in arriving at E-GIUH for ungauged locations through leave-one-out cross-validation experiment.

The PMP estimates necessary to arrive at PMF could be determined based on various approaches. Douglas and Barros (2003) proposed multifractal approach (MA) which is deemed to be effective as it considers both physics and statistics of the rainfall process, in contrast to the conventional approaches which are based either on statistical concepts or physical aspects. Their study was confined to eastern United States, and the MA has seldom been used elsewhere possibly due to its theoretical complexity. Investigations were carried out on Mahanadi and Godavari river basins to examine if PMP estimates corresponding to 1-day to 5-day durations obtained using this approach are consistent with estimates obtained using two commonly used approaches [Hershfield method (HM) and Storm Model approach (SMA)]. The SMA is based on physical aspects responsible for causing the storm event at target location, whereas HM is based on statistical concepts. For investigation, 0.5˚ resolution gridded rainfall data was considered, and PMP estimates obtained at grid scale were considered to prepare PMP maps for the basins and to arrive at PMP estimates for catchments in each of the basins. The results indicated that HM and SMA underestimate PMP (relative to MA) for larger durations (>3 days), as storm events whose accumulated rainfall forms the basis to arrive at PMP estimates are less likely to be uninterrupted. Further, among HM and SMA, PMP estimates based on the former method are found to be higher than those based on the latter method for majority of grids over all the durations. In addition, fractal maximum precipitation (FMP) and design PMP (DPMP) maps corresponding to various durations (and return periods) were prepared by applying multifractal approach to 0.25˚ gridded daily rainfall data (3890 grid points) covering the entire India (excluding high altitude Himalayan region). Results indicated that FMP/DPMP estimates cannot be obtained for 651 grid points using the approach. Majority of those 651 grid points are located in north-west (Rajasthan and Punjab states) and north-east of the country, and some parts of Maharashtra and Tamil Nadu states.

In addition, a new cluster analysis based regionalization procedure is proposed to address issues associated with construction of envelope curve in Hershfield method, which helps in averting overestimation of PMP for majority of gauges (sites) in the study area. As engineering designs of large-scale hydrological structures are conventionally based on PMF derived from PMP, reduction in PMF estimates is likely to have economic implications. The procedure involves delineation of the study area into zones (regions) on the basis of extreme rainfall characteristics. Those zones are suggested to be considered as the basis for construction of envelope curve and estimation of PMP by Hershfield method. Application of the proposed procedure to India yielded 20 homogeneous PMP zones when regionalization was performed using global K-means (GKM) clustering algorithm for both 1-day and 2-day durations. When the analysis was repeated by considering global fuzzy c-means (GFCM) clustering algorithm, the procedure yielded 17 homogeneous PMP zones.

Envelope curve constructed for each of the zones (resulting from GKM and GFCM cluster analysis) was considered as the basis to estimate PMP for each of the 0.25˚ resolution grid points in the zone. The following inferences were drawn from comparison of the PMP estimates with those obtained for the grid points by considering (a) a single envelope curve for the entire India, (b) two envelope curves (one prepared for grid points which are towards north of 20˚ latitude and another prepared for grid points towards south of the latitude) as considered by Rakhecha et al. (1992) and Rakhecha and Soman (1994).

(i) PMP estimates obtained based on single/two envelope curve(s) for the entire India are significantly higher than estimates obtained using GKM- and GFCM-based zones (regions),(ii)The differences in GKM and GFCM zone-based PMP estimates appear marginal across India, except for south-eastern part of Rajasthan, Jharkhand and Maharashtra states (in the case of 1-day PMP) and north-eastern part of India (in the case of 2-day PMP),

(iii) The differences in PMP estimates obtained based on single/two envelope curve(s) appear (a) marginal for most part of the country in the case of 1-day PMP, but (b) significant for northern part of the country in the case of 2-day PMP (owing to higher values for estimates obtained by fitting a single envelope curve for the entire India)

Additional investigations were carried out by fitting river basin specific envelop curves to estimate 1-day and 2-day PMP for each of the 0.25˚ resolution grid points in four river basins (Mahanadi, Godavari, Krishna, Cauvery). Those PMP estimates were found to be generally lower than the corresponding estimates obtained based on single/two envelope curve(s) for the entire India. The river basin based 1-day PMP estimates were significantly lower in the case of Cauvery and Mahanadi river basins. Further it was noted that GKM- and GFCM-based 1-day PMP estimates could be higher/equal/lower than the corresponding PMP estimates obtained based on single/two envelope curve(s) for the entire India or river basin-based region. The GKM- and GFCM-based 2-day PMP estimates for grid points in the river basins are lower than (i) PMP estimates obtained based on single/two envelope curve(s) for the entire India in the case of all the river basins, (ii) river basin-based PMP estimates for Mahanadi, Krishna and Godavari basins, but higher than those for Cauvery river basin. As regions delineated using cluster analysis are based on attributes affecting/depicting rainfall, PMP estimates based on those regions could be considered reliable. On the other hand, river basin constitutes a geographical area demarcated based solely on area draining streamflow on land surface which has no effect on PMP, while other regions (India-, 20˚ latitude-based regions) that formed the basis for PMP estimation are based on political boundary which has no influence on PMP.

The utility of E-GIUH and PMP estimates in arriving at probable maximum flood (PMF) for catchment of Hirakud dam in Mahanadi river basin (India) is demonstrated. Further, the sensitivity of PMF estimate to PMP estimates obtained by using Hershfield method, storm model approach and multifractal approach was examined for 1-day and 2-day durations. This involved (i) delineation of catchment of Hirakud dam into sub-catchments of reasonable size (< 5200 km2), (ii) construction of E-GIUH for the sub-catchments (using the proposed entropy based regionalization approach in the case of ungauged sub-catchments), (iii) derivation of 1-day and 2-day unit hydrographs for each of the sub-catchments from its E-GIUH, (iv) determination of 1-day and 2-day PMP estimates for each of the sub-catchments, (v) convoluting PMP estimate with unit hydrograph of corresponding effective duration to arrive at PMF for the sub-catchment, and (vi) routing the PMFs of the sub-catchments through the channel network in catchment of Hirakud dam to arrive at PMF at the dam location.