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<td>Abdel-Fattah, Mohammed; Kantoush, Sameh; Saber, Mohamed; Sumi, Tetsuya</td>
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Kyoto University
Distributed Hydrological Modeling at Wadi Samail, Oman
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Keywords: Flash Flood, Wadi, Hydro-BEAM, RRI

Recently, flash floods are frequently occurring in the arid region as Oman, which counter with various challenges to the management of wadi flash floods. In the past, Oman hit by cyclone Gonu in June 2007 causing torrential flooding and severe damages where the economic loss was about 4 billion USD, as well as nearly 50 deaths. Mitigation measures and warning system have become more critical given the expected increased extreme events due to climate changes. Oman is an arid country, where the average annual rainfall, in its capital Muscat, is only 100 mm, while the average of the whole country is only 51 mm/yr varying from less than 20 mm/yr in the internal desert regions to over 350 mm/yr in the mountain areas. Wadi Samail at the coastal area of Oman is selected as case study for flash flood hydrological modelling. Rainfall–runoff responses predictions in arid climate as wadi system always presents unique challenges. One of the main challenges beside data limitation is the hydrological models themselves, where the majority of models developed for catchments that have different characteristics than other wadi systems. Hence, the need to evaluate the suitability of alternative modelling approaches for wadi system and its scarce dataset arises. In that regard, two distributed hydrological models are selected in this study. The first one is the Hydrological River Basin Environmental Assessment Model (Hydro-BEAM) and the other is the Rainfall-Runoff-Inundation (RRI) Model. Another aspect of this contribution is to focus on both structural measures for flash flood retention as dry dams, and water harvesting. The location of such mitigation structures must be carefully designed to avoid transferring the problems to the developed downstream area of the wadi. Moreover, mitigation structures should be designed in a coordinated manner, to assess their overall effect. This study analyzes the wadi flash flood mitigation for three cases: 1) no dams, 2) distributed small dams all over the catchment in the upstream, and 3) proposed large dam in the middle or downstream area of the wadi. The effect must be quantified through a comparison of the consequences with and without mitigation structures over the whole wadi. Various factors are considered to study and improve the assessment methodologies. The simulated scenarios highlighted significant differences in calculated hydrographs when using either distributed or concentrated dams scenarios for wadi Samail. This study is expected to conclude recommendations for hydrological modelling and management at wadi system in arid environments. The next questions address how to define dam height and reservoir volume. For better assessment of several dams options, clear quantification of evaluation factors and cost-benefit approaches should be included in future. Small dry dams are effective structures. Both, Hydro-BEAM and RRI models are efficient, and emphasizes the importance of taking into account the variability and spatial properties of rainfall patterns.
Distributed Hydrological Modeling at Wadi Samail, Oman

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2nd ISFF
Oct., 2016

• Wadi: Arabic term referring to valley.
• Wadi channel is usually dry except during heavy rain events.
• Flash flood: caused by heavy rainfall in short duration< 6 hrs.

Characteristics of Wadi

Discharges (m³/s)

Wadi System & Flash Floods

Flash Floods Caused By Cyclones

Cyclones History in Oman

Date | N | Rainfall (mm)
--- | --- | ---
June 1890 | T | 285
May 1963 | T | 202
Nov 1966 | T | 99
Dec 1971 | C | 430
Jun 1977 | C | 122
Mar 1999 | L | 69
Oct 1999 | C | 58
May 2002 | C | 116
Sep 2004 | L | 626
Jun, 2007 | C | 603
June, 2010 | P | 204
June, 2015 | A | 55

50 killed persons
4 billion USD losses

Gonu 2007 Cyclone

Damages of Flash Floods Disasters
Objectives

- Proposing innovative methodology for management of flash floods disaster in ungauged wadis.
- Check the applicability of Hydro-BEAM and RRI models using available data in W. Samail.
- Comparative study by 2 models Hydro-BEAM&RRI
- To find best scenario of DDR (distributed or concentrated dams)
RRI Model

• Rainfall-Runoff-Inundation (RRI) model is a two-dimensional model capable of simulating rainfall-runoff and flood inundation simultaneously (Sayama et al., 2012).

Mass Balance eq.\[ \frac{\partial h}{\partial t} + \frac{\partial Q_x}{\partial x} + \frac{\partial Q_y}{\partial y} = r \]

Momentum eq.\[ \frac{\partial}{\partial t}(\rho w h) + \frac{\partial}{\partial x}(\rho w h u) + \frac{\partial}{\partial y}(\rho w h v) + \frac{\partial}{\partial x}(\rho v \tau_x) + \frac{\partial}{\partial y}(\rho u \tau_y) = -g \rho w h \rho w h + \rho w h \rho w h + \rho w h \rho w h + \rho w h \rho w h\]

Diffusion Wave approximation

RRI Parameter Setting

<table>
<thead>
<tr>
<th>Parameter (default)</th>
<th>Range</th>
<th>Alluvium</th>
<th>Igneous</th>
<th>Sedimentary</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta_{sat}$ (0.03 m$^{-1/2}$ s)</td>
<td>0.015 – 0.04</td>
<td>0.022</td>
<td>0.022</td>
<td>0.022</td>
</tr>
<tr>
<td>$\theta_{dry}$ (0.3 m$^{-1/2}$ s)</td>
<td>0.15 – 1.0</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>$d$ (0.471 m)</td>
<td>0.15 – 1.0</td>
<td>0.14</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>$k$ (0.1 ms$^{-1}$)</td>
<td>0.01 – 0.3</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>$k_e$ (3.56*10$^{-6}$ m$^{-2}$)</td>
<td>6.54<em>10$^{-7}$ – 1.67</em>10$^{-6}$</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\phi$</td>
<td>0.3 – 0.5</td>
<td>0.475</td>
<td>0.475</td>
<td>0.475</td>
</tr>
<tr>
<td>$\lambda_e$ (0.3163 m)</td>
<td>0.0495 – 0.3163</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
</tr>
</tbody>
</table>


Relative hydrograph peak (PE), Coefficient of determination (squared correlation coefficient) ($r^2$), Percent bias (PBIAS), Nash-Sutcliffe efficiency (NSE), Gupta efficiency (KGE): $\text{PE} = 100 \left( \frac{\sum(Y_i - \bar{Y}_s)}{\sum Y_i} \right)$, $r^2 = \frac{\sum(Y_i - \bar{Y}_s)^2}{\sum Y_i^2 - \frac{1}{n} \left( \sum Y_i \right)^2}$, PBIAS = $100 \left( \frac{\sum(Y_i - \bar{Y}_s)}{\sum Y_i} \right)$, NSE = $1 - \frac{\sum(Y_i - \bar{Y}_s)^2}{\sum(Y_i - \bar{Y}_o)^2}$, KGE = $1 - \frac{\sum(Y_i - \bar{Y}_s)^2}{\sum Y_i^2 - \frac{1}{n} \left( \sum Y_i \right)^2}$

where $\bar{Y}_s$ and $\bar{Y}_o$ are the simulated and observed values, respectively, $\bar{Y}_s$ and $\bar{Y}_o$ are the mean observed and simulated values, and $\sigma_{Y_s}$ and $\sigma_{Y_o}$ are the standard deviation of the simulated and observed values.

Long Term Flash Flood Simulation at W. Samail

Discharge vs Inundation

Wadi Samail Dam

After Gonu 2007, it was clear that this dam is not enough and further mitigation structure is needed.
Different FF Mitigation Scenarios at Wadi Samail

- Mitigation scenario 1: One big concentrated dam
- Mitigation scenario 2: Three smaller distributed dams

<table>
<thead>
<tr>
<th></th>
<th>Concentrated Dam</th>
<th>Distributed Dam 1</th>
<th>Distributed Dam 2</th>
<th>Distributed Dam 3</th>
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<tbody>
<tr>
<td>Location Y</td>
<td>23.554344</td>
<td>23.554344</td>
<td>23.371903</td>
<td>23.360908</td>
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<tr>
<td>X</td>
<td>58.103665</td>
<td>58.103665</td>
<td>58.092958</td>
<td>58.157186</td>
</tr>
<tr>
<td>Reservoir Capacity (MCM)</td>
<td>75</td>
<td>40</td>
<td>9.6</td>
<td>25.8</td>
</tr>
<tr>
<td>Height (m)</td>
<td>30</td>
<td>40</td>
<td>22</td>
<td>22</td>
</tr>
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</table>

Proposed Flash Flood Mitigation Dams

Conclusion

- Wadi system have very unique features and should be considered in flash flood hydrological modelling and management.
- RRI model could be calibrated and validated efficiently to be used in wadi system.
- Distributed dams and concentrated dams strategies are efficient in flash flood mitigation.
- Distributed dams have advantage of upstream protection, local recharge.
- More evaluating parameters for the best mitigation scenarios should be considered:
  - Optimization of each function of dams
  - Economical point of view and maintenance

Thank you for your attention