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Surface runoff estimation of Wadi Ba Al-Arid watershed NE Libya using SCS-CN, GIS and RS data

Salah Hamad*

Faculty of natural resources and environmental science Omar Al Mukhtar University, Al Baydah, Libya

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Abstract

The aim of this study is to estimate runoff in Wadi Ba Al Arid watershed for a period of ten years 2009-2018 by Soil Conservation Service Curve Number (SCS-CN) method in combination with the GIS techniques using remote sensing data. The used data are the daily rainfall data from NASA Prediction of Worldwide Energy Resource (POWER), digital elevation data (DEM) from ALOS PALSAR RTC , satellite imagery from the European Space Agency (ESA) Sentinel, and soil data represented in soil maps of a scale 1: 50,000 and some local studies carried out by several Libyan institutions. The overall area of the watershed is about 136.4 km^2 and perimeter107.3 Km. The watershed upstream and downstream is well recognized due to the topographical difference as a result of the tectonic geology. Soil maps were processed and classified into hydrologic soil groups (HSG), where the dominant HSG in the study area are C and D. The Landcover/Land use (LULC) was classified into five classes (forest, shrubs, agriculture, barren land) and built up. The HSG and LULC layers were intersected and the CN values and the weighted curve number for each Antecedent Moisture (AMC) condition were assigned. Furthermore, the runoff depth was estimated and the average runoff volume for ten years during 2009–2018 in the study area was estimated by 1.67 Mm^3 which represents 4.6 % of the observed average annual rainfall as 264.3 mm during 2009-2018. The rainfall-runoff relationship has shown a strong correlation with the value of 0.75.
Keywords: *Al-Jabal Al-Akhdar, Watershed, Hydrology, GIS, Remote sensing*

1. Introduction

Rainfall-runoff is an important component contributing significantly to the hydrological cycle, design of hydrological structures and morphology of the drainage system (Pradhan et al. 2010). Furthermore, the runoff estimate is important for dam design, surface water management and forecasting of potential flood risks and losses. Also, determining the amount of runoff is very important in projects related to sediment and erosion processes (Malekani et al. 2014). There are many different methods for estimating runoff in the watershed, one of the well-known methods is the Curve Number (SCS-CN) which is most widely used. The Soil Conservation Service Curve Number (SCS-CN) method (SCS 1956, 1964, 1971 and 1993) commonly used to estimate the direct surface runoff from rainfall events using curve number derived from watershed spatial characteristics with respect to the five-day antecedent rainfall. Also the method incorporates the land use for computation of runoff from rainfall (Shadeed and Almasri 2010). On the other hand, the Curve Number is an index developed by the Natural Resource Conservation Service (NRCS), to represent the potential for storm-water runoff within a drainage area. The CN for a drainage basin is estimated using a combination of land use, soil, and antecedent soil moisture condition (AMC), where there are four hydrologic soil groups: A, B, C and D. Group A have a high infiltration rates and group D have a low infiltration rate. The Soil Conservation Service Curve Number (SCS-CN) method is widely used for predicting direct runoff volume for a given rainfall event (Bansode and Patil 2014). Moreover, The SCS-CN method was originally developed for its use on small agricultural watersheds and has since been extended and applied to rural, forest and urban watersheds. Since the inception of the method, it has been applied to a wide range of environments, therefore in recent years, the method has received much attention in the hydrologic literature (Mishra and Singh 2003). Geographic information system (GIS) and remote sensing (RS) data also integrated with SCS-CN for mapping the curve number (CN) of the watershed by using the digital elevation model (DEM) data, and land cover classification of the satellite images in addition to soil data. In the study area the runoff is uncontrolled so there is an urgent need to evaluate the hydrological characteristics which are the basis for water harvesting techniques, floods protection, and soil conservations measures. In addition, the runoff ends in the Mediterranean Sea, which unfortunately is a non-allocated source of water. Therefore the research aim to estimate the amount of runoff in the Wadi Ba Al-Arid using GIS techniques and remote sensing data integrated with the SCS-CN method for the period from 2009-2018.

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*Corresponding author.
E-mail address (es): Shehabcad@gmail.com

2. The study area

Wadi Ba Al-Arid watershed located in Northeast of Libya in Al-Jabal Al-Akhdar (Green Mountain) region as in the figure (1) where it lies between latitudes 32° 46' 37 " N to 32° 32' 51 N, and longitude 21° 16' 27.1971" E to 21° 25' 48.3704" E The watershed is part of Northern wadis network system of Al-Jabal Al-Akhdar. Wadi Ba Al-Arid watershed, like the other watersheds of Al-Jabal Al-Akhdar has a scarcity of climatic and hydrological data although Al-Jabal Al-Akhdar region is the heaviest in terms of precipitation on the entire Libyan state. The only attempt for hydrological recording was made by Hydrogeo Consulting Engineers during the study contract with Libyan General water Authority for Groundwater resource evaluation of Al Baydah - Al Bayadah Area. Where two hydrometric stations were installed on upstream and downstream in 1981, but unfortunately, the 1981-1982 hydrological year has been a particularly dry year with 5 years return period and with no heavy storm. The lack of periodical hydrological measurements in Al-Jabal Al-Akhdar led to difficulties in evaluating and estimating the exact amount of surface water resources. However, previous hydrological studies that were developed for short periods indicated that there is the potential of surface water which can be collected by using different methods of surface water harvesting (Arghin and Hamad 2003).

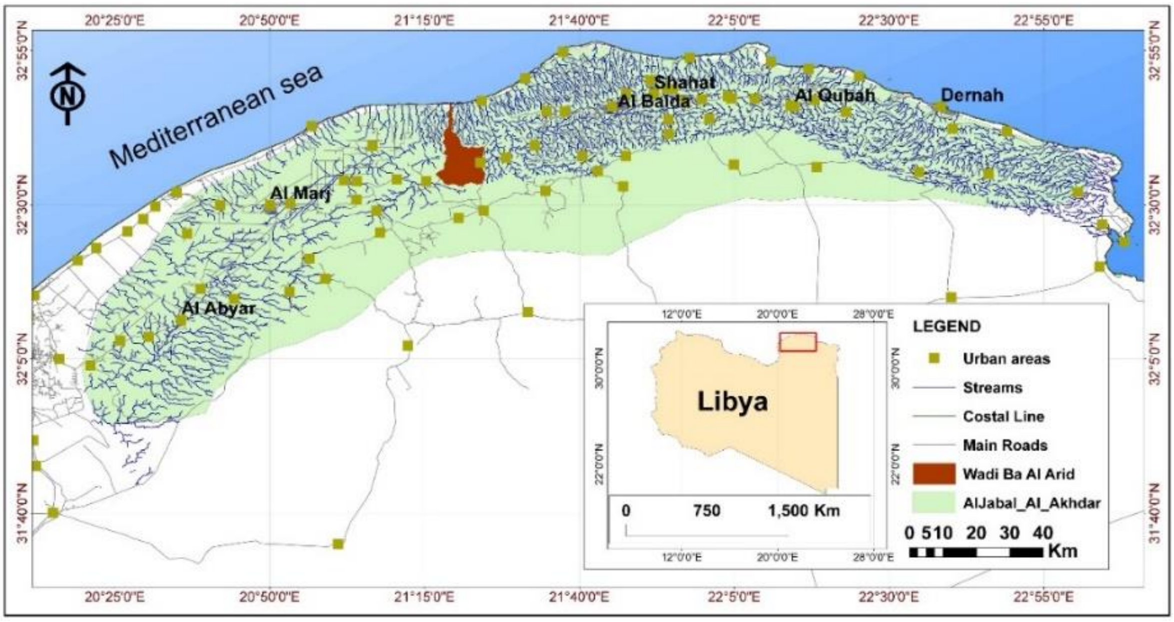

Fig 1. Location map of Wadi Ba Al-Arid watershed

3. Research Methodology

The method of study which is summarized in the flow chart figure (2) based on the data in the table (1) was carried out according to the following subsections:

3.1. Spatial Characteristics

Extraction of the spatial characteristics for the study area was carryout using radiometrically terrain-corrected (RTC) products which is a project of the Alaska Satellite Facility that makes SAR data accessible to broader community of users. The project corrects synthetic aperture radar (SAR) geometry and radiometry, and presents the data in the GIS-friendly GeoTIFF format (Alaska Satellite Facility). The RTC DEM processed using the hydrology toolset which is a tool in ESRI ArcGIS Spatial Analyst extension for processing topographic data to identify sinks, determine flow direction, calculate flow accumulation, delineate watersheds, create stream networks, and perform morphometric and hydrologic analysis (ESRI 2018).

3.2 The landcover /Land use (LULC)

Classification of (LULC) was used ESA Sentinel 2 image which was processed in Quantum GIS Semi-Automatic Classification Plug-in (SCP) which is a free open source plugin for Quantum GIS (QGIS) that allows for the semi-automatic classification (also supervised and unsupervised classification) of remote sensing images. Also, it provides several tools for the download of free images (Landsat, Sentinel-2, Sentinel-3, ASTER, MODIS), the pre-processing of images, the post-processing of classifications, and the raster calculation (Congedo 2016).

3.3 Soil group

Soil data for the study area were obtained from the soil maps (Scale of 1:50,000) carried out by Selkhoz (1980), for the Libyan Secretariat of Agriculture, in addition to the soil investigation data in the detailed study for Al-Jabal Al-Akhdar vegetation cover accomplished by Omer Al-Mukhtar University (OMU) in 2005, where it contains more information on: soil organic matter, CaCO3 percentage, pH, cation exchange capacity, soil nutrients, electrical conductivity (EC), soil texture and soil depth. Also the Libyan Soils and Terrain Digital Database (Libyan SOTER) generated by the Libyan General Water Authority and the Arab Centre for Studies of Arid Zones (ACSAD) which was carried out in 2005. The collected soil data for the study area where was processed as in figure (2), and classified according to the Natural Resource Conservation Service (NRCS) Hydrologic Soil Groups (USDA 2009), where the designated CN values were assigned to each land use-soil group polygon for the study area.

Table 1. Research data

Data	Metadata
Digital elevation Model (DEM)	Alaska Satellite Facility ALOS PALSAR RTC products Terrain-Corrected (RTC) DEM INT16 GeoTIFF 12.5m resolution Acquisition Date: 2009-09-04 Path: 628 Frame: 640
Satellite image	European space agency (ESA) Sentinel 2 Entity ID: L1C_T34SEB_A020782_20190615T090905 Acquisition Start Date: 2019-06-15T09:09:05.062Z Processing Level: LEVEL-1C Resolution:60, 20, 10
Soil	Soil Maps scale 1:50,000,Selkhozprom 1980 Soil study in the vegetation cover of Al-Jabal Al-Akhdar report, Omer Al-Mukhtar University 2005 Libyan SOTER ,GWA and ACSAD 2005
Rainfall	NASA Prediction of Worldwide Energy Resource (POWER) ,Higher Resolution Daily Time Series 1/2 x 1/2 degree ,Climatology Resource for Agroclimatology

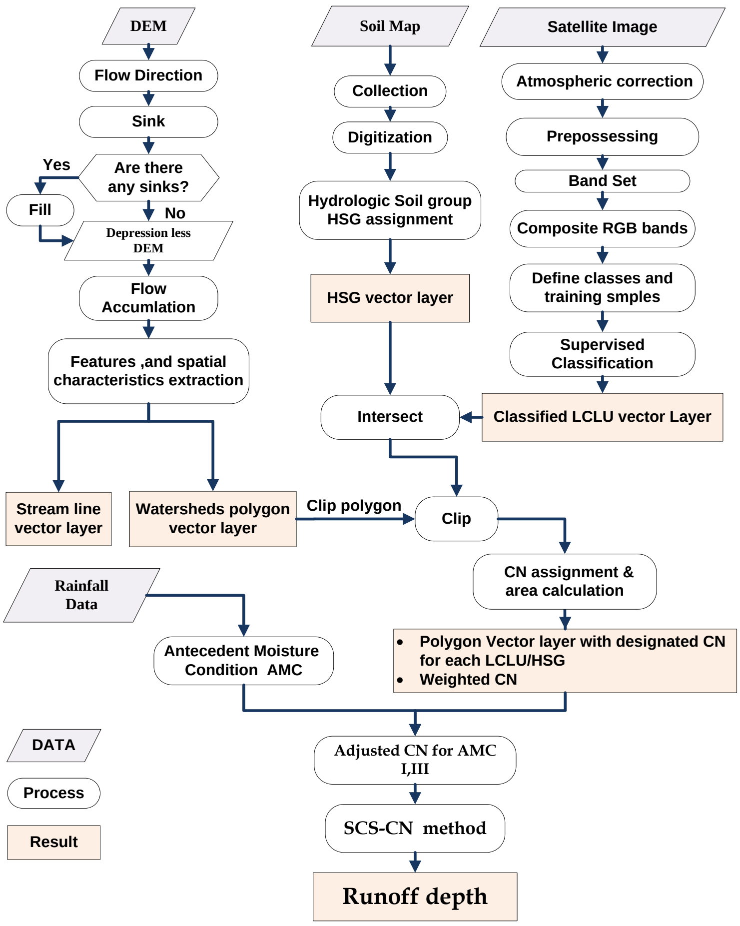

Fig 2. The implementation workflow steps for surface runoff estimation

3.4. SCS Curve number method

The SCS curve number is for the purpose of determining the ability of soils to allow infiltration of water with respect to land use/ land cover (LU/LC) and antecedent soil moisture condition (AMC) (Amutha and Porchelvan 2009), where AMC refers to the wetness of the soil surface or the amount of moisture available in the soil profile, or alternatively the degree of saturation before the start of the storm (Mishra and Singh 2003). There are three AMC (I, II & III) according to different soil conditions and rainfall limits for dormant and growing seasons as shown in table (2). The AMC-I, indicates the lowest runoff potential, because the soils are dry enough, (ii) AMC-II indicates the average soil moisture condition and (iii) AMC- III indicates to the highest runoff potential of the soil, which practically happens when areas of watershed are saturated from antecedent rains (Vinithra and Yeshodha 2016).

Table 2. Classification of Antecedent Moisture Conditions (SCS 1985)

AMC	Total 5-day Antecedent rain fall (mm)	
	Dormant season	Growing season
I	Less than 12.7	Less than 35.6
II	12.7 to 27.9	35.6 to 53.3
III	More than 27.9	More than 53.3

Since the value of CN for land use HSG assigned according to (USDA 2009) tables, those are applied only to AMC-II and in order to derive curve number values for AMC-I and III, therefore correction factors are needed to be applied, where the weighted curve number CN_w will be adjusted according to the AMC condition using the following equations (Chow et al. 2002):

$$CN_I = \frac{4.2 * CN_{II}}{10 - (0.058 * CN_{II})} \qquad equation\ 1$$

$$CN_{III} = \frac{23 * CN_{II}}{10 + 0.13 * CN_{II}} \qquad equation\ 2$$

The weighted curve number CN_w computed according to the following equation:

$$\mathrm{CN}_w = \sum \mathrm{CN}_i * \frac{A_i}{A} \qquad equation\ 3$$

Where CN_i the curve number for each land use-soil group polygon, A_i is the area of each land use soil group polygon for given CN_i, and A is the total area of the watershed. The Soil Conservation Service Curve Number method (SCS-CN) adopted for calculation of runoff depth given by (SCS 1985).

$$\mathrm{Q} = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad equation\ 4$$

Where Q is the runoff (mm), P is the rainfall and S is the potential maximum soil retention estimated by CN curve number value as follow:

$$\mathrm{S} = \frac{25400}{\mathrm{CN}} - 254 \qquad equation\ 5$$

Rainfall data for the period of 2009-2018 obtained from Prediction of Worldwide Energy Resource (POWER) project was initiated to improve upon the current renewable energy data set and to create new data sets from new satellite systems targets user communities interested in renewable Energy, sustainable Buildings, and Agroclimatology (NASA Power 2019).

4. Results and discussion

4.1. Spatial Characteristics

The results of the elevation data processing illustrated in figure (3), where the overall areas of Wadi Ba Al-Arid watershed 136.4 square kilometers and the perimeter 107.3 Km. The watershed upstream and downstream are well recognized due to the topographical difference as result of the tectonic geology of Al-Jabal Al-Akhdar as in figure (4). The upstream lies on the second plateau of Al-Jabal Al-Akhdar area characterized by high streams frequencies, floodplains composed of Quaternary fluvial wadi and deposits, the hills of moderate and steep slopes, while downstream lies on the first plateau of Al-Jabal Al-Akhdar area characterized by only the mainstream course lies between two cliffs. The spatial characteristics of the upstream and downstream of Wadi Ba Al-Arid watershed are shown in table (3).

Table 3. Spatial Characteristics of the watersheds

Parameter	Upstream	Downstream
Perimeter (Km)	84.9	35.4
Area (Sq. km)	125.3	11.1
Minimum elevation (m)	157.0	35.2
Maximum elevation (m)	576.0	407.0
Average elevation (m)	435.4	196.2
Maximum slope (%)	178.3	92.4
Average slope (%)	15.6	20.7
Average aspect	NW (323)	N (354)

4.2. Soil and LULC

The soil maps of a scale (1:50000) by Selkhoz (1980) were scanned and digitized using ArcGIS software as shown in figure (5) and the results in table (4).Where Red carbonate rendzinas and Red ferrisiallitic typical carbonate soils are the major types of soils in the study area. In which they classified into HSG according to the studied soil profiles data by OMU in 2005 in addition to the Libyan SOTER, Where the dominant hydrologic soil group in the study area are C and D as illustrated in figure (6).

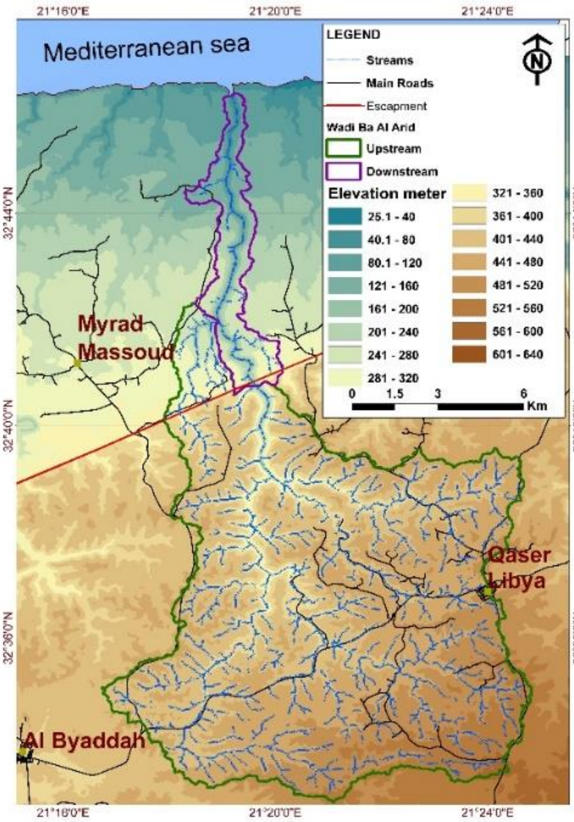

Fig 3. Elevation map of Wadi Ba Al-Arid Watershed

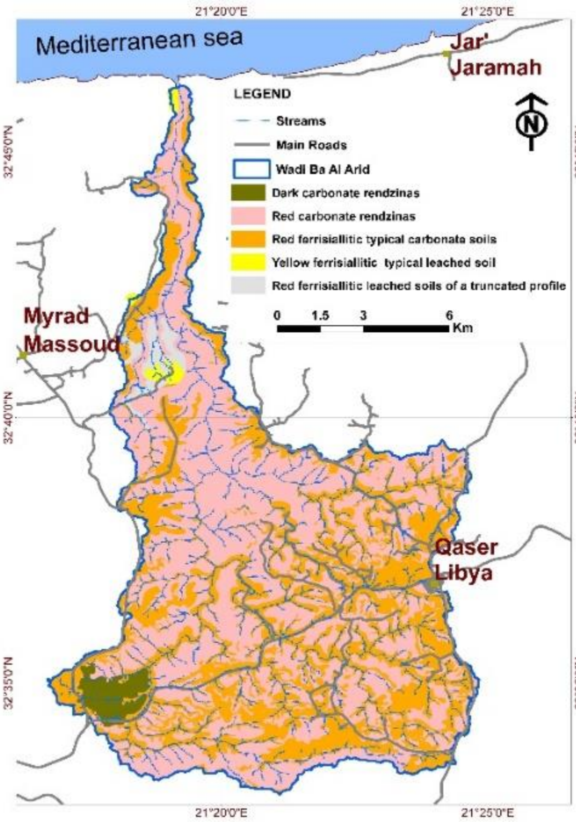

Fig 5. Soil map of Wadi Ba Al-Arid Watershed Modefied after (Selkhoz 1980).

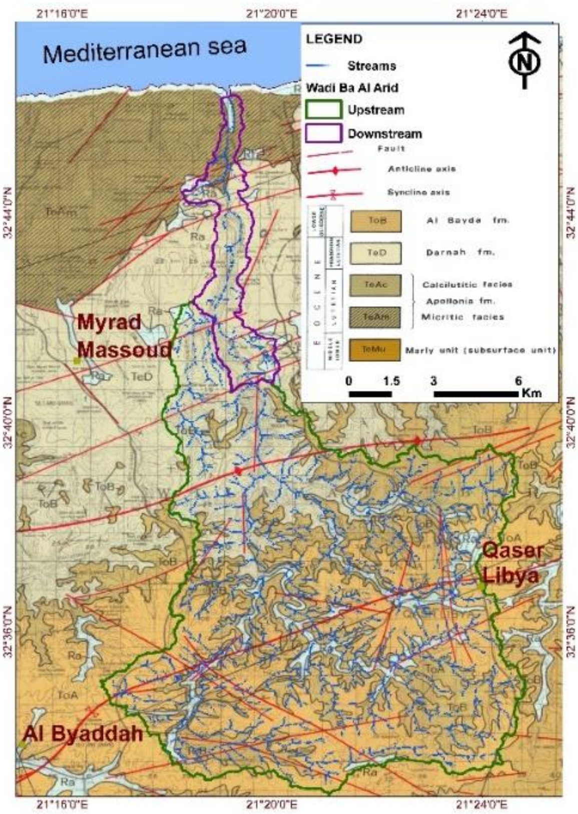

Fig 4. Geological map of Wadi Ba Al-Arid Watershed Modefied after (Hydrogeo 1996)

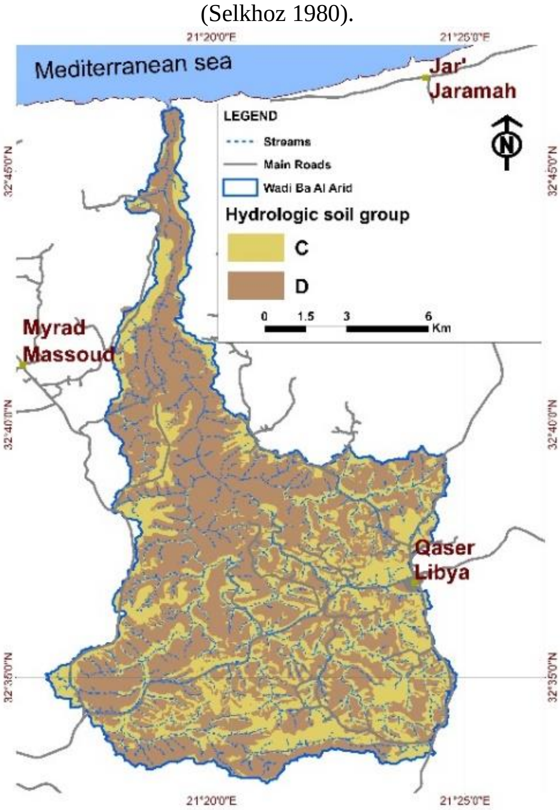

Fig 6. Hydrologic soil group map of Wadi Ba Al-Arid Watershed

Table 4. Soil types in the study area

Soil type	Area km^2	Area %	HSG
Dark carbonate rendzinas	2.77	1.96	D
Red carbonate rendzinas	71.2	53.91	D
Red ferrisiallitic typical carbonate soils	59.37	42.02	C
Yellow ferrisiallitic typical leached soil	0.9	0.62	D
Red ferrisiallitic hydrated leached soils of a truncated profile	2.16	1.49	D
The total	136.4	100	

The land cover consists mainly of forests, rain-fed agricultural lands, and the outcropped Tertiary carbonate formations are mostly composed of limestone and marl in addition to Quaternary fluvial deposits. The watershed LULC was classified into five classes; forest, shrubs, agriculture, barren land and built up as illustrated the LULC map as illustrated in figure 7. also, the area of each classes is shown on table 5 and the area percentage of each class as in in figure (8)**.** The HSG and LULC layers were intersected using ArcGIS software, and the CN was assigned as shown in (6). Furthermore, the CNI and CNIII calculated according to the equations 1 and 2 respectively and the weighted curve number for each AMC condition.

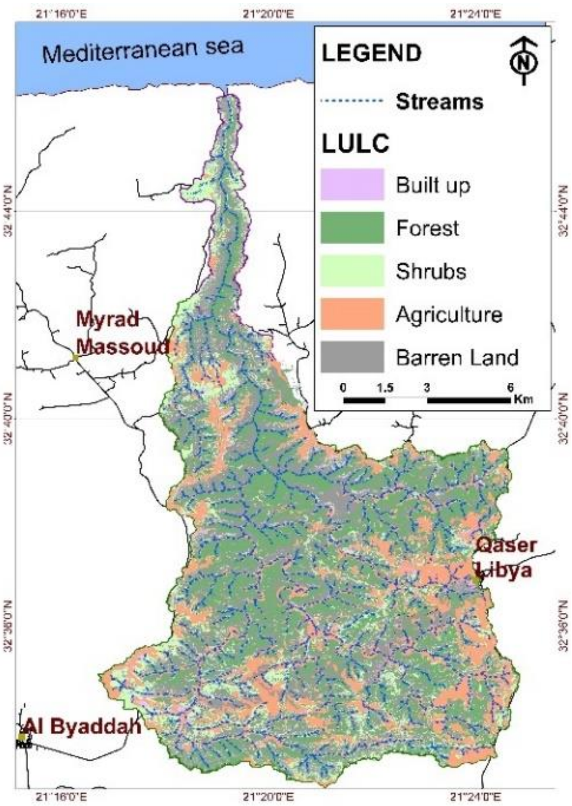

Fig 7. Landcover/Landuse map of Wadi Ba Al-Arid Watershed

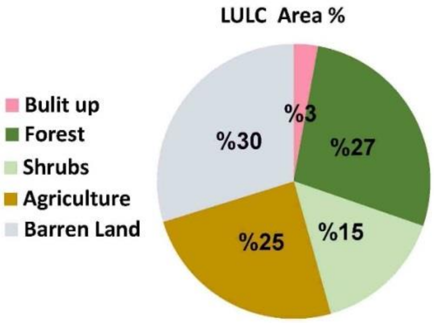

Fig 8. Area percentage of Landcover/Landuse of Wadi Ba Al-Arid Watershed

Table 5. Landcover/Landuse classes of Wadi Ba Al-Arid Watershed

LULC	Area km2	Area %
Bulit-up	4	2.9
Forest	37.3	27.3
Shrubs	21.0	15.4
Agriculture	33.5	24.6
Barren Land	40.6	29.8
Total	136.4	

Table 6. Weighted Curve Number

Land cover	HSG	CN	Area Km^2	Weighted Curve Number
Bulit up	D	88	4	AMC I=68.8 AMC II=84 AMC III=92.4
Forest	C	73	30.5	
Forest	D	79	6.8	
Shrubs	C	73	16	
Shrubs	D	79	5	
Agriculture	C	79	27	
Agriculture	D	84	6.5	
Barren Land	D	98	40.6	

4.3. Rainfall

The air masses over the Mediterranean Sea forms an area of convergence between the air of Eurasian and Saharan origin, are often rendered unstable by the sea. The result is often cyclonic precipitation over Al-Jabal Al-Akhdar, enhanced by orographic uplift, which may be intense (Allan 1973). According to the rainfall data from NASA POWER, the precipitation mainly occurs from October to March and April, and the maximum values of rainfall observed in December and January. Also, long dry periods frequently occurred within the wet seasons. Moreover, the annual rainfall from 2009 to 2018 that calculated from the daily data for the study area is shown in table (7) and figure (9), where the average for ten years was 264.3 mm. In addition, the rainfall characterized by its variability from year to year also monthly wide variability occurs.

4.4. Runoff estimation

According to equations 4 and 5, the runoff depth for Wadi Ba Al-Arid watershed computed for AMC I, II, and III conditions as illustrated in figure (10). The annual runoff during 2009–2018 in the study area are shown in table (8), where the average runoff volume for ten years is 1.67 Mm^3, which is 4.6% of the average annual rainfall during 2009-2018. The rainfall-runoff the relationship showed the correlation coefficient stated that the strong correlation value is 0.75 as shown in figure (11).

Table 7. Total annual rainfall

Year	Rainfall (mm)
2009	364.66
2010	299.12
2011	304.04
2012	205.73
2013	233.54
2014	170.13
2015	303.56
2016	193.81
2017	316.32
2018	251.65

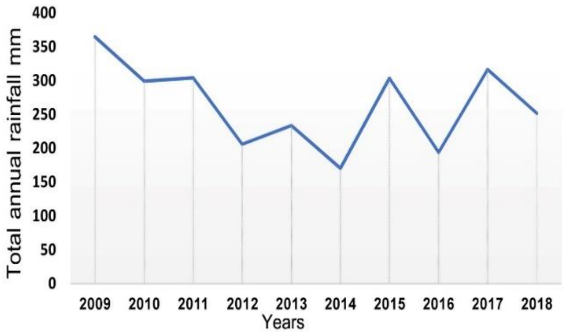

Fig 9. Mean total annual rainfall of Wadi Ba Al-Arid Watershed (2009-2018)

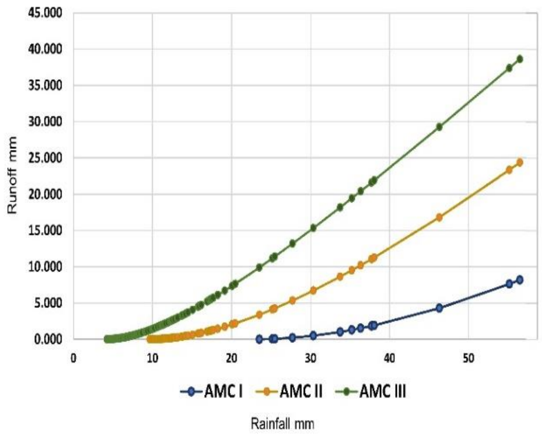

Fig 10. Solution of computed runoff equation for AMC conditions

Table 8. Annual runoff depth and volume

Year	Rainfall (mm)	Runoff depth (mm)	Runoff volume (m^3)
2009	364.66	20.53	2,799,994
2010	299.12	14.86	2,026,279
2011	304.04	15.67	2,137,122
2012	205.73	6.14	837,890
2013	233.54	9.32	1,270,616
2014	170.13	4.94	674,092
2015	303.56	14.89	2,030,600
2016	193.81	5.75	783,856
2017	316.32	18.73	2,554,693
2018	251.65	11.82	1,612,393

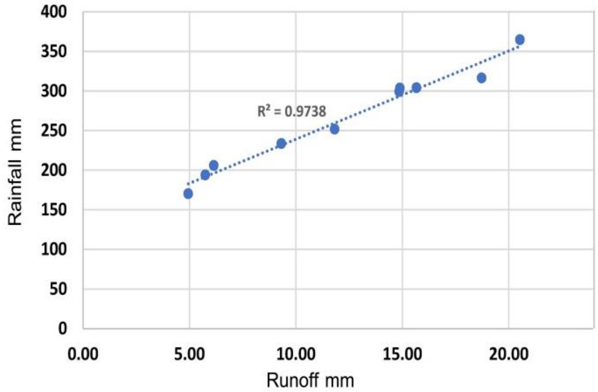

Fig 11. NASA Power rainfall and estimated runoff relation

5. Conclusion

The surface water resources in Libya are very limited, only the northern coastal areas considered with much potential especially Al-Jabal Al-Akhdar region, which is characterized by the highest rainfall rate in the country, compared with the rest of the Libyan territory. Unfortunately, this resource is not well-managed, and there is no recording for rainfall and runoff. Since the runoff is one of the baseline data for watershed planning. Therefore, the SCS-CN method in combination with GIS techniques and remote sensing data has been applied for runoff depth and volume estimation for Wadi Ba Al-Arid watershed. It is observed that the watershed generate a considerable amount of surface water which can be utilized by means of water harvesting. Also, in the absence of measured rainfall-runoff records. It is recommended for further studies to use more than one source of rainfall data with the support of field measurements to validate the modeled results.

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