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Research article

An Approach toward Integrated Management for Wadi Haseeb Watershed using Remote Sensing GIS and Hydrological modeling System, East Khartoum, Sudan

Bushra Mohammed Ahmed Musa Eisa[1]*, Amir Bakheit Saeed[1], and Mohammed Salih Dafalla[2]

[1]Department of Agricultural Engineering, Faculty of Agriculture, University of Khartoum. Khartoum, Sudan
[2]Department of Soil & Environment Science, Faculty of Agriculture, University of Khartoum. Khartoum, Sudan

*Corresponding Author: bushrae17@gmail.com

Abstract: This study has been conducted in Wadi Haseeb Watershed, which originates from the upland in South East of Khartoum State. It descends in the North West direction to the confluence with the Blue Nile. The objective of this study was to specify an integrated management strategy to harness the potentiality of the watershed for sustainable agricultural purposes. An integrated approach of remote sensing (RS), geographic information system (GIS), hydrologic engineering center geospatial hydrologic modeling extension (HEC-GeoHMS) and hydrologic modeling system (HMS4.0) was performed to develop a daily rainfall-runoff model. The watershed was delineated and divided into four basins yielding an average water volume of 23 million cubic meters month^{-1}. The results indicated that the first scenario needed 48 MCM month^{-1} whereas watershed discharge was 23 MCM month^{-1} with a deficit of 25 MCM month^{-1}. The second scenario needed 32 MCM month^{-1}, leading to a deficit of 9 MCM month^{-1}. The third scenario needed 4 MCM month^{-1} with a water surplus of 19 MCM month^{-1}. However, it was not economically and technically feasible to construct a canalization system for this small area. The questionnaire analysis indicated that high flood levels increased the cultivated area of some farms from 0.8 to 22 ha and the yield of sorghum from 400 to 2500 kg ha^{-1}. The effect of the flood on the cultivated area and crop yield was highly significant ($P \leq 0.01$) during high flood periods and significant ($P \leq 0.05$) during the low floods.

Keywords: Watershed, Hydrologic modeling, Wadi, Remote sensing, Water balance.

INTRODUCTION

Integrated watershed management (IWM) is a holistic way that respects a watershed as a holistic system where social, economic, cultural and environmental elements cooperate and intertwine together, and the basics of sustainable development are used to lead watershed management (Muschett & Campbell, 1997). The main factor of integrated watershed management is to balance development and safety in such a method that it is harmonious with local social, economic, and environmental requirements (Heath-cote, 2009). The integration necessities to be comprehensive and should consist of all aspects of watershed resources (land, water, human, and political resources; science and technology) and watershed concerns *viz*: (economic development, natural disasters, biodiversity, water scarcities, soil erosion, sedimentation, resource depletion and poverty), as long including several organizations and local communities (Smit, 2005; Yang *et al*., 2006; Heathcote, 2009). To attain this, integrated watershed management requirements to assess and consider numerous factors, for example, the spatial and temporal measure, the link between environment function and structure, diversity and integrity of the system, environment dynamics in space and time, and natural resource utilization and management by stakeholders.

The major purpose to describe socio-economic systems in the watersheds is to recognize existing and potential production limitations, and propose potential areas for aiming technology transmission for sustainable development. It needs huge data from several sources, published, unpublished and micro level investigation (Wani *et al*., 2003). Selecting the most relevant socio-economic characteristics require not only good awareness of the local condition and stakeholders included, but also access to information on costs and benefits and insight into the indirect economic influences and social factors such as labor availability, land and water rights, and risks of flooding. Thus, the aim of this study was specify an integrated management strategy to harness the potentiality of the watershed for sustainable agricultural purposes.

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MATERIALS AND METHODS

Study area

The study area for this project is located in Khartoum State, East-Nile locality. It includes Haseeb Valley and the villages around it. The area is subtended roughly by latitudes [15° 21´ - 15° 51´ N], and longitudes [32° 04´ - 33° 27´ E]. The Valley Springs in Abu Delaig upland, the eastern part of Khartoum State (Fig. 1). It drains through villages, bush-lands and agricultural areas (non-irrigated land) to, mouth into the Blue Nile.

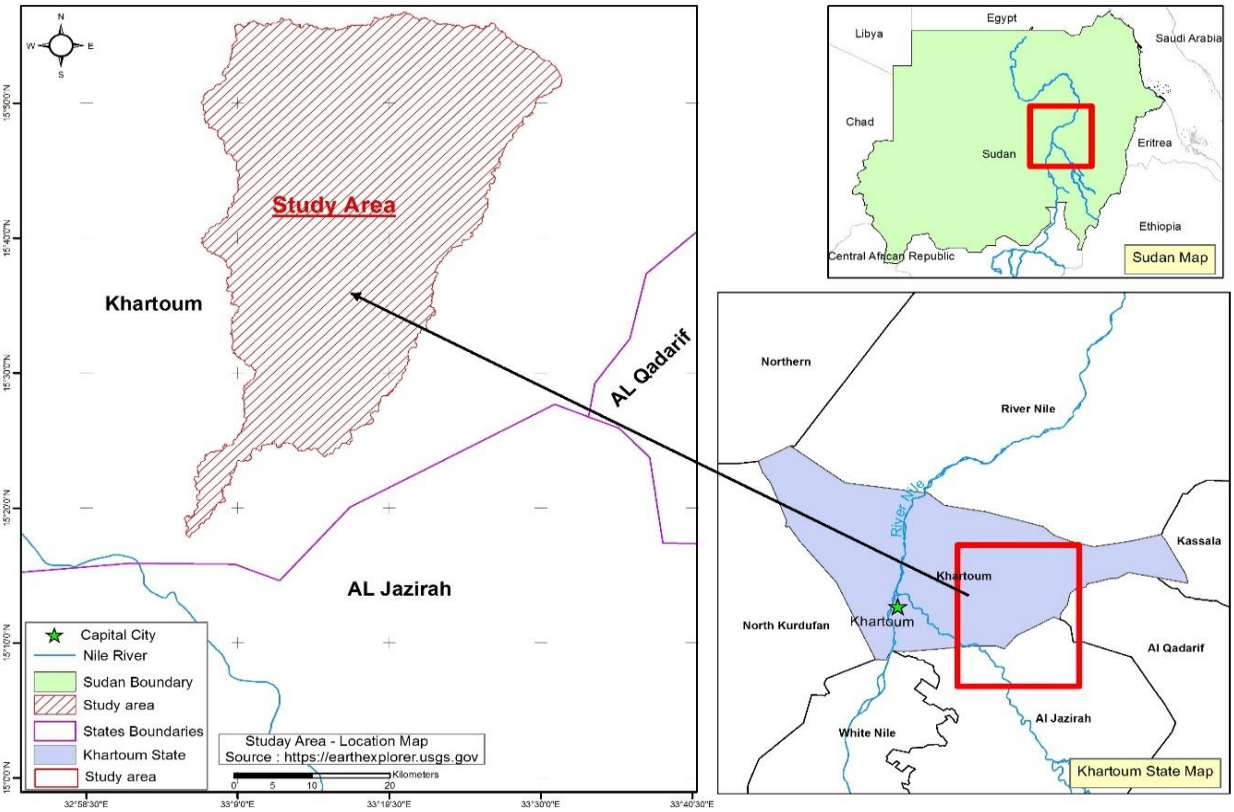


Figure 1. Study area map.

Experiment procedures

A digital Elevation Model (DEM) with 10 m resolution figure 2 was generated from LIDAR raw data obtained from Survey unit Khartoum State. The Datum, Projection, and Zone are WGS84, UTM and 36 N respectively. The satellite image (Landsat 8 -173/49) data in resolution 15 m acquired in October 2017 were also, derived from the Survey Unit, Khartoum State. Data of physical and chemical soil properties analysis for the study area were obtained from the Ministry of Agriculture, Livestock and Irrigation, Khartoum State. Annually, monthly, and daily interval rainfall data and evaporation data were obtained from Sudan Meteorological Authority, Khartoum Station. The GPS receiver was used for locations and altitudes. The floats were used for discharge measuring. For measuring the infiltration rate a double-ring infiltrometer was used. A cross-section area, discharge, water level, infiltration rate, vegetation, and socioeconomic data (a questionnaire) were obtained from fieldwork.

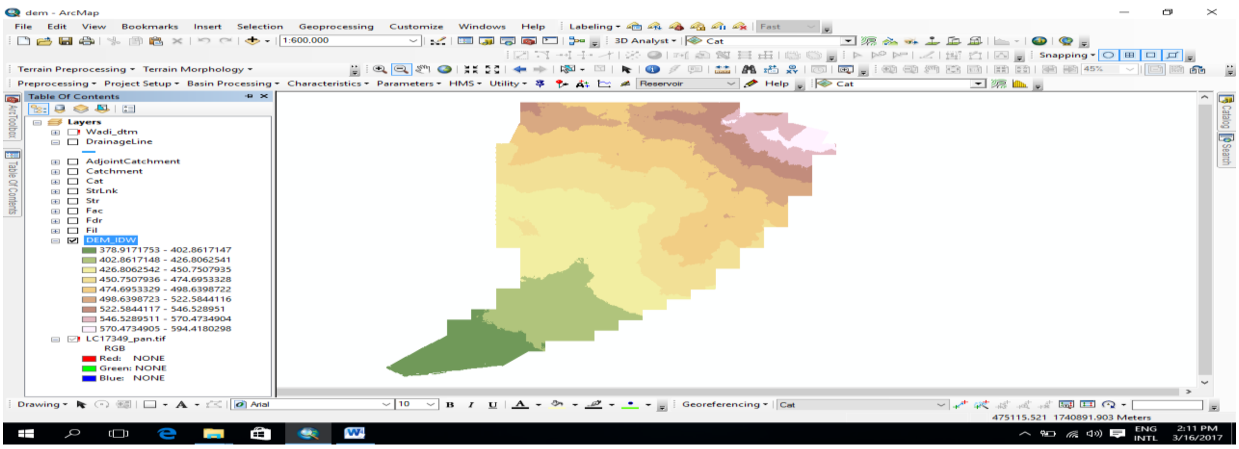


Figure 2. Digital elevation model map.

Hydrology analysis

An HMS model requires five main inputs process parameters. Among them is the precipitation loss method for overland flow, which accounts for the infiltration losses. Soil Conservation Services curve number (SCS-CN) has been adopted in this study, whose values are computed from the curve number grid. After the precipitation losses are accounted for, the SCS unit hydrograph method is chosen as a transform method for transforming overland flow into surface runoff. In the SCS method, 37.5% of the runoff volume occurs before the peak flow, and the lag time can be approximated by taking 60% of the time of concentration. The lag time defined as the length of time between the centroid of precipitation excess and the peak flow which is values were computed using the CN lag time function in HEC-GeoHMS. (Oleyiblo & Li, 2010). Figure 3 illustrates the flowchart of the SCS model.

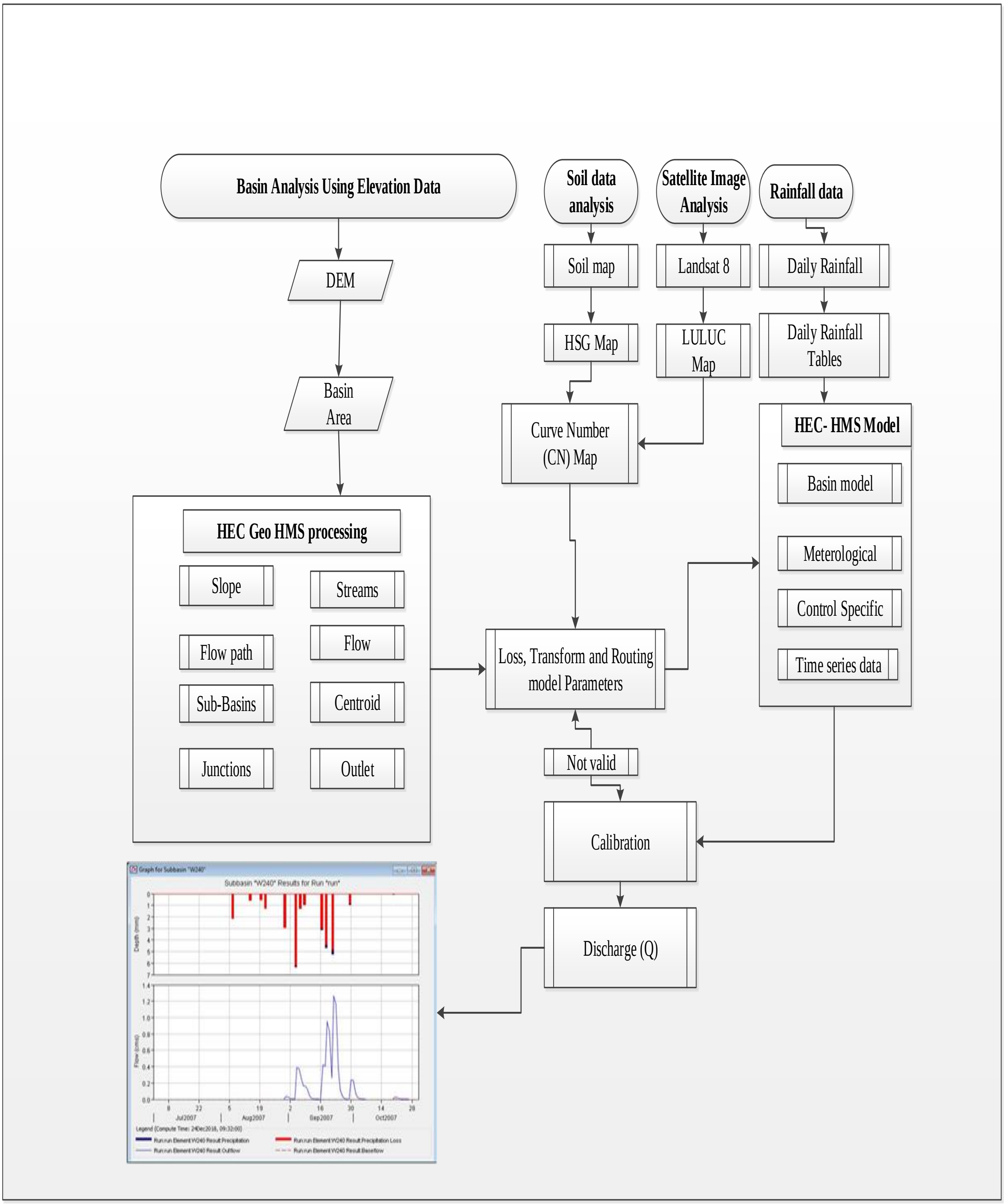


Figure 3. Method for runoff-flooding simulation for the Wadi watershed.

Land and crops suitability

The suitability of the soils for cultivation crops is assessed by different soil and land characteristics. The characteristics which included were the study of the soil, available water resources, climate and vegetation cover. Then soils suitable for agriculture were recognized, and crops or groups of crops suitable to be grown under the available climatic regime were identified.

Crop water requirement and Water balance

Evapotranspiration (ET_0) for the study area was estimated by entering climate data (min temperature, max temp, humidity, wind speed, sunshine and radiation), elevation and coordinates of Khartoum meteorological station into CROPWAT8.0 Software to identify crop water requirement. And then water balance was estimated by entering the data of crop type, crop water requirement, crop pattern and sowing date into the CROPWAT8.0 Software.

Socio-economic study

Questionnaires were designed and distributed in 6 villages with 10 copies per each along the watershed selected randomly named; Wed-Hassona and El-salama in the upstream, El-dalwo and El-hideibab in the middle-stream, and Abu-zulaig, Aulwan in downstream. The data of socioeconomic study covered some information such as Wadi flood, agriculture, animal production, and some of general services. The collected data were subjected to analysis of variance (ANOVA) using the SPSS package.

RESULTS AND DISCUSSION

Estimation of the runoff, Hydrograph and Peak Discharge

The main watercourse length was estimated at 40,000 m with a channel slope of 0.00093 m m^{-1}. This gives a time of concentration of 401 min (6.7 hrs.) and the lag time is about 240 min (4 hrs.). One of the most important parameters in routing a flood through river reaches and the reservoir is to develop a Probable Maximum Flood (PMF) hydrograph as shown in figures (4 and 5) from the maximum Inflow Design Flood (IDF).

The checked HEC-HMS model was run after preparing and supplying the required inputs with selected rainfall events for different seasons and different land use to simulate the runoff amount and distribution in different basins through generating runoff hydrographs. Figures 6 and 7 show the resulting hydrograph.

The stream-flow runoff, peak discharge and discharge volume were estimated as shown in figures 8 and 9. From the results of the hydrographs of the four sub-basins named by default in the model: W240 of a catchment area of 601 km^2 generate the volume of water 3.237 MCM with a peak discharge of 8.3 m^3 s^{-1}, W270 of a catchment area of 485 km^2 generate volume water 2.612 MCM, Junction 64 in the catchment area of 1086 km^2 supplied volume water 5.850 MCM with discharge 14.8 m^3 s^{-1} and the Outlet in the catchment area of 1708 km^2 provided water volume 9.321 MCM from discharge 24.9 m^3 s^{-1}. The total water yield of the watershed was to be approximately 28 MCM $year^{-1}$ considering the volume of 9.321 MCM repeated three times of the year. These results disagree with Mustafa (2005), Singh (2003) and Eljack & Elsheikh (2015). They reported that the peak discharge and direct runoff volume are roughly high, due to the differences in the study area conditions affected in some related factors to the runoff such as soil texture, curve number values and the slope.

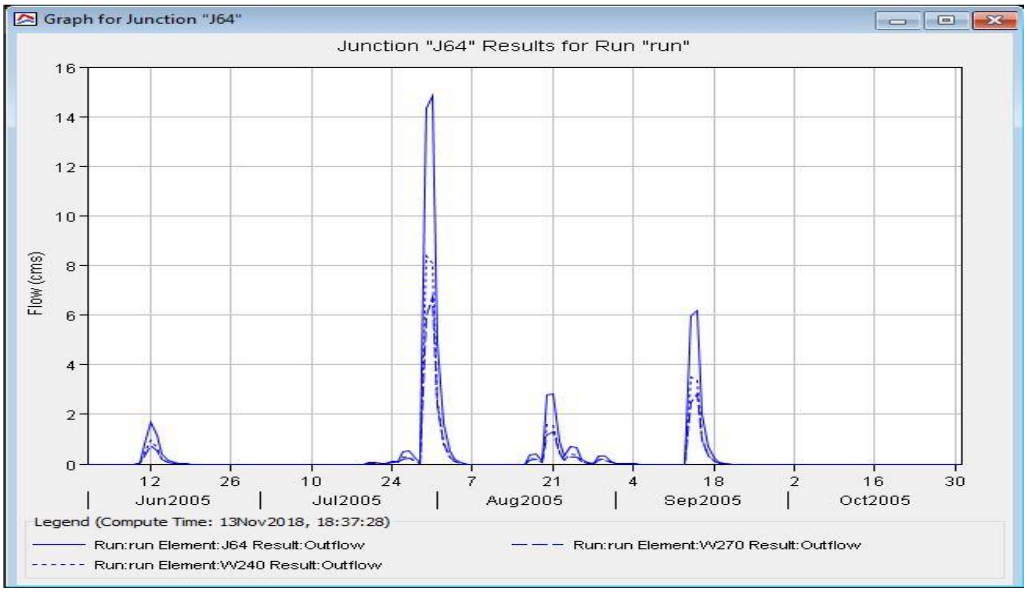


Figure 4. Probable maximum flood graph for junction 64.

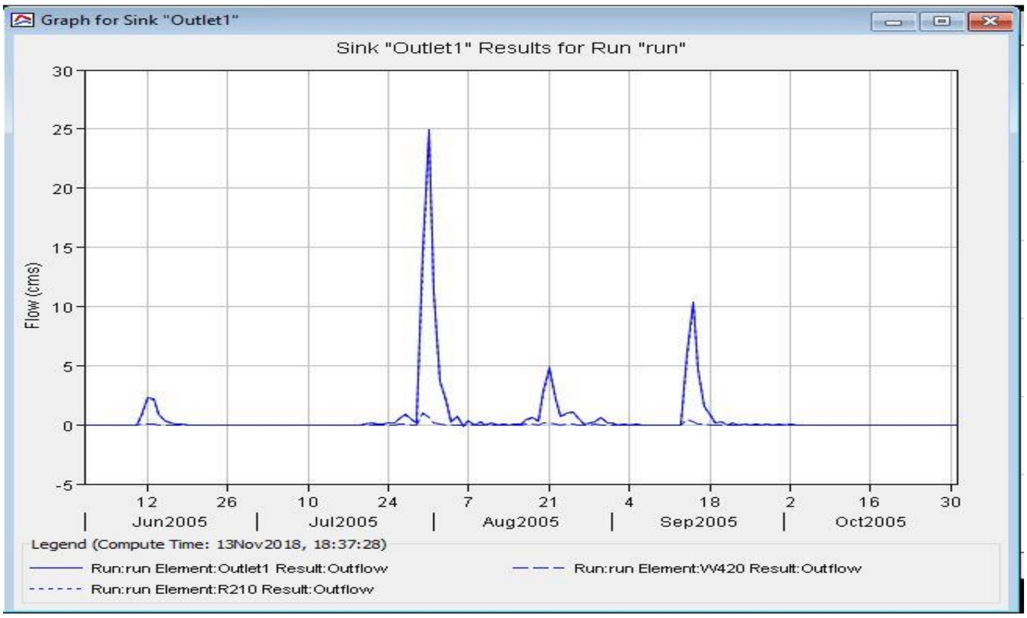


Figure 5. Probable maximum flood graph for the outlet.

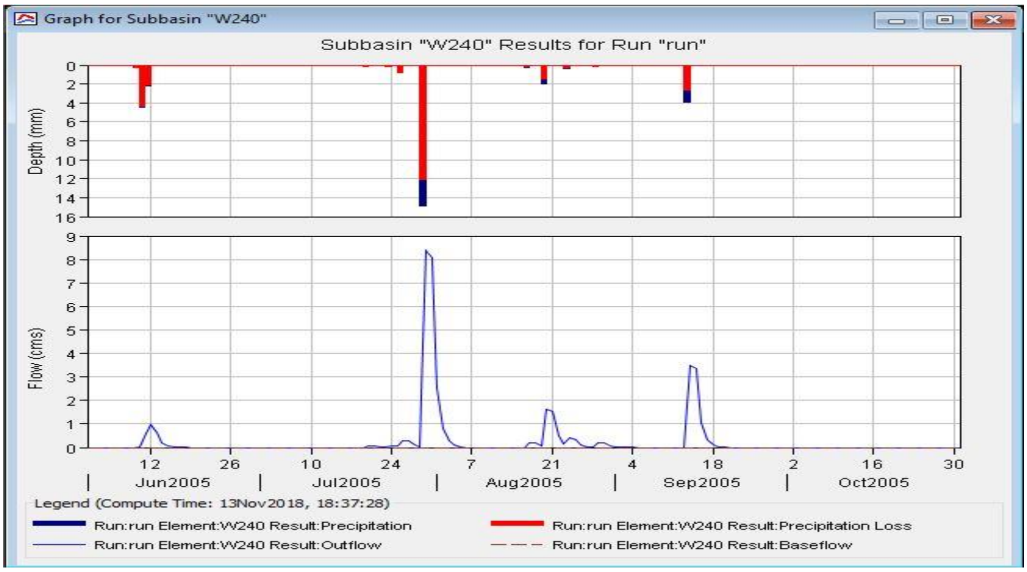


Figure 6. Depth and flow for sub-basin (W240).

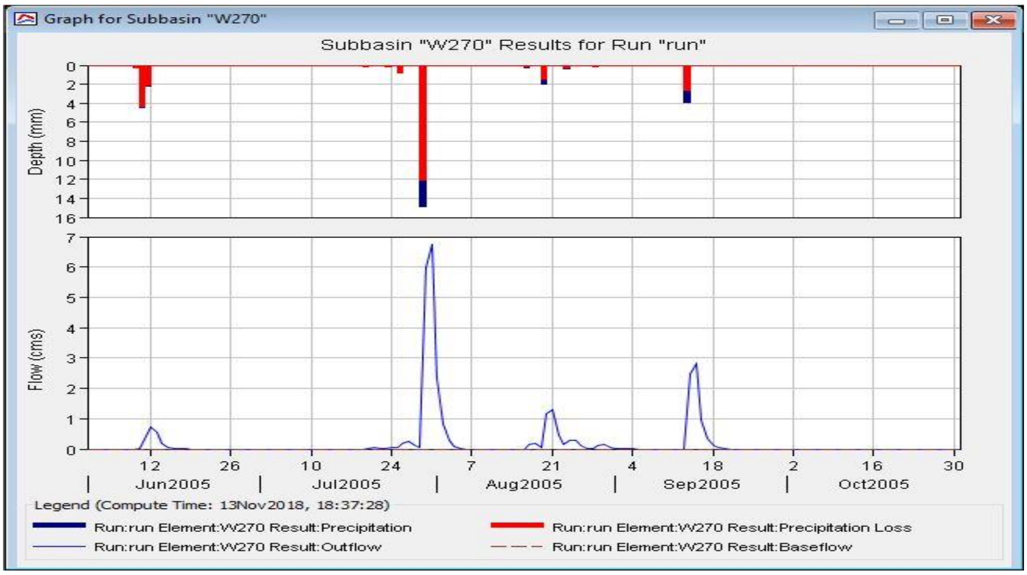


Figure 7. Rainfall depth and flow for sub-basin (W270).

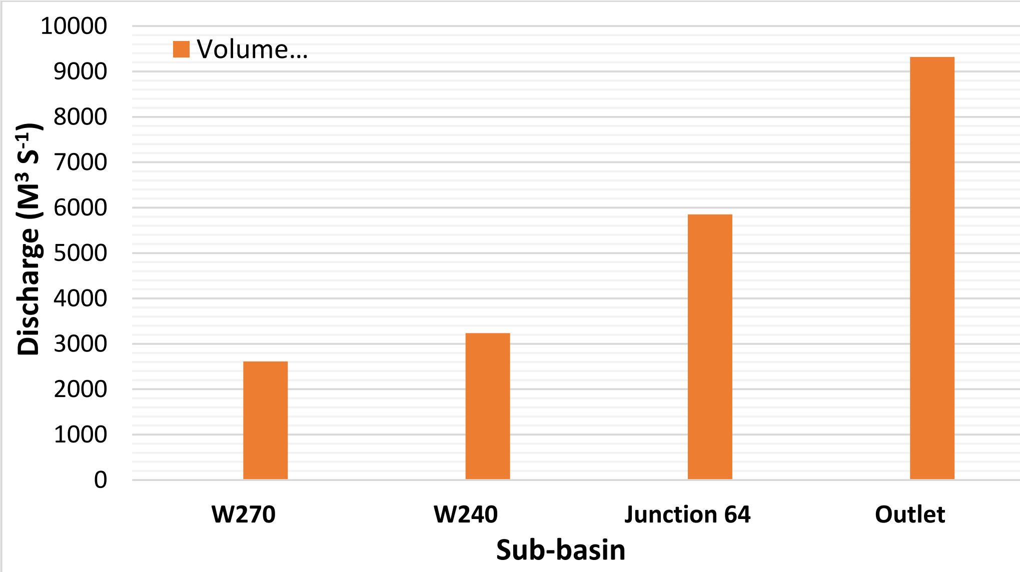
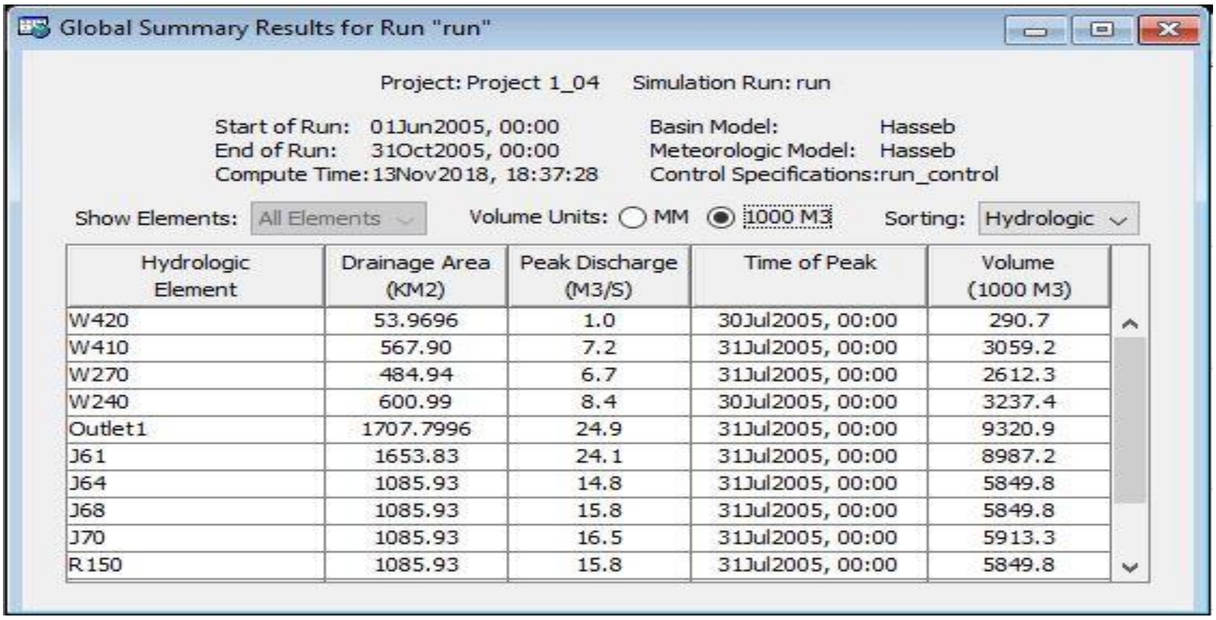


Figure 8. Runoff volume and discharge of sub-basins.


Global Summary Results for Run "run"

Project: Project 1_04   Simulation Run: run

Start of Run: 01Jun2005, 00:00   Basin Model: Hasseb
End of Run: 31Oct2005, 00:00   Meteorologic Model: Hasseb
Compute Time: 13Nov2018, 18:37:28   Control Specifications: run_control

Show Elements: All Elements   Volume Units: MM 1000 M3   Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (1000 M3)
W420	53.9696	1.0	30Jul2005, 00:00	290.7
W410	567.90	7.2	31Jul2005, 00:00	3059.2
W270	484.94	6.7	31Jul2005, 00:00	2612.3
W240	600.99	8.4	30Jul2005, 00:00	3237.4
Outlet1	1707.7996	24.9	31Jul2005, 00:00	9320.9
J61	1653.83	24.1	31Jul2005, 00:00	8987.2
J64	1085.93	14.8	31Jul2005, 00:00	5849.8
J68	1085.93	15.8	31Jul2005, 00:00	5849.8
J70	1085.93	16.5	31Jul2005, 00:00	5913.3
R150	1085.93	15.8	31Jul2005, 00:00	5849.8

Figure 9. Basin discharge and runoff volume.

Model Calibration

A cross-sectional area of 13 m^2 was determined on the Wadi watercourse in El-Faki Saad village adjacent to junction 64 (J64), the water velocity has been measured and was found to be in the average of 0.06 m s^{-1} and then the discharge was observed to be 1 m^3 s^{-1} and used for calibration the HEC-HMS model (Fig. 10). An observed discharge was different from the simulated discharge due to it has been taken in very low flow velocity and high wind speed against the float during the measurement process. These results agree in stream section and disagree in water velocity with Soupir *et al*. (2009), wherein, they noted that stream sections were not always straight and streams were not uniform bottom low and water velocities was 0.015.

Land and Crops Suitability

Tables 1 and 2 reveal Unit 4.5 with soil physical and chemical properties. It was selected as a representative of the study area based on the previous study carried out by the Ministry of Agriculture and Animal Production, Khartoum State. The soil of this Unit is deep non-cracking, with a texture of sandy clay loam; moderately well-drained, moderate infiltration rate, alkaline (pH average = 7.9), low nitrogen content (0.06). The cation exchange capacity is high with an average of 36.2 and with moderate calcium carbonate (average $CaCO_3$ % = 5.6) and non-saline (average ECe = 0.5dS m^{-1}). Therefore, due to the above analysis results a large portion of the study area is suitable for agriculture, and suits many crops. It excellent for sorghum, and maize and good for sunflower, wheat and vegetable crops (potato, onion, and tomatoes) and fruit crops (grapes and date palm). These results agree with Ibrahim *et al*. (2018) results, who stated that the soil was classified as sandy clay loam and suits both field and horticultural crops.

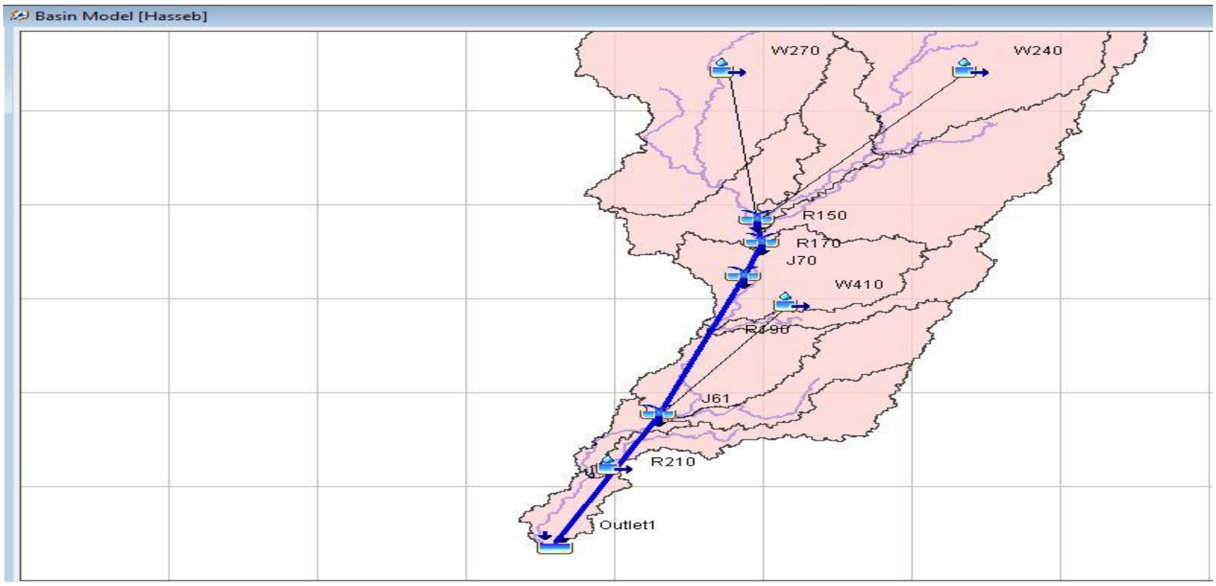


Figure 10. HEC–HMS basin model.

Table 1. Soil chemical properties analysis (531064 X - 1703066 Y).

Unit	Profile (No)	Depth (cm)	CaCO3 (%)	pH	ECe (ds/m)	Ca+Mg (mmol/l)	Na (mmol/l)	K (mmol/1)	SAR	N %	CEC
4.5	P250	0 - 20	5	7.77	0.5	3	2	0.11	1.6	0.07	37.4
		20 - 45	6.1	7.92	0.4	3	1	0.15	0.8	0.04	33.2
		45 - 80		8.03	0.3	2	1	0.15	1		33.7
		80 +		7.93	0.9	6	3	0.14	1.7		40.4
Average			5.6	7.9	0.5	3.5	1.8	0.1	1.3	0.06	36.2
Min			5	7.8	0.3	2	1	0.1	0.8	0.04	33.2
Max			6.1	8	0.9	6	3	0.2	1.7	0.07	40.4

Table 2. Soil physical properties analysis (531064 X - 1703066 Y).

Unit	Profile Number	Depth (cm)	Clay (%)	Silt (%)	Sand (%)
4.5	P250	0 - 20	41.7	15.9	42.4
		20 - 45	37	21.3	41.7
		45 - 80	37.5	18.6	43.9
		80 +	45	21	34
Average			40.3	19.2	40.5
Min			37	15.9	34
Max			45	21.3	43.9

Socioeconomic parameters

The socioeconomic surveys revealed that majority of the inhabitants were farmers and raising cattle. The Wadi floods in August and sometimes in September, the width of flood differs based on the topography ranged from 20 m to 600 m, and the height of flood ranged from 0.2 m to 1 m (Table 3). Agriculture was practiced only during rainfall season and the sorghum was the only cultivated crop, and different types of animal were raised such as cows, goats, and camels (Table 3). The questionnaire analysis indicated that high flood levels increased the cultivated area of some farmers from 0.8 to 22 hectare and the yield of sorghum crop from 400 to 2500 kg ha^{-1} (Table 3). The cultivated area and crop yield show highly significant ($P \leq 0.01$) and significant ($P \leq 0.05$) during the high and low flood periods. These results agreed with Sharan *et al.* (2001) and Das & Munda (2006), they stated that the wadis flood increase the cultivated area and the yield of crops, also stated that the study of socioeconomic is important factor in the integrated watershed management.

Integrated watershed management (Action plan)

Water yield of the watershed is presented in table 4. Water yield of the watershed obtained from the reliability method was low because this method assumed that the runoff should become from 25 % of the rainfall. In the rational method water yield depends on numerical calculation for the runoff estimation, therefore the yield attained from it is closed to the theoretical condition. The yield obtained from HEC–HMS model is more realistic and accurate, as per this method considering Land use/land cover, soil moisture and infiltration rate in the runoff estimation, therefore the water balance for the study adopted the yield of water achieved from this method, thus the water balance has been determined based on the precipitation, water yield, crop water requirement, irrigated areas and the crop pattern as shown in Tables 5 and 6. Three water balance scenarios as shown in tables (7, 8, and 9) have been adopted for utilizing the water that comes from the watershed. The first scenario was cultivating the whole area with sorghum, maize, and vegetables; the second scenario was cultivating sorghum only while the third scenario was cultivating 800 ha with sorghum for the inhabitants' self-sufficiency. The results indicated that the first scenario needed 48 MCM month^{-1} whereas watershed discharge was 23 MCM month^{-1} with a deficit of 25 MCM month^{-1}. On the other hand, the second scenario needed 32 MCM month^{-1}, leading to a deficit of 9 MCM month^{-1}. The third scenario needed 4 MCM month^{-1} with a water surplus of 19 MCM month^{-1}. However, it was not economically and technically feasible to construct a canalization system for this small area. The present study proposed constructing cascaded earth dams with small extended crested sharp wires behind them (Fig. 11), the dimensions of the wire are of 200-meter length, 0.3-meter width, I meter height, and 1-kilometer interval, located downstream and are interchangeably distributed to regulate water movement through agricultural land for maximizing water utilization. These results agree with Kumar *et al*. (2011) and Eljack & Elsheikh (2015), wherein noted that the cascaded dams suit the shallow wadis to maximize the water conservation in agricultural land located downstream these dams.

Table 3. Yield and flood/area correlation.

	Number	Minimum	Maximum	Mean
high flood/area/hectare	60	4	40	22
medium flood/area /hectare	60	4	25	14.5
low flood/ area/hectare	60	0.8	12	6.4
high flood/ha/kg	60	1000	2500	765
medium flood/ha/kg	60	640	2000	585
low flood/ha/kg	60	400	1200	350
Goat /head	60	0	200	40.5
Cow /head	60	0	50	6.4667
Camel /head	60	0	20	2.2167
flood width (m)	60	20	600	96.5833
Flood height (m)	60	0.2	1	0.4583

Table 4. Wadi water yield (MCM).

Method	Wadi Water Yield (MCM)
Reliability	8
Rational	39
HEC - HMS model	28

Table 5. Kc for suitable selected crops.

Crop name	Crop Kc
Sorghum	1.00
Maize	1.20
Tomato	1.05
Grapes	0.75

Table 6. Crop water requirement for scenario 1.

Precipitation deficit	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1. SORGHUM (Grain)	0	0	0	0	0	0	18.0	60.10	93.0	83.0	3.60	0
2. MAIZE (Grain)	0	0	0	0	0	0	19.0	79.70	118.0	88.0	2.60	0
3. Vegetables	0	0	0	0	0	0	0	37.00	77.0	124.0	109.00	59.50
Net scheme irrigation:												
in mm day^{-1}	0	0	0	0	0	0	0.5	2.00	3.2	3.0	0.80	0.40
in mm month^{-1}	0	0	0	0	0	0	15.0	61.30	97.0	93.0	24.30	11.90
in l s^{-1} h	0	0	0	0	0	0	0.1	0.23	0.4	0.4	0.09	0.04
Irrigated area (% of total area)	0	0	0	0	0	0	80.0	100.00	100.0	100.0	100.00	20.00
Irrigation for actual area (l s^{-1} h)	0	0	0	0	0	0	0.1	0.23	0.4	0.4	0.09	0.22

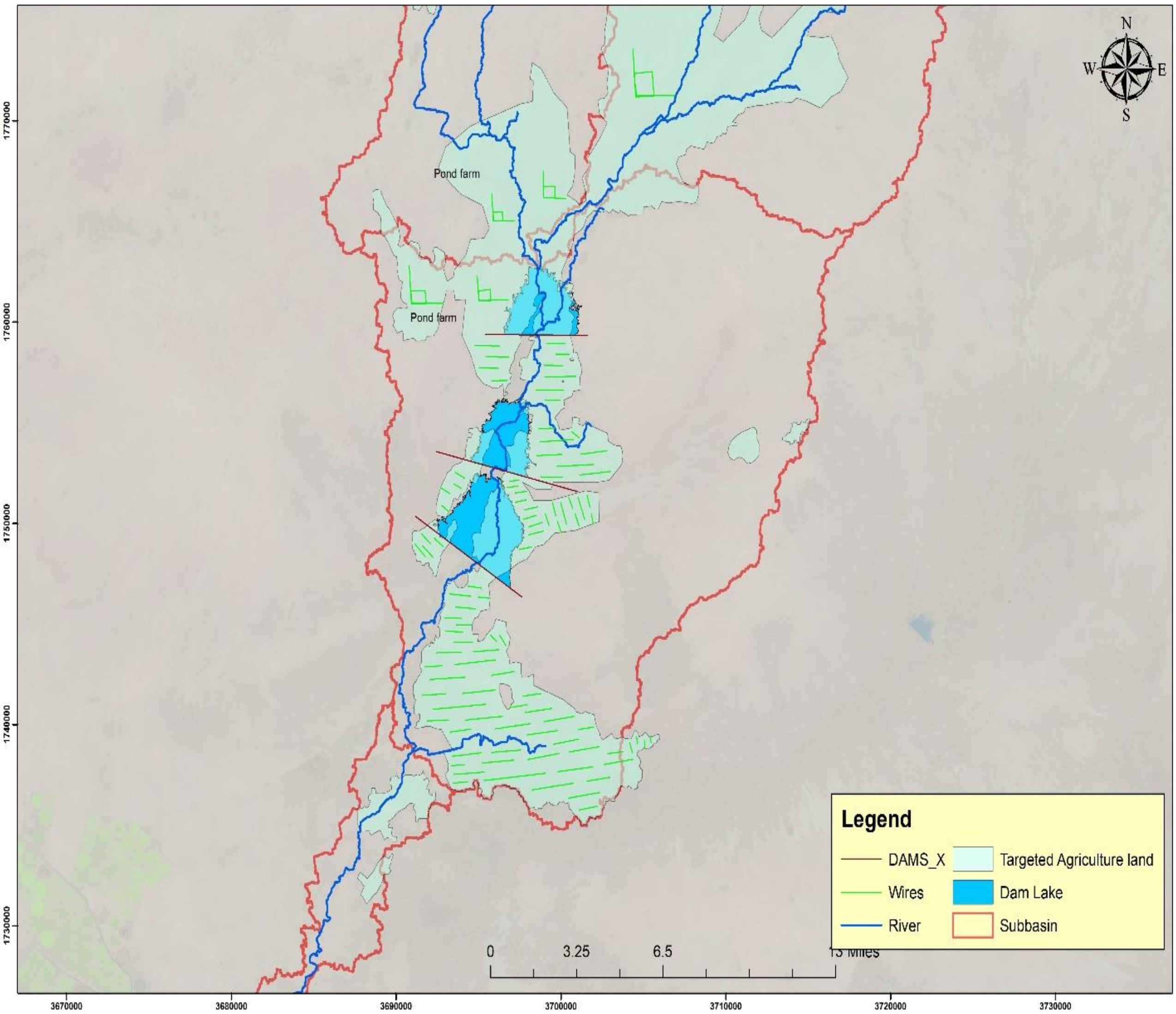


Figure 11. Integrated management map.

Table 7. Water balance for scenario 1.

Month	Discharge (Mm³month⁻¹)	IWR (Mm³month⁻¹)	Other Uses (Mm³month⁻¹)	Water Balance
Jan.	0	0	0.2	(0.00)
Feb.	0	0	0.2	(0.00)
Mar.	0	0	0.2	(0.00)
Apr.	0	0	0.2	(0.00)
May	0	0	0.2	(0.00)
Jun.	0	0	0.2	(0.00)
Jul.	1.15	2.89	0.2	(1.75)
Aug.	9.89	2.89	0.2	7.00
Sep.	6.46	15.20	0.2	(8.73)
Oct.	5.59	14.46	0.2	(8.87)
Nov.	0	3.60	0.2	(3.60)
Dec.	0	9.09	0.2	(9.09)
Total	**23.1**	**48.14**	**2.4**	**-22.64**

Table 8. Water balance for scenario 2.

Month	Discharge	IWR ($Mm^3 month^{-1}$)	Other Uses ($Mm^3 month^{-1}$)	Water Balance
Jan.	0.00	0.00	0.2	(0.00)
Feb.	0.00	0.00	0.2	(0.00)
Mar.	0.00	0.00	0.2	(0.00)
Apr.	0.00	0.00	0.2	(0.00)
May	0.00	0.00	0.2	(0.00)
Jun.	0.00	0.00	0.2	(0.00)
Jul.	1.15	2.89	0.2	(1.75)
Aug.	9.89	2.89	0.2	7.00
Sep.	6.46	14.40	0.2	(7.93)
Oct.	5.59	12.40	0.2	(6.83)
Nov.	0.00	0.40	0.2	(0.42)
Dec.	0.00	0.00	0.2	(0.02)
Total	**23.10**	**32.98**	**2.4**	**(12.28)**

Table 9. Water balance for scenario 3.

Month	Discharge	IWR (Mm^3 $month^{-1}$)	Other Uses (Mm^3 $month^{-1}$)	Water Balance
Jan.	0	0	0.2	0
Feb.	0	0	0.2	0
Mar.	0	0	0.2	0
Apr.	0	0	0.2	0
May	0	0	0.2	0
Jun.	0	0	0.2	0
Jul.	1.15	0.5	0.2	0.45
Aug.	9.89	0.5	0.2	9.19
Sep.	6.46	0.496	0.2	3.764
Oct.	5.59	0.643	0.2	2.747
Nov.	0	0	0.2	-0.2
Dec.	0	0	0.2	0.2
Total	**23.1**	**4.139**	**2.4**	**16.56**

CONCLUSION

The surface runoff of the Wadi Haseeb watershed ranged from moderate to low and the floods can be controlled for agricultural and household uses. On the other hand, the geospatial models have proved to be highly efficient in integrated water management. The study recommended maximizing the utilization of flood by constructing cascaded earth dams coupled with weirs to regulate the water flow, offer suitable hydraulic heads, alleviate soil erosion problems, and, enhance agricultural activities such as the plantation of sorghum, maize, and vegetable crops.

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