water MDPI

Supplementary information

Multi-Spatial Resolution Rainfall-Runoff Modelling – A Case Study of Sabari River Basin, India

SI1. Methods used in the HEC-HMS model to simulate hydrological processes

SI1.1 Excess Rainfall

Excess rainfall estimates by soil conservation service (SCS) – curve number (CN) method is a function of land use and land cover, soil cover, cumulative precipitation and antecedent moisture. Initial losses during the rainfall is a function of maximum potential retention.

$$R_e = \frac{(P-I_a)^2}{(P-I\_a+S)} \quad \text{(SE1)}$$

where; $$S = \frac{25400}{CN} - 254 \quad \text{(SE2)}$$

where; R_e is effective rainfall in mm, P is the cumulative precipitation in mm, S is the potential maximum retention in mm, CN is curve number, ranges from 30 to 100 and I_a is considered as 30 % of S.

SI1.2 Direct Runoff

SI1.2.1 Clark's Unit Hydrograph method

Transformation of excess rainfall to runoff derived by two methods; translation and attenuation. The translation is the movement of excess rainfall through the watershed area to the outlet without any attenuation but with a delay. Attenuation is the reduction of the magnitude of the discharge due to storage of excess rainfall throughout the watershed.

Translation of excess is implicitly determined by a time-area histogram. The ratio between the drainage area contributed at time t to the total watershed area is a function of time of concentration, T_c. A typical time area histogram built in the HEC-HMS is given below.

$$\frac{A_t}{A} = \begin{Bmatrix} 1.414\left(\frac{t}{T_c}\right)^{1.5}; t \le \frac{T_c}{2} \\ 1 - 1.414\left(1-\frac{t}{T_c}\right)^{1.5}; t \ge \frac{T_c}{2} \end{Bmatrix} \quad \text{(SE3)}$$

where; A_t is a cumulative watershed area at time t, A is the area of the watershed, T_c is the time of concentration of the watershed. From the continuity equation, which is the common representation of storage in the watershed;

$$\frac{dS}{dt} = I_t - O_t \tag{SE4}$$

And storage at time t is a function of outflow;

$$S = RO_t \tag{SE5}$$

Where $\frac{dS}{dt}$ is the change in the reservoir storage with time t, I_t and O_t are the inflow and outflow at time t in the reservoir. R is a constant linear reservoir parameter or storage coefficient. However, the storage cannot be the same at every point of watershed and outflow is always depends on the storage. By solving Eq. (S4) and (S5) using finite difference approximation;

$$O_t = C_A I_t + C_B O_{t-1} \tag{SE6}$$

where O_t is outflow at time t, C_A and C_B are routing coefficients

$$C_A = \frac{\Delta t}{R + 0.5\Delta t} \tag{SE7}$$

$$C_B = 1 - C_A \tag{SE8}$$

$$\bar{O}_t = \frac{O_{t-1} + O_t}{2} \tag{SE9}$$

Where $\bar{O}_t$ is the average outflow at time t.

SI1.3 Baseflow

The HEC-HMS uses the exponential baseflow method to model the baseflow at any time during the event by an initial baseflow value. The initial baseflow is the initial condition of the model, which is expressed as a flow rate (m3/s) or flow per unit area ($m^3/s/km^2$). Flow per unit area can be useful when there are no initial flow values available or when the initial baseflow to be mentioned for an ungauged basin. An exponential decay constant, k is the ration between the baseflow of the present and previous time step.

$$Q_t = Q_0 k^t \tag{SE13}$$

Where Q_t is the baseflow at time t (days), Q_0 is the baseflow at initial step and k is an exponential decay constant or recession constant.

The HEC-HMS model requires three parameters to estimate the baseflow; Q_0, k and ratio to peak (R_p). Q_0 is mentioned as above in either way by flow rate or flow per squre kilometer. Recession constant, k may be estimated by several methods from [2] and [3] and ratio to the peak is the threshold as a ratio to the computed peak flow (if the computed peak flow is 1000 m^3/s and R_p is 0.1 then threshold is 100 m^3/s).

SI1.4 Channel flow

Muskingum routing is one of the popular methods used to model the channel flow by estimating the storage from the continuity equation. Storage represented at each time step as the sum of the wedge and prism storages. The equation for the storage and outflow at time t is given as;

$$S_t = K[XI_t + (1 - X)O_t] \qquad \text{(SE14)}$$

where;

$$O_t = \left(\frac{\Delta t - 2KX}{2K(1-X)+\Delta t}\right) I_t + \left(\frac{\Delta t + 2KX}{2K(1-X)+\Delta t}\right) I_{t-1} + \left(\frac{2K(1-X)-\Delta t}{2K(1-X)+\Delta t}\right) O_{t-1} \qquad \text{(SE15)}$$

where; S_t is the computed storage at time t, K is the travel time of the flood wave in the reach; X is weighing factor to inflow and outflow $(0 \leq X \leq 0.5)$, I_t and O_t are the inflow and outflow at time t and Δt is the length of the computational interval.

$$K = \frac{L}{V_W} \qquad \text{(SE16)}$$

where L is the channel length (km) and V_W is the flood wave velocity.

$$V_W = \frac{1}{B}\frac{dQ}{dy} \qquad \text{(SE17)}$$

where B is the top width of the water surface (m), $\frac{dQ}{dy}$ is the slope of the rating curve at the known cross section. HEC-HMS technical manual suggests that the flood wave velocity normally 1.33 to 1.67 times the average velocity, which can be computed by Manning's equation.

$$X = \frac{1}{2}\left(1 - \frac{Q_0}{BS_0V_W\Delta x}\right) \qquad \text{(SE18)}$$

where; Q_0 is the reference flow from the inflow hydrograph, an average flow, midway between the baseflow and peak flow[4], S_0 is the friction or bed slope, V_W is the flood wave celerity (m/s) and Δx is the length of the reach. HEC-HMS requires K and X, estimated from the above methods.

The HEC-HMS model solves the above mentioned equations and calibrates parameters provided input data including observed streamflow.

SI2. Parameters with respect to sub-basin area

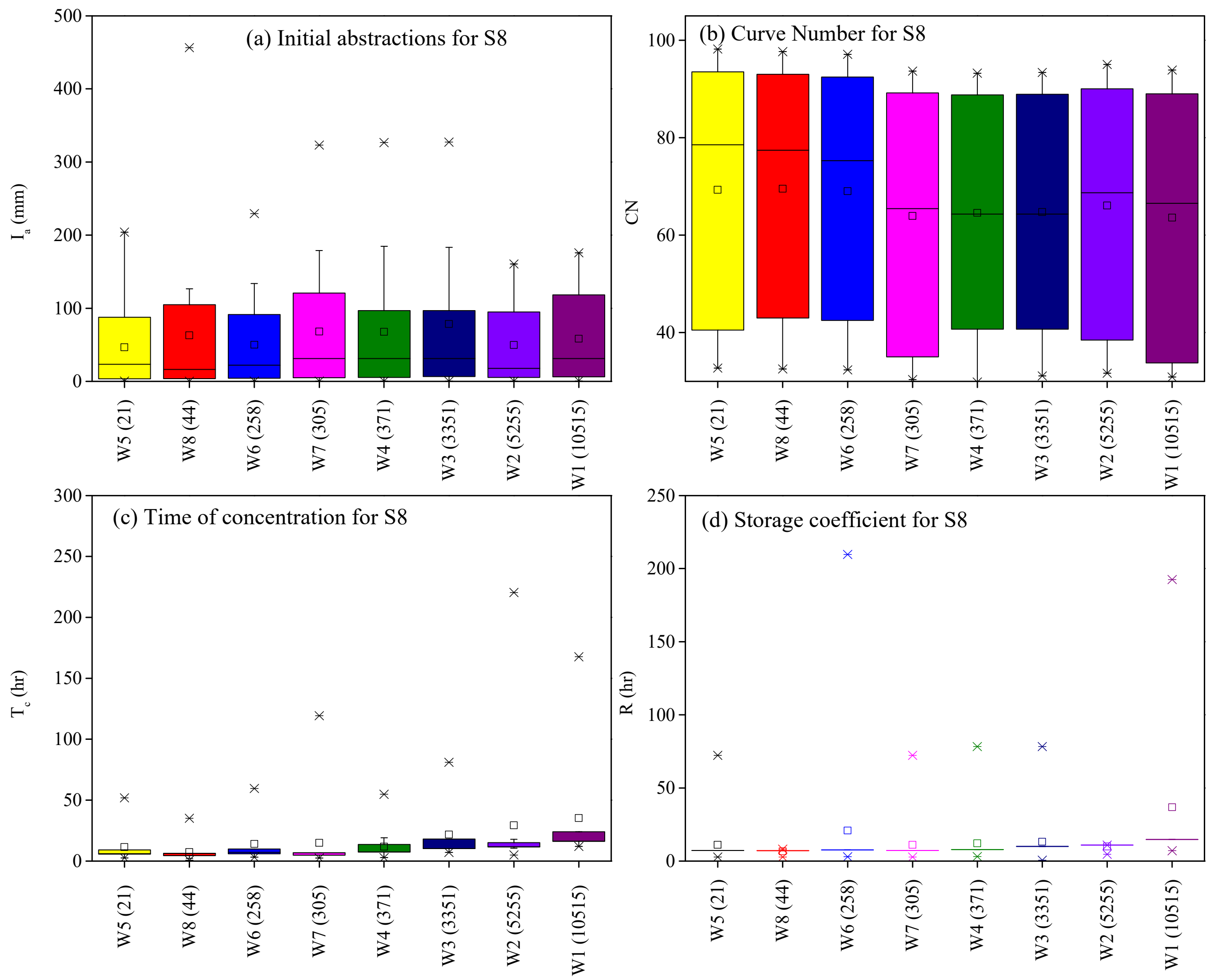

Figure SI1. Boxplots of the calibrated parameter for 15 events of S8 configuration with respect to the sub-basin area. Each panel corresponds to a parameter, and panels in the clockwise direction from top left correspond I_a (a), CN (b), T_c (c) and R (d). Area in km^2 is mentioned in the brackets of X-axis lables.

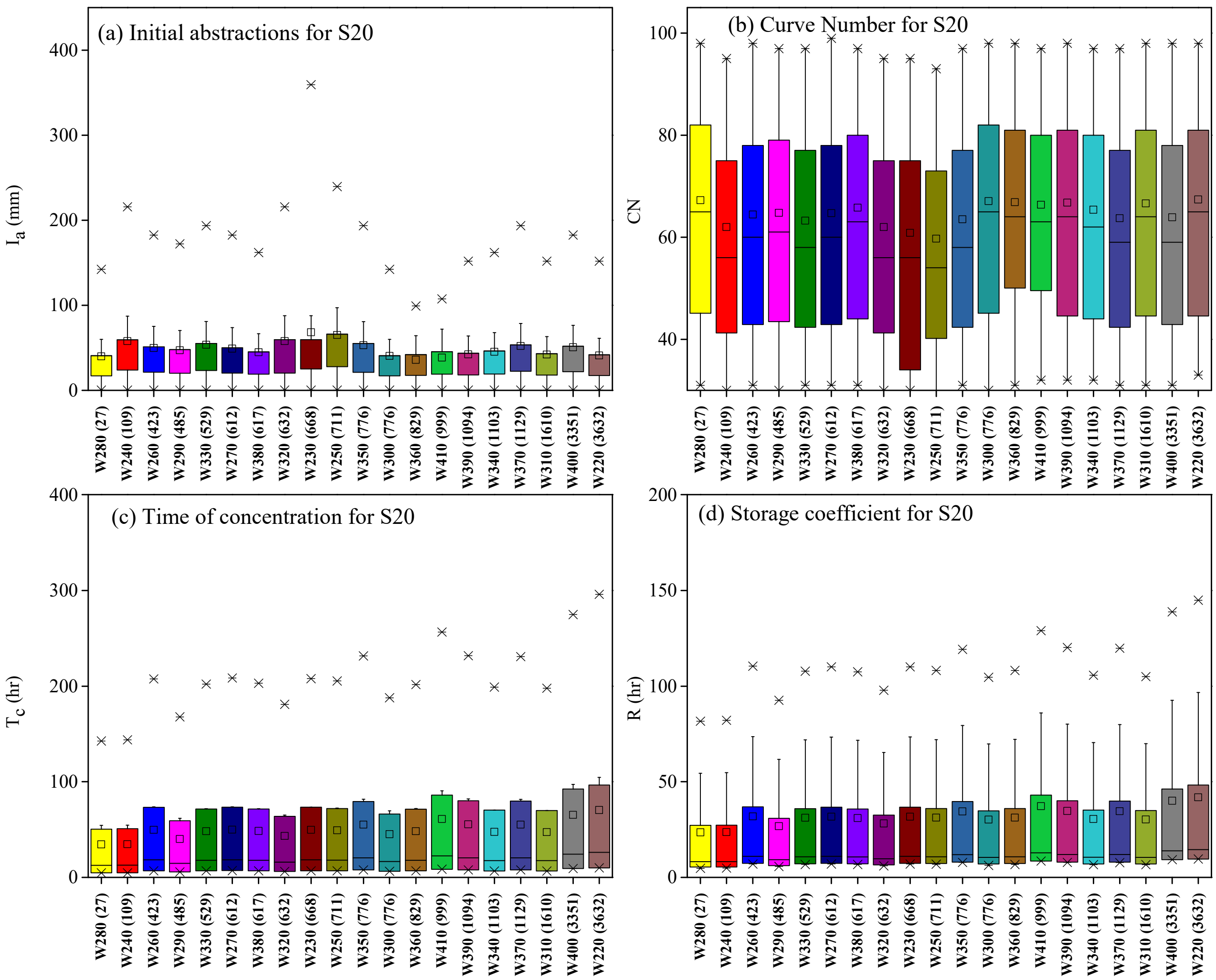

Figure SI2. Boxplots of the calibrated parameter for 15 events of S20 configuration with respect to the sub-basin area. Each panel corresponds to a parameter, and panels in the clockwise direction from top left correspond I_a, CN , T_c and R . Area in km^2 is mentioned in the brackets of X-axis lables.

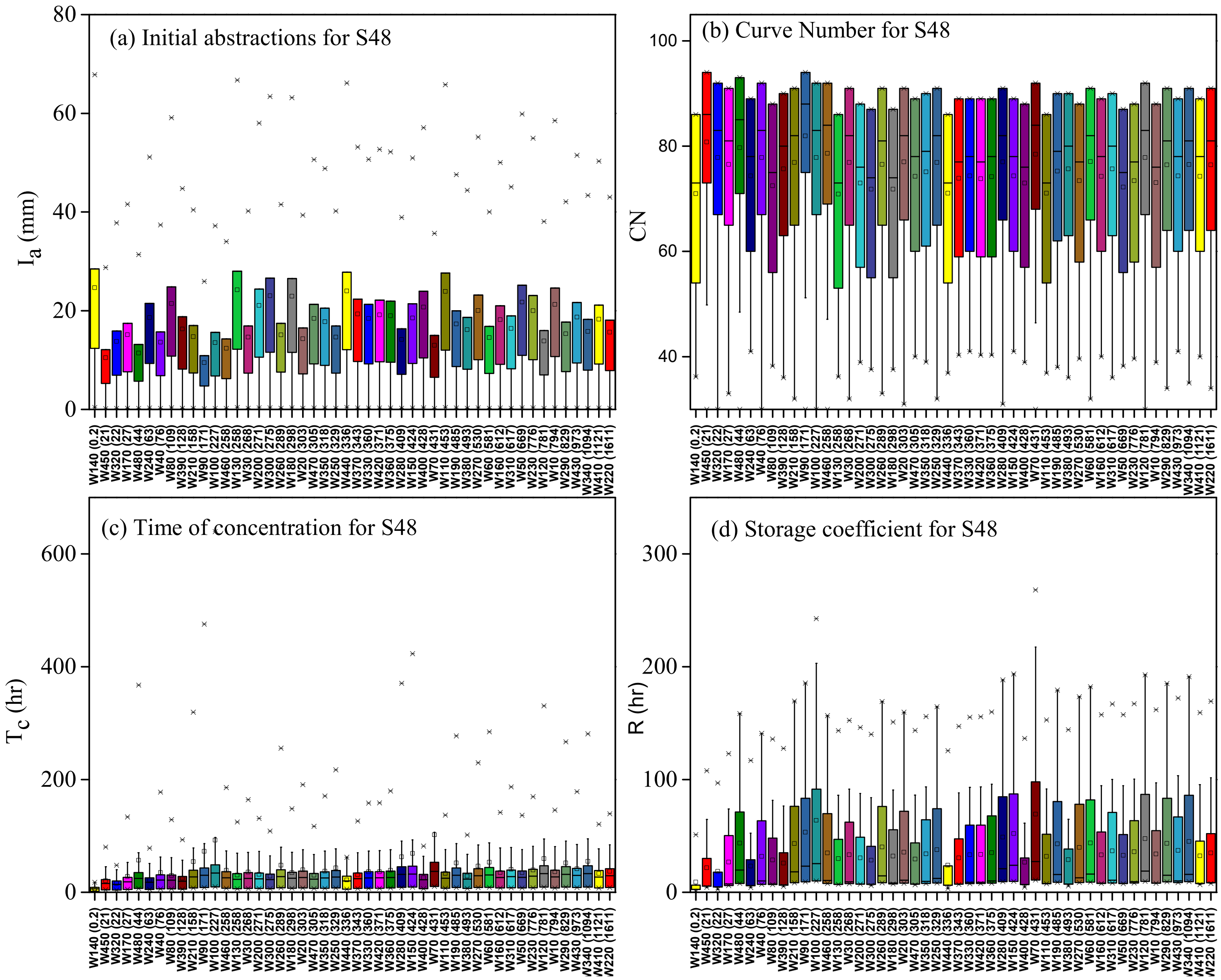

Figure SI3. Boxplots of the calibrated parameter for 15 events of S48 configuration with respect to the sub-basin area. Each panel corresponds to a parameter, and panels in the clockwise direction from top left correspond I_a, CN, T_c and R . Area in km^2 is mentioned in the brackets of X-axis lables.

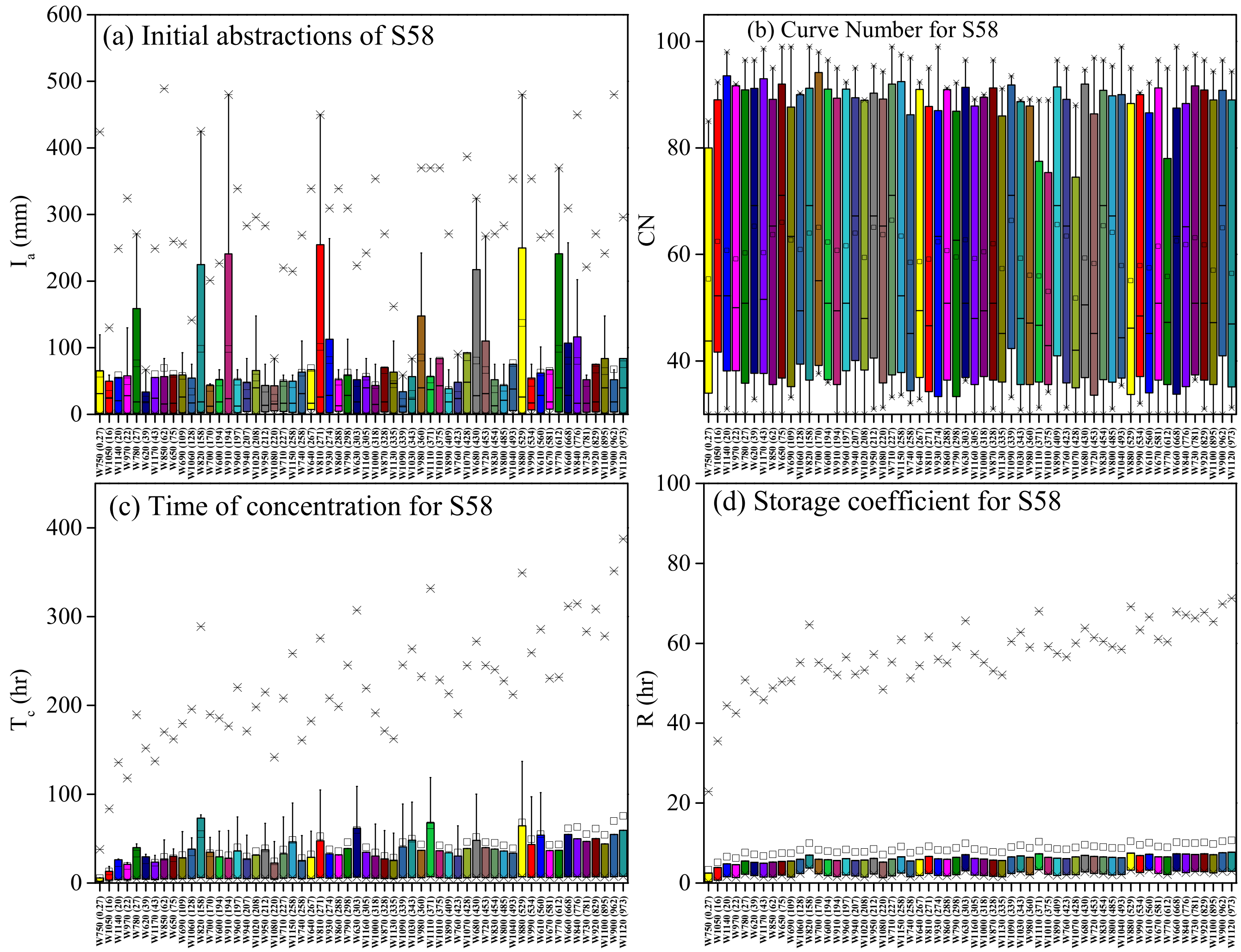

Figure SI4. Boxplots of the calibrated parameter for 15 events of S58 configuration with respect to the sub-basin area. Each panel corresponds to a parameter, and panels in the clockwise direction from top left correspond I_a, CN, T_c and R . Area in km^2 is mentioned in the brackets of X-axis lables.

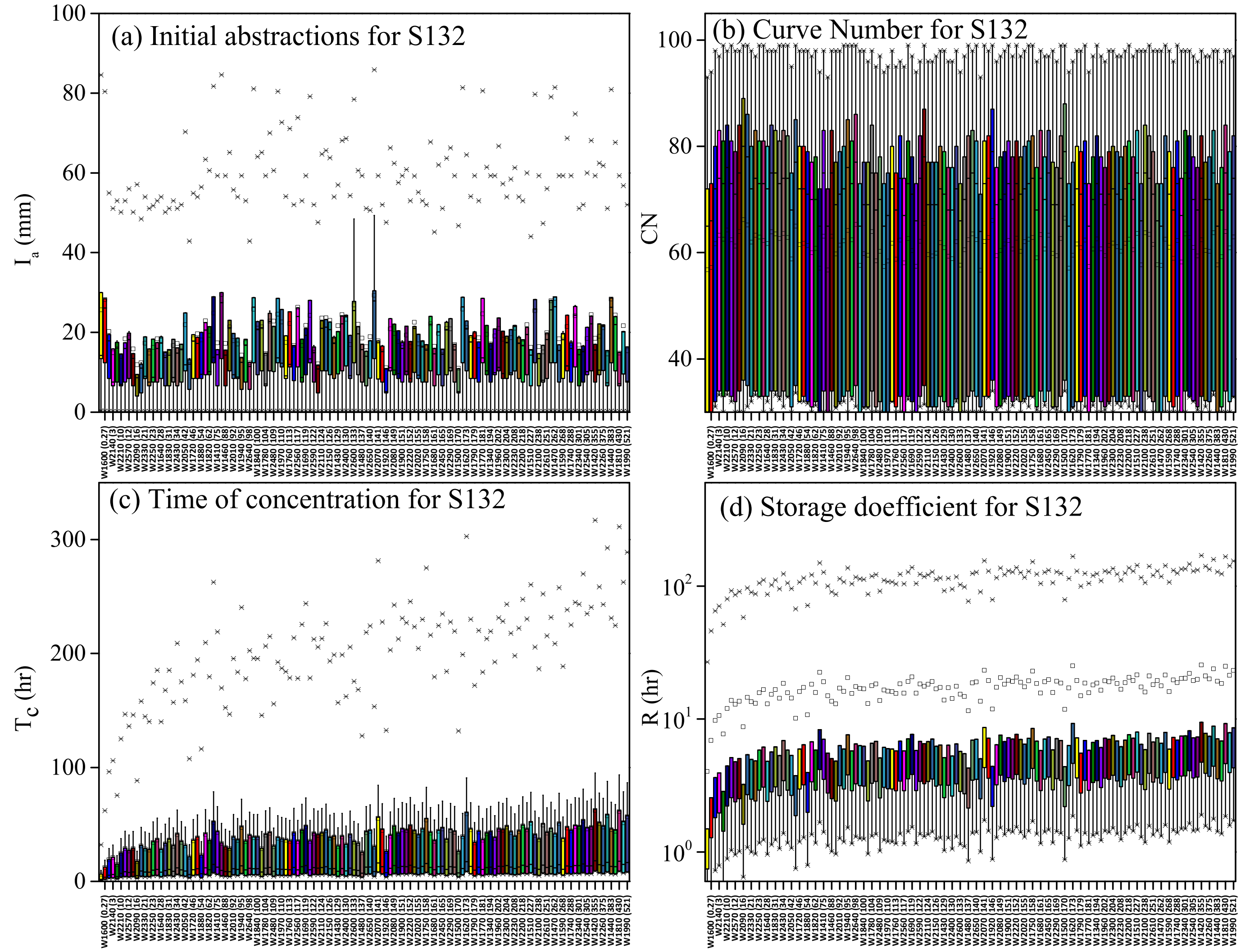

Figure SI5. Boxplots of the calibrated parameter for 15 events of S132 configuration with respect to the sub-basin area. Each panel corresponds to a parameter, and panels in the clockwise direction from top left correspond I_a, CN, T_c and R . Area in km^2 is mentioned in the brackets of X-axis lables.

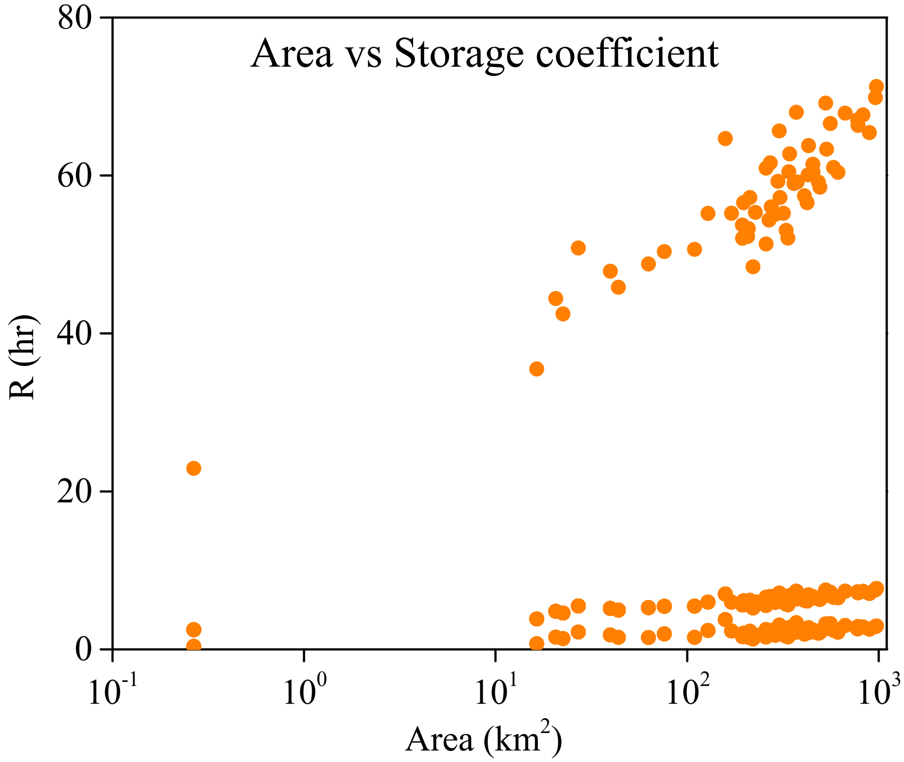

Figure SI6. Storage coefficient (R) with respect to the area for S58 configuration. The X-axis is on logartihamic scale and plot suggests an exponential increase in the R values

References

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