Rainfall-runoff modeling at different spatial scales: Application of semi-distributed hydrological modeling in the Godavari River Basin, India

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Abstract

Increased space-time resolution of hydrologic information in combination with better understanding of hydrologic processes allowed evolution of rainfall-runoff modeling from lumped mode to distributed mode. Relatively, lumped modeling is simple, less data intensive and use less computing resources; typically, semi-distributed modeling falls between lumped- and distributed modeling on a scale of various parameters including modeling complexity, data and computing resources. To understand the influence modeling complexity and hydrologic information on performance of hydrologic models in monsoon driven river basins, we performed a hydrological study on Sabari River Basin, from a tributary of Godavari river basin, delineated at three different spatial scales. Then, The Hydrologic Engineering Center- Hydrologic Modeling System (HEC-HMS) model driven in both event- and continuous modes in lumped and semi-distributed modes. The model calibrated and then validated using various verification metrics. Analysis of verification metrics provided insights on different aspects of flood forecasting

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ABSTRACT

Increased space-time resolution of hydrologic information in combination with better understanding of hydrologic processes allowed evolution of rainfall-runoff modeling from lumped mode to distributed mode. Relatively, lumped modeling is simple, less data intensive and use less computing resources; typically, semi-distributed modeling falls between lumped- and distributed modeling on a scale of various parameters including modeling complexity, data and computing resources. To understand the influence modeling complexity and hydrologic information on performance of hydrologic models in monsoon driven river basins, we performed a hydrological study on Sabari River Basin, from a tributary of Godavari river basin, delineated at three different spatial scales. Then, The Hydrologic Engineering Center- Hydrologic Modeling System (HEC-HMS) model driven in both event- and continuous modes in lumped and semi-distributed modes. The model calibrated and then validated using various verification metrics. Analysis of verification metrics provided insights on different aspects of flood forecasting.

STUDY AREA : Sabari sub-basin

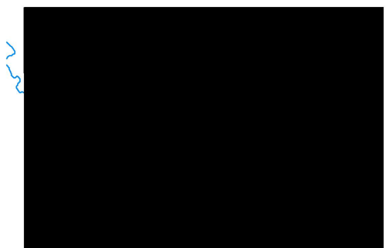

Figure 1: Map showing Sabari sub-basin from Godavari river basin, India.

Table: Salient features of Sabari sub-basin

S.No	Feature	Quantity
1	Area	20,121 Km^2
2	Length of the river	418 Km
3	Elevation range	19 – 1677 m
4	Annual average rain (1966-2017)	1405 mm
5	Daily average flow at 'Konta' (1966-2017)	470 m^3/s
6	Gauge and discharge stations	05

- The objective of the study is to assess the rainfall-runoff process at fully lumped and semi-distributed scale with 08 sub-basins using HEC-HMS 4.3 framework for the selected events and continuous mode .

DATA

Hydro-meteorological data:

- Daily IMD gridded rainfall : Pai et al., 2014
- Daily discharge (Q): Central Water Commission, Krishna & Godavari Basin Organization (KGBO), Hyderabad, India.

Terrain data:

- Land use and land cover, ORNL DAAC (Roy et al., 2015)
- Elevation model, SRTM (30m) (Jarvis et al., 2008)
- Harmonized World Soil database (FAO) (Fischer et al., 2008)

Streamflow events selection:

- Criteria: Andrews et al., 2011
- Number of single peak events for this study: 13 (7 calibration, 6 validation)
- Continuous events: 06 (3 calibration and 3 validation)

METHODOLOGY

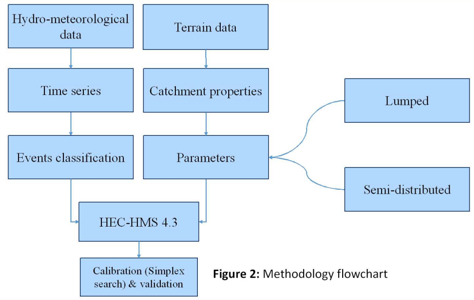

Figure 2: Methodology flowchart

i. Watershed models:

Rainfall-runoff modeling was performed based on two ways; Entire sub-basin as a single unit, and delineating individual sub-basins which are directly connecting to the higher order streams (08 sub-basins).

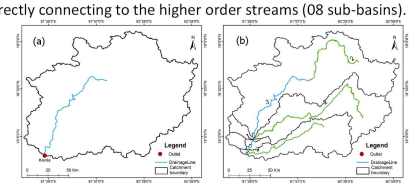

Figure 3: Sub-basin discretization (a) fully lumped (b) semi-distributed model with 08 sub-basins

ii. Parameter estimation:

SCS-CN (NRCS) method was adopted to compute the runoff volume at daily step. Curve Numbers were computed and assigned based on AMC conditions. Clark's UH model was used as transform method, Tc and R were estimated through empirical equations and further investigated for turbulent and laminar flow conditions. Base flow recession method were adopted to find the subsequent flows from the initial flow at starting of the event. Muskingum parameters were estimated and achieved the stable condition for the reaches. The initial parameters were optimized using Peak-Weighted RMSE and sum of squared residuals (USACE,2000) and proceeded for the validation. All the parameters were obtained for lumped and semi-distributed models. In the continuous mode 'deficit and constant rate' model used to account rainfall losses for multiple peak events.

iii. Selection of events and classification:

If the flow exceeds 90 percentile of the total flow for at least two time steps and continuous for next such steps until 90th percentile flow reduced for 4 consecutive steps, then other event will be after 5 days (Andrews et al., 2011). The events further classified into single, double and multiple peak. In the present study, single peak events were modelled by different methods.

iv. Continuous modeling was performed for 06 events of 5 year time step, showed how the optimized parameters from event based modeling capturing the watershed runoff in between precipitation events.

ACKNOWLEDGEMENTS

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REFERENCES

1. Pai, D.S., Sridhar, L., Rajeevan, M., Sreejith, O.P., Satbhai, N.S. and Mukhopadhyay, B., 2014. Development of a new high spatial resolution (0.25× 0.25) long period (1901–2010) daily gridded rainfall data set over India and its comparison with existing data sets over the region. *Mausam, 65*(1), pp.1-18.
2. Roy, P., Roy, A., Joshi, P., Kale, M., Srivastava, V., Srivastava, S., Dwevidi, R., Joshi, C., Behera, M., Meiyappan, P. and Sharma, Y., 2015. Development of decadal (1985–1995–2005) land use and land cover database for India. *Remote Sensing, 7*(3), pp.2401-2430.
3. Fischer, G., F. Nachtergaele, S. Prieler, H.T. van Velthuizen, L. Verelst, D. Wiberg, 2008. Global Agro-ecological Zones Assessment for Agriculture (GAEZ 2008). IIASA, Laxenburg, Austria and FAO, Rome, Italy.
4. Andrews, F.T., Croke, B.F. and Jakeman, A.J., 2011. An open software environment for hydrological model assessment and development. Environmental Modelling & Software, 26(10), pp.1171-1185.
5. Fennessey, L.A., Miller, A.C. and Hamlett, J.M., 2001. ACCURACY AND PRECISION OF NRCS MODELS FOR SMALL WATERSHEDS 1. JAWRA Journal of the American Water Resources Association, 37(4), pp.899-912.

RESULTS AND DISCUSSIONS

(a) Event based modeling :

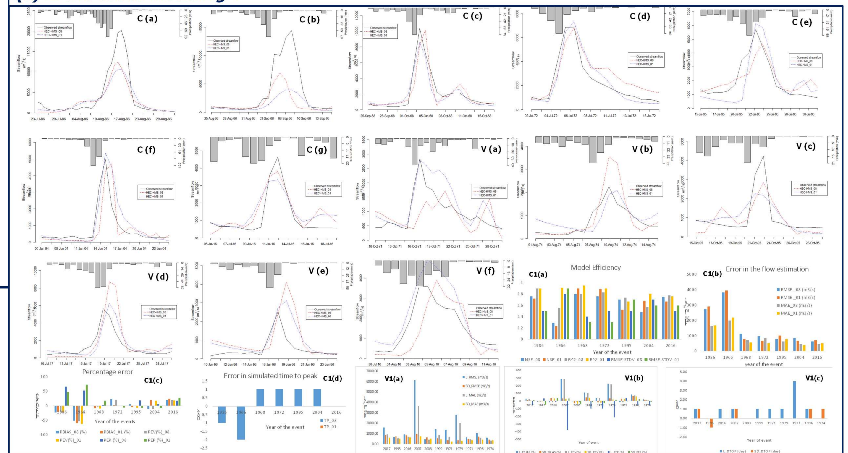

Figure 3: Comparison of Hydrograph characteristics (C(a) to V(f)) between observed and HEC-HMS simulated at lumped and semi-distributed scales. Model performance metrics for calibration (C1(a) to C1 (d)) and validation results from V1 (a) to V1 (c). **Note:** C is Calibration and V is Validation

During the calibration phase, both lumped and semi-distributed models showed an average of 65% agreement with the observed hydrograph, some instances lumped model was performing better than semi-distributed model. In the validation phase always lumped model performed better than semi-distributed. However, lumped model was able to capture the average response.

(b) Continuous modeling :

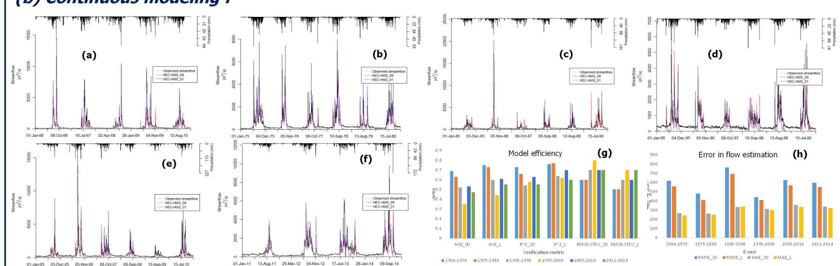

Figure 4: Comparison of continuous flows modelled from lumped and semi-distributed model . From (a) to (f) shows hydrograph comparison and (g) to (l) are verification metrics. Note: L is Lumped SD is semi distributed.

Low flows are always under estimated in both the cases. Lumped model was performing better in calibration and validation phase, however, there is less differences in the verification metrics found between both the scales. Deficit and constant rate model was able to capture the volume above average but not able to model peak flows, time to peak and.

CONCLUSIONS

- ✓ Rainfall-runoff response of the Sabari sub-basin was studied in two different spatial and temporal scales.
- ✓ Streamflow events were identified based on the Andrews et al., 2011 scheme.
- ✓ In the event based modeling, model was performing good at both the scales in the calibration phase and lumped model performed better in the validation phase. Optimized parameters were used in continuous modeling.
- ✓ In the continuous modeling, lumped and semi-distributed schemes worked well in the calibration phase, whereas lumped model performing better in the validation phase.
- ✓ Optimized parameters compared to different hydrograph characteristics and further investigations were made to establish the various relationships to forecast the future scenarios.