Rainfall storm distribution effect on flood value for wadi Banban in Saudi Arabia

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Abstract

In arid regions rainfall storms are characterized by spottiness and short duration. Also in arid regions reliable rainfall and runoff data are rare and unreliable if available. Hence most engineers use methods developed for ungaged watershed for flood computations such NRCS (formerly SCS), Snyders and Regional Frequency Analysis method. Unfortunately, few works were published regarding the storm rainfall internal distribution and its effect on the flood peak value and time of occurrence in arid region. This paper will highlight the effect of different storm rainfall distribution on the flood hydrograph for wadi Banban in Riyadh region, central of Saudi Arabia.

Wadi Banban is located north east of Riyadh city with watershed area of 553 km² and basin length of 56 km and a basin slope of 2.8%. Wadi Banban flows from the upper north east of ArRiyadh to the south west when its confluence with wadi AlHosan to form wadi AsSolay which continue downstream passing through the east district of ArRiyad city.

IDF curve were developed for wadi Banban watershed and a number of historical storms were reviewed to develop the possible rainfall storm distribution. Different storm distributions were used to generate flood events using WMS and HEC-HMS softwares. Results shows that, rainfall storm distribution affect the flood peak discharge, and the time of its occurrence.

Introduction

Design hyetographs is an important task in the hydrologic designs as it has a significant influence on the shape and peak value of the hydrograph. For the establishment of design hyetographs, several methods are available in the literature. According to Chow et al. (1988), for gauged watershed, available methods can be classified into two categories. Design hyetographs produced from storm events (i.e. Huff (1967), Pilgrim and Cordery (1975), and Yen and Chow (1980)) or developed from IDF curves (i.e. the Chicago method, and the alternating block method). In addition to the above, a stochastic approach was used to develop design hyetographs Cheng et al. (2001). In the other hand, To obtain a design hyetograph for ungaged site, which is the case for most arid and semiarid regions, synthetic design hyetographs were used, such as triangular hyetographs, Soliman (2008) and SCS hyetographs.

The objectives of this paper are to study the effect of design hyetograph on the shape and peak value of flood hydrograph of wadi Banban and the consequences on the design of flood protection structures.

Study Area

Wadi Banban is the northern upper tributary of wadi AsSolay in ArRiyadh city, the capital of Saudi Arabia. It originates from the elevated sedimentary rocks of the Najd plateau that borders the Arabian Shield, approximately 1000m above sea level. Geology of Saudi Arabia indicates that the rocks outcrop in a great curving belt and form a series of essentially west-facing escarpments, each with a resistant limestone cap (the Jubaila Limestone ) (GoSA,1966). The rocks consist of alternating non-marine and marine units. Towards the east the lithology alternates between
marine shale and interbedded carbonates grading into sandstone to the south and north. Wadi Banban predominantly flows through the Upper Jurassic rocks consisting of mostly carbonate, shallow water limestone facies (GoSA,1966). Lime sand mixed with lime-mud predominates. Wadi Banban flows in a south/south-easterly direction in the ArRiyadh city north of King Khalid International airport before its confluence with Sha'eeb AlHosan to form wadi AsSolay. The wadi channel meanders and widens towards its lower reaches and wadi bed consists of Quaternary sandstone alluvium deposits. Figure 1 show wadi Banban and the boundary of the catchment area.

**Catchment Area Characteristics**

Riyadh region lies within a semi-arid climatic zone, in which it receives approximately 90mm of rainfall annually with an average daily temperatures of 37°C and the daily maximum rainfall on record is 70mm (Sen,2008). Rainfall is mostly observed throughout the months of November to February, and is observed less frequently throughout the months of June to August. The soil characteristic for the whole of the Wadi Banban catchment was considered to be represented by the NRCS (Natural Resources Conservation Service) soil group B. The catchment area consisted of topsoil dominated by loose to dense silty to loamy sand, partly sandy clay and silty sand with gravel in some areas (MAW 1995). These top soils are considered to have moderate infiltration potential which is represented by soil group B. Vegetation is sparse in the study area due to the semi-arid conditions.

![Figure 1: Wadi Banban catchment area boundary.](image)

The soil group information was represented as the Curve Number incorporated in the NRCS hydrological method for deriving the catchment peak flow.

Land use was obtained from the ADA as Shape files that detailed the extents of different land use categories (such as agricultural land, education areas, road networks). The information provided land use for 2008 and future projected changes in land use to 2023.

Digital Elevation Model (DEM) – ASTER GDEM data based on square cell size of 30m was used to derive hydrological catchment and sub-catchment areas utilizing WMS computer software. It was also used to provide the topographic elevation information for the hydraulic model simulations. The DEM was updated with observed information collected during site visits.

**Hydrologic Analysis**

Wadi Banban is like many areas in central Saudi Arabia, has no flow gauge data within the catchment and hence synthetic hydrograph will be used in this study. Rainfall data are collected from a nearby rain gauge station located 35 km south of the wadi Banban watershed. Riyadh R452(formerly R001) station started recording rainfall for short durations since
1964 and still running with 24h duration since 2001. Other stations are nearby but with total daily rainfall measurements. Rainfall data between the years 1964 to 2011 was used in several frequency analysis tests to generate annual maximum rainfall for different storm durations for specific return periods. The annual extreme values of precipitation for eight different recorded durations, namely: 10, 30 min and 1, 2, 3, 6, 12 and 24h have been extracted, and Gumbel method was found to represent the distribution properly. IDF curves for selected return periods are shown in Figure 2.

Figure 2: IDF curves for selected return periods for ArRiyadh.

More than 110 rainfall storms were extracted from the records and analyzed to understand the frequency, duration and the shape. Analysis of these storm shows that 60% of the storms has storm duration less than 7h, Figure 3, and maximum recorded storm was 32 mm for storm of 6h duration, Figure 4. This indicates that storm of short duration are more frequent and more severe as well, and hence this should be considered by modellers for better flood prediction.

**Methodology**

Based on the available data and using WMS and HEC-HMS computer packages, flow hydrographs were determined for different design storms. Total catchment area subdivided into 4 sub-catchments and the characteristic parameters for each sub-catchment were assessed. Figure 2 used to determine design rainfall intensity for predetermined storm durations and return periods.

Figure 3: Maximum rainfall depth for different storm durations.

Figure 4: percentage number of events for different storm durations.

From the above hydrologic analysis, recommended storm duration of 6 hours was selected. Also time-of-concentration for the subbasins ranges from 3.5h up to 4.9h which support the selected storm duration.
Three internal storm distribution were used, namely SCS, triangular and alternating block method. Six hours storm duration was used for 50 years return periods with total storm depth of 27.48 mm. For triangular hyetograph, storm advancement ratio (R) of 0.33 (Soliman, 2010) was used and for alternating block methods three hyetographs were developed, which extracted from IDF curves for regular intervals, for three storm advancement ratios, namely 0.25, 0.33 and 0.5.

The inflow hydrographs were created based on the SCS (now NRCS) unit hydrograph and corresponding SCS method to derive the peak flow and time to peak. Kirpich equation of the following form was considered suitable for the studied area (Wheater and Al-Weshah, 2002):

$$t_c = 0.01947 \ L^{0.77} \ S^{-0.38}$$  \hspace{1cm} (1)

Where, $t_c =$ time of concentration in minutes, $L =$ length of the longest path of water in metres and $S =$ the average slope of the basin.

Muskingum-Cunge routing method was used for flood routing through the wadi channels for selected cross section along wadi Banban.

Hydrographs determined from sub-catchment characteristics using SCS method.

**Flood Hydrographs**

Using WMS, wadi Banban catchment area was delineated into 4 subbasins. Basin characteristics including area length, slope and time of concentration were evaluated and Table 1 shows summary of subbasin characteristics.

Flood hydrographs for different storm hyetographs were computed according to the methodology mentioned above for similar conditions. Flood hydrographs for the upper subbasin are shown in Figure 5. This figure shows clearly that peak discharges affected clearly by the rainfall hyetograph, as for triangular distribution peak discharge was obtained equal to 45.6 m$^3$/s and occurred after 6:35 h from the beginning of the storm. While for Alternating block method for the same storm advancement ratio, the peak discharge was 47.6 m$^3$/s and occurred 4:35 h from the beginning of the storm. Maximum peak discharge was found from SCS method with value of 54.9 m$^3$/s at 3:45 h from the beginning of the storm.

On the downstream basin outlet, where flood routing considered from the upper subbasins, flood hydrographs are shown in Figure 6. This figure shows that SCS has the highest peak discharge of 133.6 m$^3$/s at 5.1 h from the beginning of the storm. Block method has highest peak discharges with 120.4 m$^3$/s at 6:20 h from the beginning of the storm for R=0.5 and for other storm advancement ratios, peak discharges reduced with reduced R value and peak occurs faster for low R values. Triangular distribution has the lowest peak discharge and the latest to occur compared to other hyetographs.

The above findings shows clearly that rainfall hyetograph plays important roles in flood peak value and time of occurrence of the peak and should be considered as a limiting factor in flood prediction in ArRiyadh region.

Table 1: Wadi Banban subbasins characteristics

<table>
<thead>
<tr>
<th>Subbasin</th>
<th>Area (km$^2$)</th>
<th>Length (m)</th>
<th>Slope (%)</th>
<th>CN</th>
<th>TC hrs</th>
<th>Max Flow (m$^3$/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2B</td>
<td>185.8</td>
<td>28837</td>
<td>0.275</td>
<td>81.97</td>
<td>4.23</td>
<td>35069</td>
</tr>
<tr>
<td>3B</td>
<td>160.7</td>
<td>21461</td>
<td>0.309</td>
<td>73.99</td>
<td>4.85</td>
<td>33188</td>
</tr>
<tr>
<td>4B</td>
<td>136.9</td>
<td>17652</td>
<td>0.235</td>
<td>84.71</td>
<td>3.52</td>
<td>28383</td>
</tr>
<tr>
<td>5B</td>
<td>68.51</td>
<td>15778</td>
<td>0.35</td>
<td>74.24</td>
<td>4.07</td>
<td>25099</td>
</tr>
</tbody>
</table>
The flood analysis showed clearly that rainfall hyetograph plays important roles in flood peak value and its time of occurrence. Hyetographs developed by alternating block method gave the highest peak discharges and fastest time of occurrence compared to those developed by triangular hyetograph. Hence rainfall hyetograph shape should be considered as a limiting factor in flood prediction in ArRiyadh region.

References
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