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Kyoto University
Highly Flexible Rainfall-Runoff Model Using Multiple Spreadsheets
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**Keywords:** Rainfall-runoff Modeling, Spreadsheets, Dimensionless Hyetograph, Dimensionless Hydrograph

This contribution presents a highly flexible spreadsheet model for rainfall-runoff processes. The model uses dimensionless equations for both hyetograph and hydrograph. These dimensionless equations help to generalize the model to handle various types of storms and also various hydrograph shapes. The model uses SCS-CN method as a loss model. This allows studying the land use and land cover (LULC) changes easily and straightforwardly. The circular reference option in Excel provides quick and immediate results for investigating the effect of storm pattern; stochastic storms, storm duration, hydrograph shape, and LULC changes. The model results are presented in colorful figures with a very nice graphical interface that helps the analysis of the results.

The model has been tested with well know software such as HEC-HEMS and is applied on a real case study in the Kingdom of Saudi Arabia.
Highly Flexible Rainfall-Runoff Model Using Multiple Spreadsheets

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Department of Hydrology and Water Resources Management, Faculty of Meteorology, Environment and Arid Land Agriculture, King Abdulaziz University, Kingdom of Saudi Arabia

Outline
- Research Objective.
- The RARUSM Model.
- Storms in Saudi Arabia.
- Modelling Storms Using Dimensionless Equations.
- Rainfall Storm Models in RARUSM.
- Generalized Runoff Hydrograph Model in RARUSM.
- Case Study.
- Conclusions.
- Future Work.

Research Objective
- Development of a spreadsheet rainfall-runoff model that is highly flexible and has the following features:
  2. Handy to adjust input parameters.
  3. Get immediate output results while changing input.
  4. Using the built-in graphical interface in the spreadsheet.
  5. All calculations are visible in the sheets.

The RARUSM Model.
- It is a rainfall-runoff model.
- It uses dimensionless equation for the rainfall model.
- It uses dimensionless equation for the hydrograph shape.
- It uses the timing equations of the SCS method.
- It uses the SCS-CN model for estimation of infiltration losses.
- It calculates the convolution integral to transfer the unit hydrograph to the storm hydrograph in a tabular form.

Dimensionless cumulative mass curves of storms in station TAO02

Storm Classification
- Storm Pattern:
  - 1st quartile: The maximum intensity is located from the beginning of the storm up to 25% of the storm duration.
  - 2nd quartile: The maximum intensity is located between 25% to 50% of the storm duration.
  - 3rd quartile: The maximum intensity is located between 50% to 75% of the storm duration.
  - 4th quartile: The maximum intensity is located between 75% to 100% of the storm duration.
Dimensionless cumulative hyetographs for KSA compared with Huff (1967) and SCS Types I, II and IA

Dimensionless Cumulative Hyetograph

\[ R(t) = \frac{1 - a \left(\frac{t}{D}\right)^b}{1 - a} \]

Where, \( R(t) \) is the cumulative rainfall depth at each elapsed time, \( t \), \( R_T \) is the total rainfall, \( t \) is the elapsed time since the storm begins, \( D \) is the storm duration, and \( a \) and \( b \) are the fitting parameters.

Makkah Al-Mukaramah Region DL Hyetograph

SCS Model Equations

\[ S_{\text{max}} (mm) = 10 \left( \frac{2540}{CN} - 25.4 \right) \]

\[ R_v = \frac{\left[ P - 0.2S_{\text{max}} \right]}{\left[ P + 0.8S_{\text{max}} \right]} \]

\[ F = (P - 0.2S_{\text{max}}) - R_v \]

Timing in The Hydrograph

\[ T_L = \frac{L^{0.8} \left( 2540 - 22.86CN \right)^{0.7}}{14104CN^{0.7}T^{0.5}} \]

in which, \( L \) = catchment length in hours, \( I \) = rainfall intensity (inches per hour), \( CN \) = runoff curve number, and \( T \) = ground infiltration rate in inches per hour. In U.S. customary units, the formula is:

\[ T_L = \frac{D}{2} + T_p \]

Where \( T_p \) = time to peak (hours)
\( D \) = duration of excess rainfall (hr)
\( T_c \) = time of lag (hr)

Dimensionless Hydrograph

\[ Q(t) = Q_{\text{max}} \left( \frac{t}{t_p} \right) \exp \left[ 1 - \frac{t}{t_p} \right] \]

\[ K = 6.5 \left( \frac{Q_{100}}{V} \right) \]

Where, \( Q_{100} \) is the maximum runoff, \( t_p \) is the time to peak of the inflow hydrograph, and \( V \) is the volume of the inflow hydrograph, the value of \( K \) is 3.77.

(\text{Haan, 1970})
Unit Hydrograph (1 mm), Peak Value

\[ q = C \frac{A}{T_p} \]

where

- \( q \) = runoff rate in m/s
- \( A \) = watershed area in ha.
- \( T_p \) = time of peak in hours

\( C = 0.0021 \)

Excess rainfall calculation

Convulsion table form UH to SH

Storm Hydrograph (1st Quartile Storm)

Storm Hydrograph (Uniform Storm)
The Second International Symposium on Flash Floods in Wadi Systems

Storm Hydrograph (4th Quartile Storm)

CN Changes

CN Changes

CN Changes

CN Changes

CN Changes

CN Changes
Dimensionless Hydrograph Shape $K=1$

$Q(t) = Q_{\text{max}} \left[ \left( \frac{t}{\tau_p} \right) \exp \left( \frac{1 - \frac{t}{\tau_p}}{K} \right) \right]^K$

Dimensionless Hydrograph Shape $K=4$

$Q(t) = Q_{\text{max}} \left[ \left( \frac{t}{\tau_p} \right) \exp \left( \frac{1 - \frac{t}{\tau_p}}{K} \right) \right]^K$

Dimensionless Hydrograph Shape $K=20$

$Q(t) = Q_{\text{max}} \left[ \left( \frac{t}{\tau_p} \right) \exp \left( \frac{1 - \frac{t}{\tau_p}}{K} \right) \right]^K$

Dimensionless Hydrograph Shape $K=50$

$Q(t) = Q_{\text{max}} \left[ \left( \frac{t}{\tau_p} \right) \exp \left( \frac{1 - \frac{t}{\tau_p}}{K} \right) \right]^K$

Dimensionless Hydrograph Shape $K=200$

$Q(t) = Q_{\text{max}} \left[ \left( \frac{t}{\tau_p} \right) \exp \left( \frac{1 - \frac{t}{\tau_p}}{K} \right) \right]^K$

Case Study: Wadi Qows in Jeddah

The study area consists of two parts, which are:
- Upper stream area (63, 36 km²)
- Downstream area (35, 5 km²)

Coordinate of the location:
- Latitude: 21.5° north
- Longitude: 39.3° east

Kuwantoro, 2013
### The Second International Symposium on Flash Floods in Wadi Systems

#### 25-27 October 2016

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**Statistical rainfall analysis for stations J102, and J134.**

![Graphs showing statistical rainfall analysis](image)

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**Comparison between RARUSM and HECHMS**

<table>
<thead>
<tr>
<th></th>
<th>Qp (m³/s)</th>
<th>Volume (1000 m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HECHMS</td>
<td>231.6</td>
<td>5430.3</td>
</tr>
<tr>
<td>RARUSM</td>
<td>231</td>
<td>5444</td>
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</table>

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**Conclusions**

- RARUSM Model is highly flexible rainfall-runoff spreadsheet model since it uses dimensionless equations.
- Its capability has been shown in this presentation.
- It produces almost identical results to HECHMS, however, it is more handy and easy to run various scenarios.
- The circular reference option in Excel allows to present continues changes in the runoff hydrograph due to changes in CN, storm pattern parameters, stochastic storms, and dimensionless hydrograph shape.

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**Future Work**

- Automation of some items in the model.
- Make it as a software.
- Make it more user friendly.
- Introducing uncertainty aspects in the model input and the corresponding model output.
- Make continuous variation of other parameters like rainfall intensity, duration, etc.
- Finding out the most suitable hydrograph shape for arid environment.

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Obtained from Elsisi et al. (2018)