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Spatiotemporal Runoff Features of Hydrological Modeling in Arabian Wadi Basins through Comparative Studies

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Synopsis

The arid and semi-arid regions are characterized by scarcity of water resources, an ever-increasing demand on water supplies, the paucity of data, drought and flash flood threat. So, this paper aims to introduce an effective methodology for sustainable management and efficient utilization of the water resources as well as flood control in the arid regions to sustain a minimum resource base. A physically-based, distributed hydrological model was proposed in W. Al-Khoud (Oman), W. Ghat (Saudi Arabia) and W. Assiut (Egypt). This approach can satisfactorily evaluate Wadi runoff behaviors such as discontinuously surface flow and estimating transmission losses. A comparison study has been done between different wadis to understand the effect of watershed characteristics and climatic condition on Wadi runoff. The results of numerical simulation exhibit good fitting with the observed ones however the paucity of high quality data.

Keywords: transmission losses, Wadi system, kinematic wave model, discontinuously surface flow

1. Introduction

A wadi is a stream that runs full for only a short time, mostly during and after a rainstorm. Not every rainstorm, however, necessarily produces surface runoff. It is seldom that wadi flow at a certain section can be described as perennial. If so, the flow is then extremely variable from one event to another. In other words; Wadi is an Arabic word for ephemeral streams in the arid regions, and they are a vital source of water in most arid and semi-arid countries. Catastrophic flash floods occurring in wadis are, on one hand, a threat to many communities and, on the other hand, major groundwater recharges sources after storms. The scarcity of data and the lack of high quality observations as well as the potentially discontinuous occurrence of flow in both space and time are important characteristics of the ephemeral streams in the arid regions and consequently the difficulty of developing the powerful hydrological models.

One third of the world's land surface is classified as arid or semi-arid (Zekai, 2008). As stated by Pilgrim *et al.* (1988) and according to UNESCO (1977) classification, nearly half of the countries in the world face aridity problems.

In the arid areas, it is well known that there are many crucial problems, for instances, the shortage of water resources which affects the economic activity and human live and increasing the losses (evaporation, initial and transmission losses). Despite the critical importance of water in arid and semi-arid areas, hydrological data have historically been severely limited. Moreover, those countries of the arid areas are facing the problem of overpopulation, and consequently the demand of water resources for the agricultural, manufacturing and domestic purposes, in other words, these regions are undergone to severe and increasing water stress due to expanding populations, increasing per capita water use, and limited water resources. In the arid and semi-arid regions, appropriate utilization and strong management of renewable sources of water in wadis is the only optimal choice to overcome water deficiency problems.

Ephemeral streams are characterized by much higher flow variability, extended periods of zero surface flow and the general absence of low flows except during the recession periods immediately after moderate to large high flow events (Knighton and Nanson, 1997).

Generally the majority of countries in arid and semi-arid regions depend either on groundwater (from both shallow and deep aquifers) or on desalinization for their water supply, both of which enable them to use water in amounts far exceeding the estimated renewable fresh water in the country (IPCC, 1997). Also they depend on a small number of springs and falajes and treatment of waste water. However, there are some important water-related problems in these countries are the depletion of aquifers in several areas, saline-water intrusion problems, and water quality problems such as those associated with industrial, agricultural, domestic activities as well as human effect. All have a major threat to those scarce resources.

Floods are infrequent, but extremely damaging and represent a threat for human lives stability and their infrastructure, especially with the effect of regional climatic change all over the world.

The Arabian Peninsula as an arid to semi-arid region is suffering from low rainfall and high temperatures in addition to a high humidity in the coastal areas. Water resources are so limited, yet the availability of a sufficient supply of high quality water is the major requirement for social, industrial, agricultural and economic development of the region.

Effective water management, utilization of wadi surface flow and appropriate decision support systems, including modeling tools based on the availability of the data, as well as of their analysis are urgently needed. In this study, a trial is made to develop an effective methodology for estimation spatiotemporal surface runoff in some Wadi systems in different Arabian countries. Particularly, to overcome the prescribed struggles for water resources management and flood control purposes, in addition to evaluate the transmission loss and its effect on both surface and subsurface water. Moreover, investigating and depicting the characteristics of Wadi system and runoff behaviors in the arid regions.

2. Wadi system characteristics

In arid regions, water is one of the most challenging current and future natural-resources issues. The importance of water in arid regions is self-evident indeed. Water is not only the most precious natural resource in arid regions but also the most important environmental factor of the ecosystem.

The arid and semi-arid regions of the world are characterized by the expanding populations, increasing per capita water use, and limited water resources as well as draught and flash flood thread. The most obvious characteristics in the ephemeral streams in the arid areas are the initial and transmission losses in addition to the discontinuous occurrence of flow in both space and time.

Water resources in the arid and semi-arid regions, there are limited water resources, for instances; ground water which is the most important resource, desalinated water, and some perennial streams in some regions, however, the quality and quantity of them are inadequate to cover the current needs for domestic, agricultural, manufacturing and economic use in such arid areas. In the Arabian countries as Saudi Arabia, Oman, and Egypt, they depend mainly on the ground water as the main water resources however it is likely that the groundwater aquifers be contaminated and affected by the sea water intrusion.

Rainfall is the primary hydrological input, but rainfall in arid and semi-arid areas is commonly characterized by extremely high spatial and temporal variability. The temporal variability of point rainfall is well known. Annual variability is marked and observed daily maxima can exceed annual rainfall totals (Wheater *et al.*, 2008).

Initial losses occur in the sub-basins before runoff reaches the stream networks, whereas transmission losses occur as water is channeled through the valley network. Initial losses are related largely to infiltration, surface soil type, land use activities, evapotranspiration, interception, and surface depression storage.

Transmission losses are important not only with respect to their effect on stage flow reduction, but also to their effect as recharge to groundwater of underground alluvial aquifers. It was suggested that two sources of transmission losses could be occurring, direct losses to the wadi channel bed, limited by available storage, and losses through the banks during flood events as shown in Fig.1.

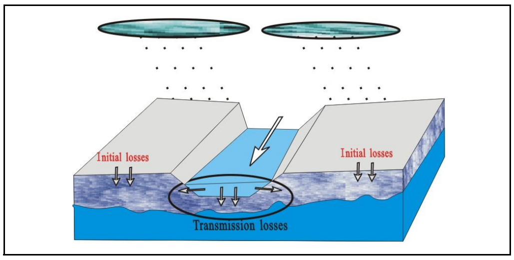


Fig.1 Conceptual model showing transmission and initial losses in the Wadi System

The rate of transmission loss from a river reach is a function of the characteristics of the channel alluvium, channel geometry, wetted perimeter, flow characteristics, and depth to groundwater. In ephemeral streams, factors influencing transmission losses include antecedent moisture of the channel alluvium, duration of flow, storage capacity of the channel bed and bank, and the content and nature of sediment in the stream flow. The total effect of each of these factors on the magnitude of the transmission loss depends on the nature of the stream, river, irrigation canal or even rill being studied (Vivarelli and Perera, 2002).

Transmission losses in semiarid watersheds raise important distinctions about the spatial and temporal nature of surface water–groundwater interactions compared to humid basins. Because of transmission losses, the nature of surface water–groundwater interactions can be limited to brief periods during runoff events and to specific areas associated with the runoff production and downstream routing (Boughton and Stone, 1985). Walters (1990) and Jordan (1977) provided evidence that the rate of loss is linearly related to the volume of surface discharge. Andersen *et al.* (1998) showed that losses are high when the alluvial aquifer is fully saturated, but are small once the water table drops below the surface.

Sorman and Abdulrazzak (1993) provided an analysis of groundwater rise due to transmission loss for an experimental reach in Wadi Tabalah, S.W. Saudi Arabia and they stated that about average 75% of bed infiltration reaches the water table.

Surface water–groundwater interactions in arid and semi-arid drainages are controlled by transmission losses. In contrast to humid basins, the coupling between stream channels and underlying aquifers in semiarid regions often promotes infiltration of water through the channel bed, i.e. channel transmission losses (Boughton and Stone, 1985; Stephens, 1996; Goodrich *et al.*, 1997).

The relationship between Wadi flow transmission losses and groundwater recharge depend on the underlying geology. The alluvium underlying the Wadi bed is effective in minimizing evaporation loss through capillary rise (the coarse structure of alluvial deposits minimizes capillary effects). Wheater *et al.* (1997) and Telvari *et al.* (1998) stated that surface water and groundwater interactions depend strongly on the local characteristics of the underlying alluvium and the extent of their connection to, or isolation from, other aquifer systems. Sorey and Matlock (1969) reported that measured evaporation rates from streambed sand were lower than those reported for irrigated soils.

3. The Target Watershed Basins

Due to the aforementioned characteristics and problems of Wadi system in the arid and semi-arid regions, some Wadi catchments were selected from the Arabian countries in this study for application such as Wadi Alkhoud in Oman, Wadi Ghat in Saudi Arabia, and Wadi Assiut in Egypt. They were selected due to their importance not only as water resources but also as flash flood and drought threat. In other words, due to the direct and major impact of wadi system on security of life of urban and rural populations in such regions.

3.1 Wadi Al-Khoud in Oman.

Wadi Al-Khoud in Oman is located in the northern part of Oman and at the western-north part of Muscat, the capital of Oman. The downstream of catchment is towards northeast Gulf of Oman. It is located between Long: 57° 58′ W & 58° 02 E ′ and Lat: 24° 00′ N & 23° 00 S ′ as shown in the location map Fig 2.

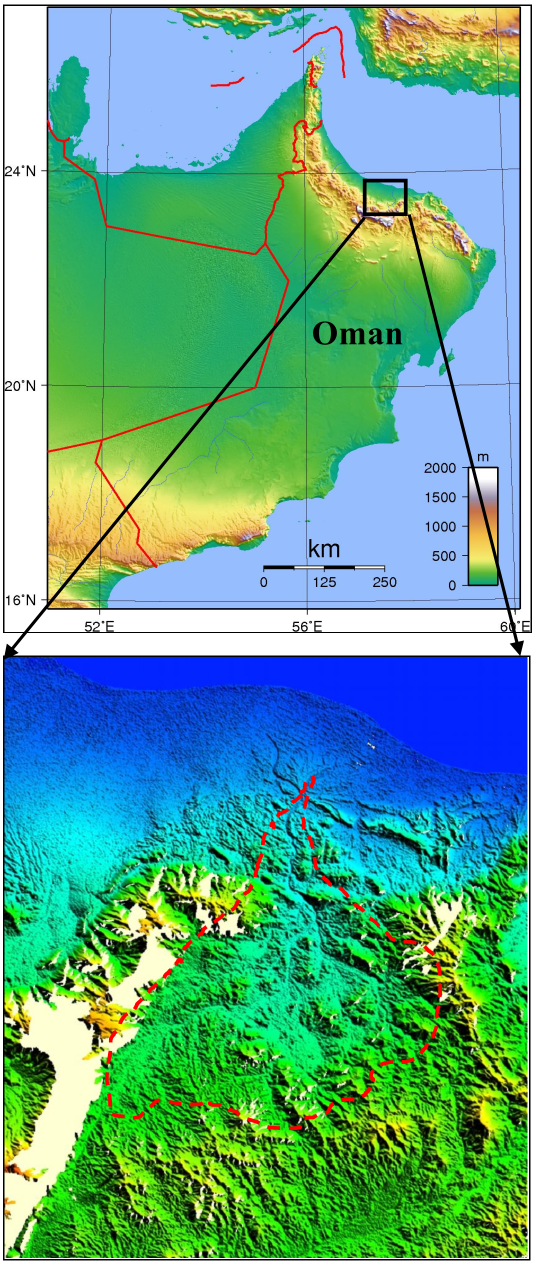


Fig. 2 Location map and DEM of W. Al-Khoud watershed, Oman.

The total area of its catchment is 1874.84 Km^2 as calculated from SRTM DEM, 100 m resolution using ArcView GIS. It is characterized by arid zone characteristics and its importance as the main water resources for use in this area, especially for agriculture and domestic purposes.

3.2 Wadi Ghat in Saudi Arabian.

Wadi Ghat watershed is a sub-catchment of Wadi Yiba, one of the Saudi Arabian basins in the south-western part of the kingdom, and drains from the Asir Mountain Range towards the Red Sea as shown in Fig. 3.

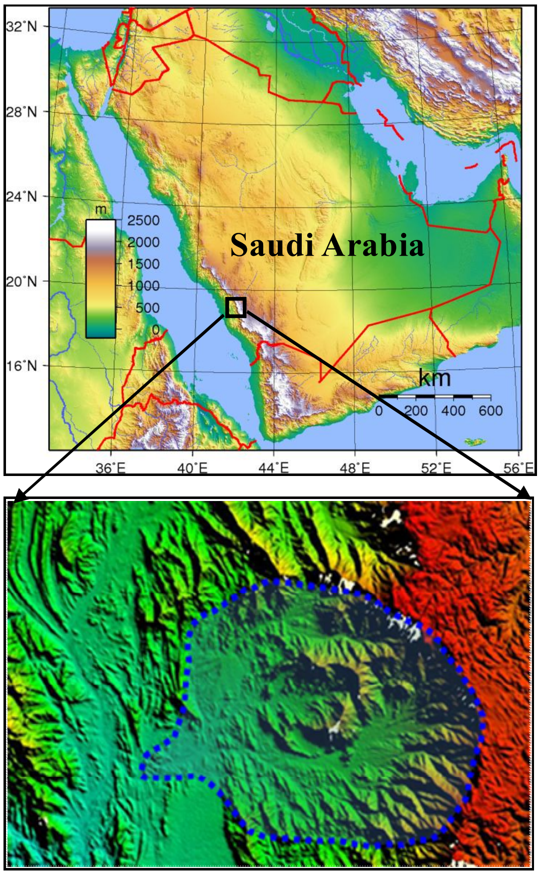


Fig. 3 Location map and DEM of Wadi Ghat Watershed, Saudia Arabia.

It is located between Long: 41° 46′ W & 42° 10 E ′ and Lat: 19° 20′ N & 19° 00 S ′. The total area of its catchment is 649.55 km2 as calculated from DEM using GIS. It is characterized by arid zone characteristics, and approximately 90 percent of the catchment comprises of rock outcrop and shallow soils. Annual precipitation is 322mm and approximately 90% of the catchment consists of rocky outcrops and shallow soils. Intense convectional rain storms produce typical flash floods with steep rising limbs and rapid recession to zero base flow.

3.1 Wadi Assiut in Egypt

Wadi Assiut watershed (Fig. 4) is located in the Eastern Desert of Egypt. It is one of the most populous countries in Africa. The great majority of it estimated 80 million people live near the banks of the Nile River and in the Nile Delta, in an area of about 40,000 square kilometers, where the only arable agricultural land is found. Thus finding and proposing new and appropriate regions to overcome the ever-increasing of population is urgently needed. Wadi Assiut Watershed is located between Long: 32°30′ E & 31°12 W ′ and Lat: 27°48′ N & 27°00 S ′, and it is considered as sub-basin of the Nile River Basin.

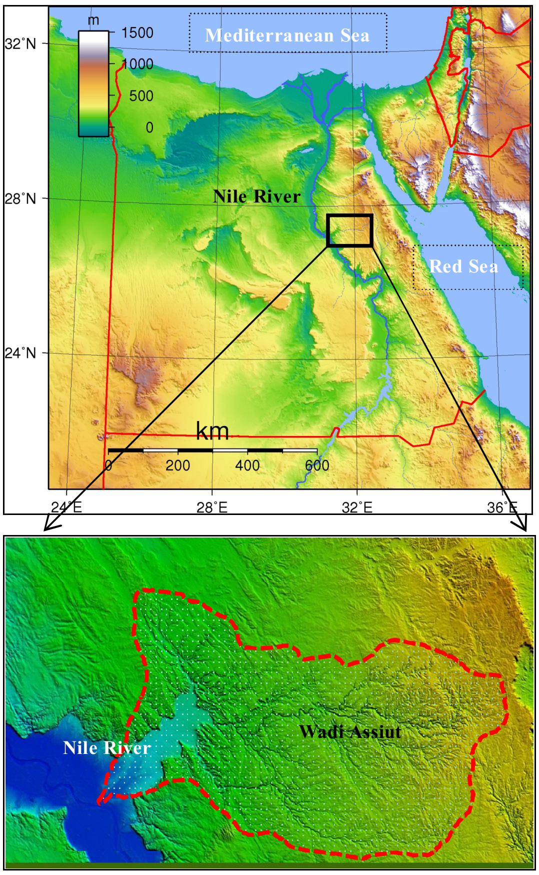


Fig. 4 Location map and DEM of W. Assiut

The total area of Wadi Assiut catchment is 7109 km2, the perimeter is 496.91 Km and the length of the main channel is 165.09 km. Most of its area is a desert except some part of urbanization, and very small areas of agriculture which are closed to Assiut city along the Nile River Basin. So, studying this area is important due to the propagation of populations and consequently the demand of water resources for agricultural, domestic, social and industrial activities.

Wadi Assiut catchment has undergone a number of improvements over the past centuries, where many of the past studies were applied and many of projects established there due to its importance. Presently, the establishment of new town, which will be in the near future crowded by populations and consequently the importance of hydrological modeling for water resources management and flood threat control, is so essential.

4. Methodology and Model components

Due to the severe problems in the Wadi system in the arid areas, it is recommended to develop distributed hydrological models, including surface water/groundwater interactions in the active Wadi channel, sediment transport, evaporation processes and consumptive use of Wadi vegetation, and the wider issues of groundwater recharge. These are challenging studies, with particularly challenging logistical problems, and require the full range of advanced hydrological experimental methods and approaches to be applied. A distributed hydrological model in the Wadi system is proposed. This model is based on the modification of Hydro-BEAM (Hydrological Basin Environmental Assessment Model) which has been chosen for simulation the surface runoff model and estimation of the transmission losses.

Hydro-BEAM was first developed by Kojiri *et al.* (1998) as a tool to assist in simulating long-term fluctuations in water quantity and quality in rivers through an understanding of the hydrological processes that occur within a watershed. It has since been used in a pioneering work on comparative hydrology, where a methodology for assessing the similarity between watersheds was proposed (Park *et al.*, 2000), to investigate sediment transport processes in the large watershed of the Yellow River, China (Tamura and Kojiri, 2002), and to investigate pesticide levels in rivers and their effects on hormone levels in fish (Tokai *et al.*, 2002).

The proposed approach is a physically-based numerical model and it can be summarized as following; the watershed modeling using GIS technique is processed, surface runoff and stream routing modeling based on using the kinematic wave approximation is applied, the initial and transmission losses modeling is estimated by using SCS (1985) method (an empirical model for rainfall abstractions suggested by the U.S Soil conservation Service) and Walter's equation (1990) respectively, Groundwater modeling based on the linear storage model is used.

4.1 Model Components

Rainfall-runoff modeling is the process of transforming a rainfall hyetograph into a runoff hydrograph. This can be achieved through the use of data-driven or statistical mathematical techniques, through developing physical descriptions of the rainfall-runoff process, or through various combinations of these approaches.

Hydro-BEAM has been chosen for simulation the surface runoff in the arid area due to its flexibility of application to accomplish many purposes of hydrological simulation.

The watershed is modeled as a uniform array of multi-layered mesh cells, each mesh containing information regarding surface land use characteristics, ground surface slope direction, runoff, and the presence/absence of a channel. The original Hydro-BEAM model that was used for the humid conditions can be adopted for simulation in the arid areas in Wadi system as described in the following sections. Initial and transmission losses are evaluated as subroutine model in Hydro-BEAM in this study, as crucial resource for the subsurface water in such areas.

The watershed to be investigated is divided into an array of unit mesh cells. A mesh cell can be arranged as a combination of a surface layer and several subsurface layers. The following description considers Hydro-BEAM calibrated with four subsurface layers, labeled A, B, C and D. A-Layer is calibrated using kinematic wave model for the overland flow evaluation and the other C-D layers (subsurface layers) are calculated by the linear storage model.

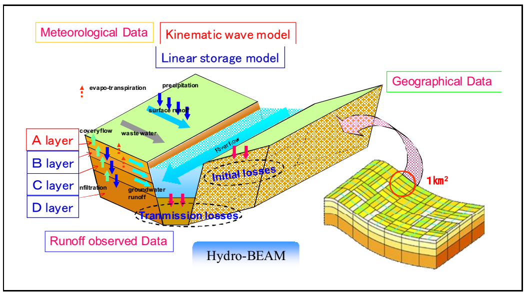


Fig. 5 Conceptual model of Hydro-BEAM

(1) Watershed Modeling

The data of digital elevation model (DEM, (SRTM （Shuttle Radar Topography Mission), 100 m resolution) can be used to delineate and determine the watershed and stream networks in the studied Wadi basins.

By processing DEM using Global Mapper and Golden Surfer softwares, then importing the data into Arcview GIS tool, the watershed basin, sub-basin watersheds were delineated and stream networks were determined for the target Wadi catchments (Wadi Al-Khoud (A), Wadi Ghat (B), Wadi Assiut (C)) as shown in Fig. 6.

Some geomorphologic information such as watershed area, perimeter, and main channel length were calculated. the following processes in the watershed modeling must be taken in consideration such as:

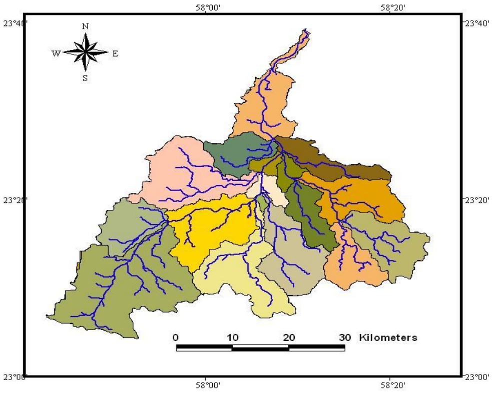
i) determination of the watershed boundary location,

ii) division of the watershed into a regular grid of mesh cells (1 km or 2 km),

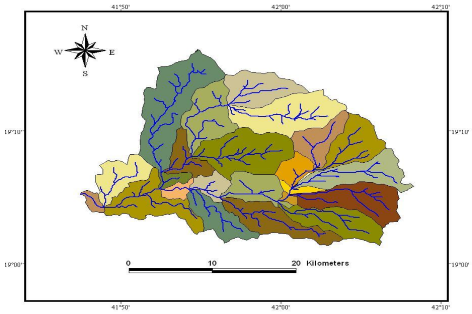
iii) determination of a flow routing network based on mesh cell elevation as given by a DEM and checked against a topographical maps.

(a) Flow Routing Map

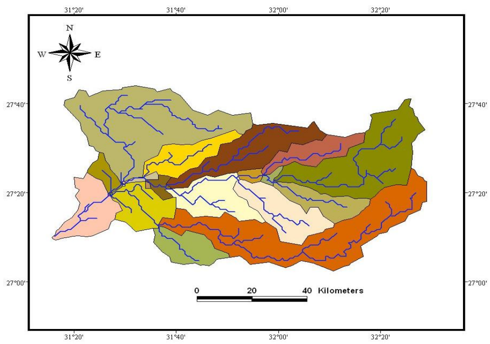
As well known, there are two types of flow routing system; 4 directions and 8 directions to determine drainage of flow water direction of drainage basin. Hydro-BEAM was originally developed to use a 4-direction flow routing map.



(A)



(B)



(C)

Fig. 6 Watershed delineation and stream network determination of Wadi Al-Khoud (A), Wadi Ghat (B), Wadi Assiut (C).

The function of a flow routing map is to define a downstream destination for the discharge resulting from every cell in the watershed, with the exception of the furthest downstream mesh cell located at the watershed mouth. Flow direction from any given mesh cell can be estimated using the DEM elevations of the corners of each mesh cell as declared in Fig. 7.

Where the flow path of each mesh is decided based on the elevation values of each corner. On the other hand, the perpendicular direction of slope of the two half of the mesh is estimated based on dividing of each mesh into 20 parts. So, the flow direction in each mesh depends on the direction of its slope, then manually the opposite and paradox flow directions can be corrected based on the elevation and topographic maps.

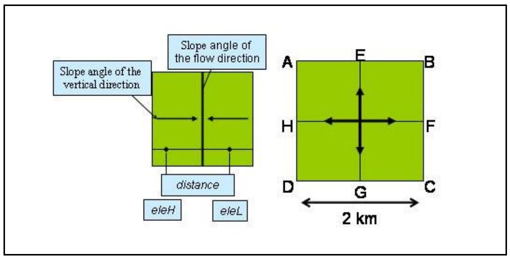


Fig. 7 Schematic diagram of the flow direction determination

(b) Land Use Classification

Land use information is used to specify the structure of each mesh, its infiltration and runoff characteristics. Hydro-BEAM is set to use five categories of land use types, where they are grouped and represented as a percentage land cover of the total area of the mesh cell.

The land use distribution data of the world, GLCC (Global Land Cover Characterization) and ECOCLIMAP Data (a global database of land and surface parameters at 1km resolution in meteorological and climate models) were used for identify and extract the land use distribution of the studied Wadis.

Land use data of GLCC is divided into 24 land use types. For the reason of hydro-BEAM is set to use five land use categories, we reclassified those types 24 into 5 types to be compatible with Hydro-BEAM, The five categories of land use types are; Forests, paddy field (rice field), desert, urban or city, water as given in table 1.

Table 1 Land use types of modified Hydro-BEAM

Category	Description
Forests	Densely-vegetated regions (forests)
Field+ Paddy field	Agricultural regions including farms
Desert	Most of the Wadi areas are desert

Urban area	Paved or impervious urban regions
Water body	Bodies of water

(2) Climatic Data

The metrological data are needed for each mesh in hydro-BEAM as input data to calculate evapotranspiration. So, the climatic data of NCDC （National Climatic Data Center）, Global Hourly data (Table 2) can be used in this work. Due to the lacking of many kinds of data, we adopted Thornthwaite method to calculate daily mean potential evapotranspiration as given in Equations 1, 2, 3, and 4. The mean air temperature and duration of possible sunshine of each mesh are needed as meteorological data for our model.

$$E_p = 0.553 D_0 \left(\frac{10T_i}{J} \right)^a \quad (1)$$

$$a = 0.000000675J^3 - 0.0000771J^2 + 0.01792J + 0.049293 \quad (2)$$

$$J = \sum_{i=1}^{12} \left(\frac{T_i}{5} \right)^{1.514} \quad (3)$$

$$E_a = M \times E_p \quad (4)$$

Where, E_a, *and* E_p *(mm/d)* are the actual and the potential evapotranspiration; *Ti* (^0C) is the monthly average temperature, *J*: Heat index, D_0 *(h/12h)* is the potential day length and *M* is the reduction coefficient, vapor effective parameter.

Table 2 Types of input data and its resources

Type of data	Source of the data
DEM Data; SRTM (Shuttle Radar Topography Mission)	CGIAR-CSI (Consortium for Spatial Information)
Land use; GLCC (Global Land Cover Characterization) And ECOCLIMAP data (1 km resolution)	USGS(U.S. Geological Survey)
Climatic Data; Surface Data, Hourly Global data	NCDC(National Climatic Data Center)

(3) Kinematic Wave Model

The kinematic wave equations as given in Equations 5 and 6 are derived from the St. Venant equations by preserving conservation of mass and approximately satisfying conservation of momentum. The momentum of the flow can be approximated with a uniform flow assumption as described by Manning's equation. In this study, kinematic wave approach is applied for surface runoff and stream routing modeling based on using the kinematic wave approximation with the assumption of the river channel cross section is supposed as a triangle shape.

A finite difference approximation of the kinematic wave model can be used to model watershed runoff on the surface and layer A in Hydro-BEAM. The various features of the irregular surface geometry of the basin are generally approximated by either of two types of basic flow elements: an overland flow element, or a stream- or channel- flow element. In the modeling process, overland flow elements are combined with channel-flow elements to represent a subbasin.

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = r(x,t) \quad (5)$$

$$q = \begin{pmatrix} \alpha (h - d)^m + ah \\ ah \end{pmatrix}, \quad when \begin{pmatrix} h \geq d \\ h < d \end{pmatrix}, d = \lambda D \quad (6)$$

Where, $\alpha = \frac{\sqrt{sin\,\theta}}{n}$ (Manning),

$a = \frac{k \sin\theta}{\lambda}$ (Darcy), $m = \frac{5}{3}$

Where, *h*: water depth (m), *q*: is discharge per unit length of flow [m^3/m.s], *r* is rainfall intensity [m/s], *t* is time [s], *x* is distance from the upstream edge, and α, m is constant concerning friction, sinθ: Slope, *n*: Equivalent roughness $m^{-1/3}s$ of slope and *k*: hydraulic conductivity ms^{-1}, *λ*: porosity -,*D*: Thickness (m), *d*: Saturation pondage m

In Hydro-BEAM, the integrated model of kinematic wave is used for surface flow and A-layer, where the paddy field is formulated as the double

Tanks Model where the upper tank is recognized as the surface zone. The upper hole in the tank means the overflow discharge from the surrounding paddy path, the lower hole does the runoff discharge from normal release gate and the infiltration rate through paddy path, and the bottom hole does the vertical infiltration. The water demand to be supplied is calculated as the difference between water depth of the surface tank and the desired ponding depth as expressed in Equations 7 and 8.

$$\frac{dh}{dt} = r(x,t) - q \tag{7}$$

$$q = \sum_j a_{P_j} \max\left(h - Z_{AP_j}, 0\right) \tag{8}$$

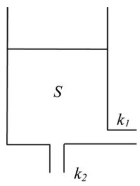
Where, h: Storage height m, and AP: subscription of compound tank model constant s-1 and Z_{Ap}: Compound tank model constant (m).

(4) Linear Storage Model

Linear storage method as given in Equations 9 and 10 is used for modeling of groundwater in layers B, C, and D layers in each mesh of the catchment area, thus the ground water storage can be evaluated in the proposed model.

$$\frac{dS}{dt} = I - O \tag{9}$$

$$O = (k_1 + k_2) \cdot S \tag{10}$$



Where S: is storage amount [m], I: is inflow [ms^{-1}], O: is outflow [ms^{-1}], k_1, k_2: are outlet coefficients.

(5) Initial and Transmission Losses Model

Due to the importance of the losses in the arid areas, one subroutine was added to Hydro-BEAM to calculate the initial and transmission losses in each mesh.

(a) Initial Losses

Initial losses occur in the sub-basins before runoff reaches the stream networks. It is related largely to infiltration, surface soil type, land use activities, evapotranspiration, interception, and surface depression storage. In other words, the initial abstraction I_a, which is equal to the accumulated rainfall from the beginning of the storm to the time when direct runoff started.

The NRCS method is adopted to calculate initial losses in the target catchments. The method is suited for humid, arid and semiarid conditions (SCS. 1985) and it has been successfully applied to ephemeral watersheds in SW US (Osterkamp *et al.* 1994), which resemble the desert in Oman, Saudi Arabia and Egypt, climate, topographical and land use. Runoff in sub basins occurs after rainfall exceeds an initial abstraction (I_a) value. Rainfall excess, P_e, in NRCS method is related to the effective potential retention value, S, as given in Equation 11.

The curve number (CN) method uses the following Equations 12, 13 and 14:

$$P_e = \frac{(P - I_a)^2}{(P - I_a) + S} \quad \text{for } P > I_a ,$$

$$P_e = 0 \quad \text{for } P < I_a \tag{12}$$

$$I_a = \lambda S \tag{13}$$

$$CN = \frac{25400}{254 + S} \tag{14}$$

Where: P is the depth of rainfall (mm), P_e is the depth of runoff or excess rainfall (mm), I_a is the initial abstraction (mm), S is the maximum potential retention after runoff begins (mm). λ is a dimensionless parameter varying from 0 to 1, CN is the curve number.

The initial abstraction is suggested by NRCS to be approximately 20 % of the maximum potential retention value. It consists mainly of interception, infiltration prior to runoff, and surface storage, and it is related to potential maximum retention (Empirical relationship of Ia and S) as given in Equation 13.

The optimum values of λ obtained in the least squares fitting procedure were around 0.05 for most experimental plots which was observed by Hawkins *et al.* (2002). Therefore, it was decided to set it as 0.05 in this research. In some other studies similar low initial abstraction ratio are close to the suggested ratio of 0.05 (Hawkins *et al.*, 2002) have been reported (Mishra and Singh, 2004; Jiang, 2001).

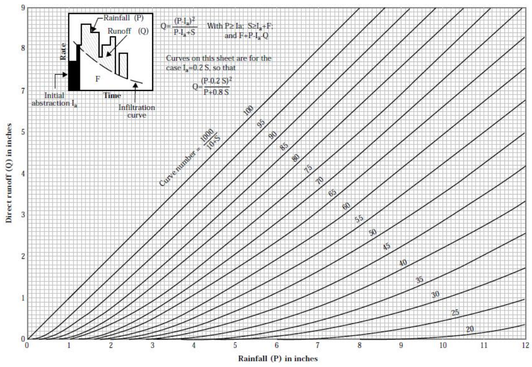


Fig. 8 Curve number values based on SCS method to estimate intial abstractions.

The catchment's capability for rainfall abstraction is inversely proportional to the runoff curve number. For CN = 100, no abstraction is possible, with runoff being equal to total rainfall. On the other hand, for CN = 1 practically all rainfall would be abstracted, with runoff being reduced to zero as declared in Fig. 8 (SCS, 1997).

The curve number CN value depends on hydrologic soil group and land use cover complex. The hydrologic soil groups are A, B, C, and D. They are classified based on the soil type and infiltration rate. So, based on the land use, soil type and infiltration rate, the curve number of the land use can be estimated as given in table 3.

Table 3 Curve number values of the land use type

Land use	Soil group	Curve number
Forests	A	45
Field	B	71
Desert	A	63
Urban	B	86

(b) Transmission Losses

Transmission losses are important not only for their obvious effect on flow reduction, but also as a source of ground water recharge to underlying alluvial aquifers. The variables that are considered useful in estimating the variation in the transmission loss included; 1-the flow volume at the upstream end of the reach, 2-channel antecedent condition, 3-chaneel slope, 4- channel bed material, the duration of the flow, 5- channel width. Two regression model forms were developed by Walter's (1990) to assess transmission losses as given in Equations.15 and 16. Units of the two equations were converted from its original units (acre-ft) into metric units (cubic meter) as follow:

$$V_1 = 2.72975836 \times 10^{-6} W^{1.216} V_A^{\ 0.507} \qquad (15)$$

$$V_1 = 0.025734951 V_A^{\ 0.872} \qquad (16)$$

Where V_1 =transmission loss for the first kilometer (cubic meter), V_A = upstream flow volume (cubic meter), W=active channel width (m).

The first equation was adopted in this study to estimate transmission losses where transmission losses can be estimated in each mesh based on the flow direction from the upstream to the downstream point.

5. Numerical Simulation and Discussions

Hydro-BEAM is a multilayer hydrological model, four layers (A-D) ; A-Layer is composed of the surface and soil surface layer. kinematic wave model and Manning equation are used to estimate the surface runoff and roughness coefficient in each mesh of the watershed basin. B-D-Layers are subsurface layers, which are evaluated using linear storage model, with the assumption of that the flow in both of B and C layers is toward the river, but D-layer is considered as groundwater storage. It makes the ground-water zone which does not exert influence in river flow. When storage water content reaches to thickness and becomes saturated state, water content flows into the upper layer of model as returns style.

Modeling processes and programming were accomplished using programming language of FORTRAN. Hydro-BEAM consists mainly of three main modeling parts; climatic modeling, watershed modeling and the main program modeling. The simulation periods are chosen based on the availability of data in the target basins where the geographical and climatic data of 2007 (three rainfall events) are used in Wadi Al-Khoud, 1985 (one rainfall event) in Wadi Ghat and from 1994 to 1995 (one rainfall event) in Wadi Assiut.

The watershed modeling of the selected Wadis is achieved based on DEM (SRTM, 100 m resolution) by processing it using Arc View GIS.

The Digital Elevation Models of Wadi Al-khoud, Wadi Ghat, and Wadi Assiut are developed as declared in Fig. 9 A, Fig 10 A, and Fig 11 A, respectively. It is clear that the maximum elevation in W. Al-Khoud and W. Ghat is about 2000 m but in W. Assiut is approximately 900 m, on other words, they more steep than W. Assiut, hence; the elevation has a big influence on runoff characteristics in these basins.

Land use types can be reclassified from using GLCC data and ECOCLIMAP data into five categories. Land use types in the arid regions were distinguished into the flowing five categories as follow; forests, field (paddy field & field) and field, desert, city or urban areas and Water. The results of land use distribution in the target basins were depicted as Forests, field, desert, city, and water for W. AL-Khoud, W. Ghat, and W. Assiut as shown in Fig. 9 (B-D), Fig. 10 (B-D), and Fig. 11 (B-E), respectively.

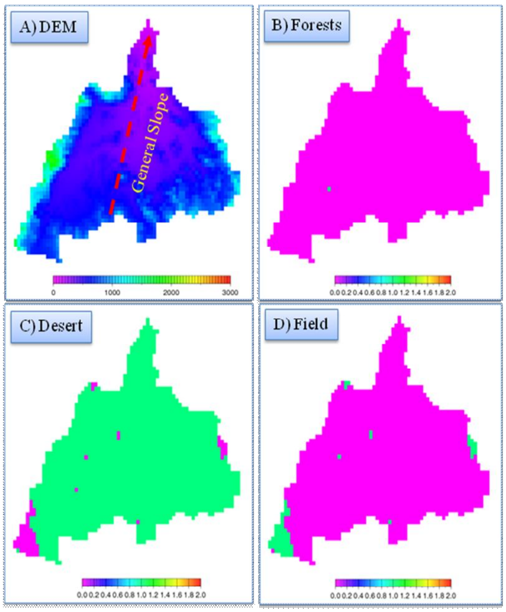


Fig. 9 Digital elevation model (DEM) (A), and distribution maps of forests (B), field (C), desert (D) of Wadi Al-Khoud

From the distribution maps of land use types, it was found that the forests, urban and water are limited in the target wadi bsins except in some small parts. Field land use type is distributed in some parts in the wadis especially at the vicinity of downstream. One the other hand, majority of Wadis is desert areas which reveal the aridity conditions of these regions.

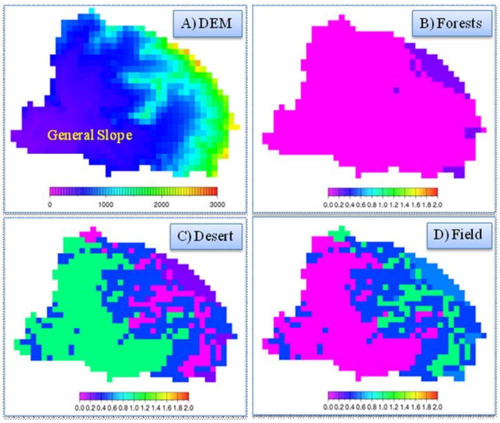


Fig. 10 Digital elevation model (DEM) (A), and distribution maps of forests (B), field (C), desert (D) of Wadi Ghat.

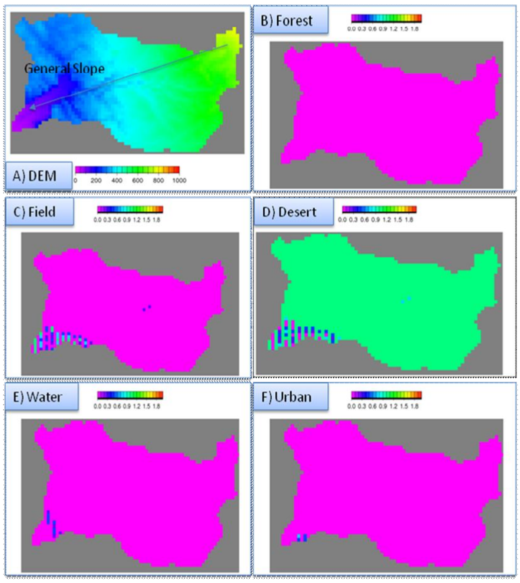


Fig. 11 Digital elevation model (DEM) (A), and distribution maps of forests (B), field (C), desert (D), city (E), water (F) of Wadi Assiut.

The climatic data of the three catchment areas as modeled from NCDC and ECOCLIMAP data showing the relationship between temperature and actual evaporation using Thowrnthwaite method to estimate evaporation, and the rainfall events showing the frequency of rainfall in the studied regions. Rainfall is the main input in the hydrological models of runoff and it has the largest effect on the conditions of runoff hydrographs. The more frequent events the highest discharge peaks and longer duration of flow.

It is obvious that from rainfall events charts showed that the average of rainfall events in W. Al-Khoud is multiple events every year which are more frequent than W. Ghat where it is one event every two years. But in W. Assiut is one event every five years as shown in Figs. 12, 13 & 14.

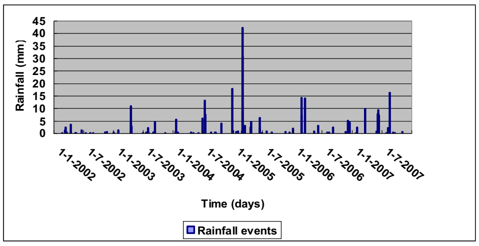


Fig. 12 Rainfall events of W. Al-Khoud (2002- 2007).

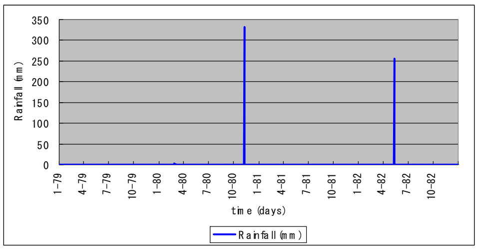


Fig. 13 Rainfall events of W. Ghat from 1979-1982

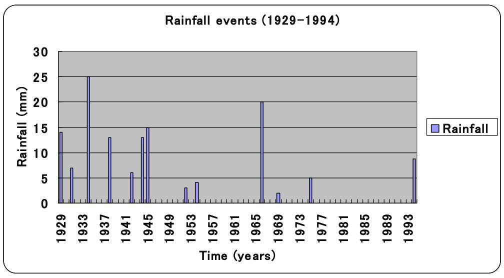


Fig. 14 Rainfall events in Wadi Assiut from 1929-1994, where the average of events one event every five years.

The aforementioned conclusion is based on the available data and these conditions might be different if we considered another historical data. Rainfall events reflect the degree of aridity where W. Assiut more arid than the other two wadis

The surface flow discharge in the arid regions is characterized by behaviors which are different from the humid areas. It is showing short time for starting and finishing the flood event, in other words, it is extremely steep rising and rapid recessing during the same event. In addition to, there is a lag time between the rainfall hyetographs and runoff hydrographs.

In this work, surface runoff was estimated in wadi Al-Khoud using the climatic and topographical data of one year (2007) due to the availability of observed runoff data; however they include some missing data. The simulated results of discharge is showing good fitting with the observed ones. One of the most important merits of this work is evaluating multiple consequent storm events in spite of their including rainy and non rainy periods as well as the time difference between the events is almost big. The simulated hydrographs of the three infrequent events of rainfall were accomplished very well as depicted in Fig.15

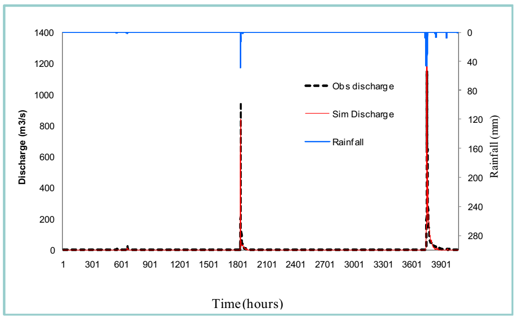


Fig. 15 Hourly hydrographs of simulated and observed discharges in wadi Al-Khoud during three infrequent events of rainfall.

The first event is two small consequence events (Feb. 23- 2007). It exhibits not so good agreement between hourly simulated hydrographs and observed ones as shown in Fig 16.

The second event is strong storm during (Mar. 18- 2007), where the maximum peak of the observed runoff is 950 m^3/s and the maximum peak of the simulated runoff is 838 m^3/ indicating satisfied fitting between both of them however there is underestimate in the peak value of simulated discharge as shown in Fig. 17.

The third event is also strong storm during (Jun. 6- 2007). The maximum peaks of the observed and simulated hydrographs are 1185 m^3/s and 1200 m^3/s respectively as declared in Fig. 18.

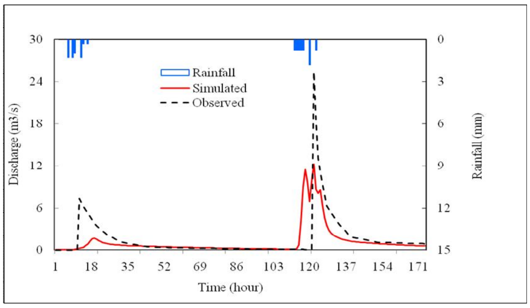


Fig. 16 Hourly hydrographs of simulated and observed discharges in wadi Al-Khoud during two small consequence events (Feb. 23- 2007)

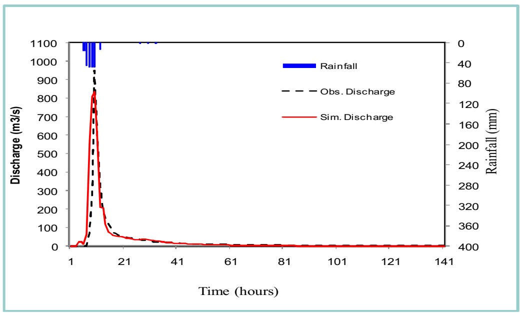


Fig. 17 Hourly hydrographs of simulated and observed discharges in wadi Al-Khoud during the event (Mar. 18- 2007)

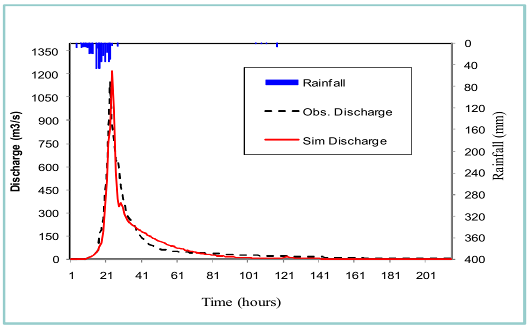


Fig. 18 Hourly hydrographs of simulated and observed discharges in Wadi alkhoud during the event of (Jun. 6- 2007)

From these results of numerical simulation of rainfall-runoff modeling, it is obvious that there are notable agreements between both of simulated and observed hydrographs of discharge in W. Al-Khoud which reflects appropriate performance of the proposed approach to predict or forecast the future events, which will be our mission after this work.

Furthermore, the characteristics of wadi runoff were evaluated in this research and they were concluded as follow:

- Both of hyetographs and hydrographs are not simultaneous, but there is a time lag in the hyetograph peaks with respect to hydrograph peaks.
- Hydrographs starting and cessation time is so short, it takes some hours.
- The runoff hydrographs are showing only direct flow not base flow as humid regions.

The model parameters of wadi system were identified based on these results where the average of runoff coefficients fluctuates between 0.608 and 0.653 for desert and 0.135 for forests. Roughness coefficient also fluctuates in the range from 0.02 to 0.07 for the different kinds of land use.

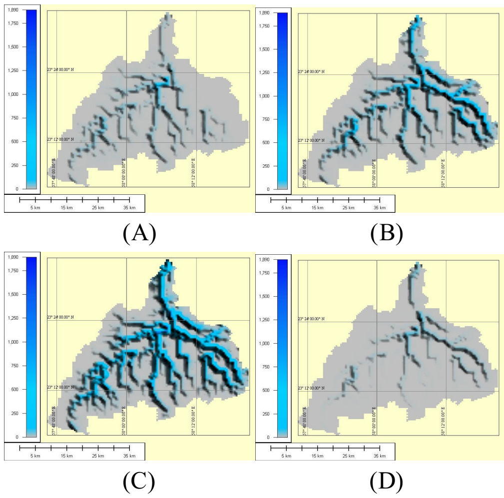


Fig. 19 Distribution maps of surface runoff of event of (Mar. 18- 2007) in W. Al-Khoud; (A) Early stage of surface flow, ; (B) hydrograph is rising toward the maximum peak of discharge; (C) reaching to the maximum of distribution; (D) starting the recession of surface flow to zero flow.

The distribution maps of surface runoff in Wadi Al-Khoud reveal the characteristics of wadi flow during the different stages of the hydrographs. For instance, at the early stage of flow or rising of the hydrograph limb toward the maximum peak, discontinuously surface flow appeared and with increasing the flow rate, this phenomena of discontinuously surface flow will be connected so that reaching to the maximum flow and finally in the stage of ascending of hydrograph, the discontinuously occurrence of surface flow will appear again until the flow will be zero flow (Fig.19). The discontinuously surface flow phenomena which appeared in Wadi system was declared in both space and time as shown in Fig. 19.

The proposed approach is applied in both of W. Ghat in Saudi Arabia, and in W.Assiut in Egypt to understand and showing the effect of watershed characteristics and climatic conditions on the runoff features in Wadi system.

Wadi Ghat simulation results show the same characteristics of Wadi Al-Khoud which have mentioned before.

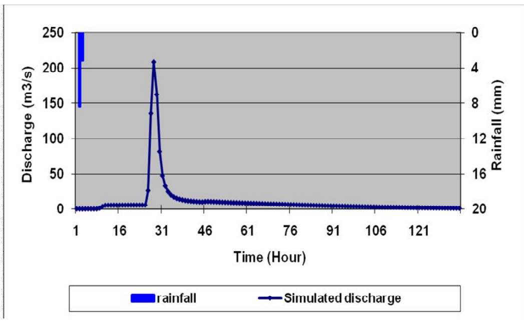


Fig. 20 Hourly hydrographs of simulated discharge in wadi Ghat throughout one event (12 May 1985).

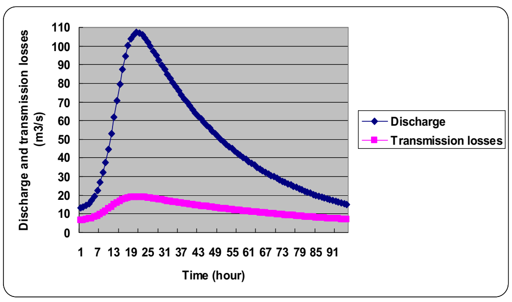


Fig. 21 Hourly hydrographs of simulated discharges and transmission losses in wadi Assiut of one event (November 2-5-1994)

Surface runoff hydrographs show steep rising and rapid ascending where the maximum peak of discharge is 208m^3/s, as shown in Fig. 20.

Wadi Assiut runoff simulation, based on the same calibrated parameters of wadi Al-Khoud, Wadi Assiut was simulated during one event (November 2-5-1994). Both of discharge and transmission losses were simulated showing linear relationship which means that transmission losses are affected by the surface flow as shown in Fig 21. The distribution maps of surface runoff in Wadi Assiut show the characteristics of wadi flow during the different stages of the hydrogrphs as similar as Wadi al-Khoud and W.Ghat. They are depicting discontinuously surface flow at the early and lately stages of rising and ascending of hydrographs (Figs.22 and 23).

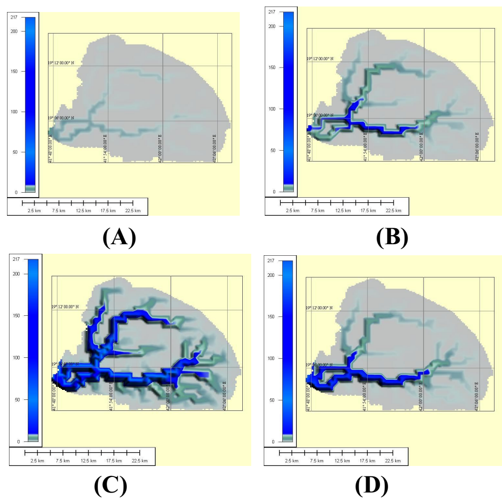


Fig. 22 Distribution maps of surface runoff in W. Ghat; (A) Early stage of surface flow, ; (B) hydrograph is rising toward the maximum peak of discharge; (C) reaching to the maximum of distribution; (D) starting the recession of surface flow to zero flow.

Transmission losses in the studied wadis were evaluated simultaneously with runoff simulation by using Walter's equation. The results of simulation reveal that transmission losses are affected by the volume of surface runoff as evidence that the rate of losses is linearly related to the volume of surface discharge. That means that they are very important as the main source of ground water recharge in the arid regions. Walters (1990) provided evidence that the rate of loss is linearly related to the volume of surface discharge. These results ensure that there is linear relationship between both of surface flow volume and transmission losses in the wadi system.

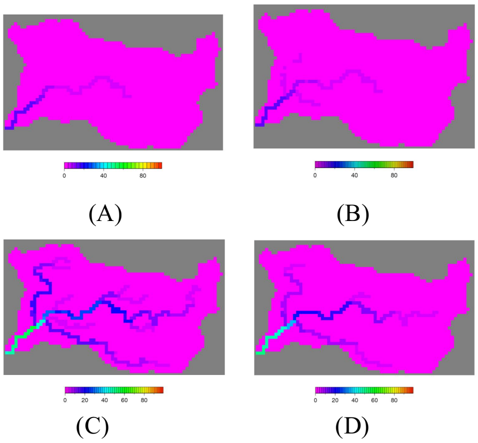


Fig. 23 Distribution maps of surface runoff in W. Assiut; (A) Early stage of surface flow, ; (B) hydrograph is rising toward the maximum peak of discharge; (C) reaching to the maximum of distribution; (D) starting the recession of surface flow to zero flow.

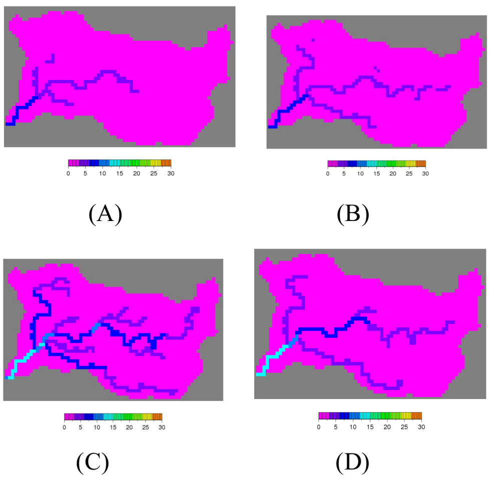


Fig. 24 Distribution maps of transmission losses in W. Assiut; (A) Early stage of surface flow, ; (B) hydrograph is rising toward the maximum peak of discharge; (C) reaching to the maximum of distribution; (D) starting the recession of surface flow to zero flow.

The distribution maps of transmission losses depict the same behaviors as runoff which reflects the effect of surface flow on the transmission losses; you can see the discontinuous occurrence of transmission losses in Wadi system as depicted in Fig. 24

In this paper, a comparative study has been done between the target wadi basins to understand and declare the effect of some factors on runoff characteristics in Wadi system.

It is obvious from the aforementioned results of runoff and transmission losses in the targets basins that runoff behaviors are extremely affected by some factors; the catchment area has visible role to affect on the peak of discharge, time to reach to the peak, and duration of flow as well as the maximum peak value, where in W. Al-Khoud and W. Ghat, the area is smaller than W. Assiut but the discharge is higher at the downstream points of both of them than W. Assiut. The reason is due to the travel time to reach the downstream point is shorter than in W. Assiut and consequently the peak discharge time to peak will be earlier than wadi Assiut.

Table 4 Results of numerical simulation as comparative study in some Arabian wadis.

	Khoud (Oman)	Ghat (Saudi A.)	Assiut (Egypt)
Area (Km^2)	1874.84	649.55	7109.2
Slope	Steep	Steep	Gentle
rainfall	More frequent	Infrequent (1/2 yrs)	Infrequent (1/5 yrs)
Land use (forests)	Rare	Rare	Non
Land use (Field)	Spread in downstream	Spread in downstream	Rare
Land use (Deseret)	majority	majority	majority
Land use (urban)	Non	Non	Rare
Land use (Water)	Non	Non	Rare

Slope and elevation have an important role on the runoff features where in W. Al-Khoud and W. Ghat the maximum elevation more than 2000 m which means that the slope will be steep, on the other hand in W. Assiut, the maximum elevation is approximately 900m and consequently the slope will be gentle. Which state that the surface runoff is higher in both of them than in W. Assiut as deduced from the numerical results of simulation as shown in Table 4.

That reveals the effect of slope onsurface runoff where with increasing the maximum elevation and slope, the flow rate will be high and consequently the surface water will be increased. Moreover in the large area catchments, the availability of losses (evaporation and initial and transmission losses are high) as declared in the numerical results that initial and transmission losses are higher in Wadi Assiut than wadi khoud than wadi Ghat due to the effect of catchment area and hence affecting the flow rate.

As well known the effect of rainfall rate and frequency is very observable as it is the main input resource of water in such regions. So, you can see the effect where in W. Al-khoud, the rainfall events are more frequent than those in W. Ghat and W. Assiut during the simulated periods and thus the peak of discharge higher than in Ghat and Assiut wadis.

In this paper transmission losses can be evaluated as distributed values is not from one point to another one as the previous publications as depicted in Fig. 24. It is obvious that the transmission losses are mainly concentrating on the stream channels of Wadi system.

6. Conclusion

Hydro-BEAM has been chosen as distributed model for the Wadi System modeling. Modifications of Hydro-BEAM have been made to simulate the surface runoff in the ephemeral streams and to estimate the transmission losses as the main source of the recharge to subsurface water.

Simulation of hourly discharges are accomplished in the studied wadis, and it is clear that the results of hourly simulations are completely coincide in their behaviors with the monitored data which means that characteristics of surface runoff and transmission losses in Wadi system were evaluated using the proposed distributed hydrological model.

From the distribution maps of surface runoff in the Wadi system, we noticed that the discontinuous flow is perfectly depicted, so the most import characteristics (the discontinuously surface flow) in the ephemeral streams is successfully evaluated.The proposed approach can help us to understand Wadi system characteristics such as the discontinuously surface flow in space and time, in addition to estimate transmission losses due to its important for groundwater recharge and its inversely effect on the surface flow. Hence, the interaction between surface and subsurface water were evaluated as essential and sustainable management of water resources in Wadi system.

The transmission losses also investigated using Walter's equation. It is concluded that transmission losses participate as the main source of recharge to the subsurface. It is noticed that it is affected by the volume of surface runoff as evidence that the rate of losses is linearly related to the volume of surface discharge.

Runoff features in the ephemeral stream are characterized by different behaviors from the runoff in the humid area or the perennial streams. As the main purpose of the current study is to understand such behaviors and what kinds of factors affecting on it, for instances, rainfall, slope, catchment area, climatic conditions as temperature and evaporations and transmission losses in the active channels as well as land use and soil properties. Thus, a comparative study between some wadis has been done in this research.

Runoff features and characteristics in the ephemeral stream were summarized based on the results in this research as follow:

-There is a time delay (lag) in the hyetograph peaks with respect to hydrograph peaks which means that both of them are not simultaneous

-Flood event time or hydrograph time including starting and cessation is short as showing in the steep rise and rapid recession of hydrographs in wadi system.

-The runoff hydrographs are revealing only direct flow, there is no base flow as comparing with the humid regions

-Initial and transmission losses are considered the main source of subsurface water recharge. Wadi system is characterized by the discontinuously surface flow especially at the early stages of runoff and the cessation of it.

Understanding of Wadi system characteristics and hence its hydrological processes have been accomplished and depicted in this research. Runoff behaviors and factors that control it, transmission losses and its effect on both surface flow and subsurface storage are perfectly evaluated.

It is concluded that the proposed approach is considered an applicable methodology in the arid regoins and consequently, a vital contribution to estimate the distributed surface runoff and transmission losses regionally not only in some Arabian wadis but also in the other arid regions. Much more powerful and appropriate approaches are recommended for the Wadi system modeling based on the observed data and the regional application considering the physical based approaches for estimation transmission losses are totally needed.

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ワジ流域における流出特性の比較研究

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要旨

乾燥地域では，乾季には水不足になる一方で雨季になると急に出水して洪水が起こるなど，様々な水資源問題が発生している。本研究は，乾燥域における持続可能な治水・利水方法を提案することを目的とし，ワジの流出特性を把握するべく提案モデルを用いて解析を行った。その結果，断続的な表流水現象の再現，移動損失量分布の推定などワジにおける流出特性を再現推定することが出来た。また，様々なワジを比較することにより，流出特性や気候特性がワジに与える影響を示すことができた。

キーワード：移動損失量，ワジシステム，キネマティックウェーブ，断流表流水