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Floodwater harvesting of the Arghastan River basin of Kandahar in Afghanistan

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Abstract

Climate change and population growth are the important factors that place additional pressures on water resources, and generally, predictions indicate that these pressures are increasing continuously, so it is necessary to regulate surface water sources. Afghanistan has a semi-arid climate and already received worse effects of climate change; therefore, there is an extremely needed regulation of river flow across the country. Arghastan River is in the southern west parts of the country, thousands of cubic kilometers of water in this river are wasted annually, and drought and floods are the main problems of the residents due to non-management of river flow. The main objective of the study conducted by GIS was to find a dam site along the river for proper water management. A contour map was created for the entire watershed by using 5-meter DEM, that the most suitable site for the dam is at the coordinate of 66°48'34.468"E 31°35'4.512"N, it is possible to build up to 170-meter-high dam. The purpose site of the reservoir has the capacity to store about 1700 million cubic meters of water at an elevation of 170 meters, while the average monthly discharge of the Arghastan River up to the specific point of the investigation is about 38.6 m3/s. Suppose the floodwater of this River basin is harvested. In that case, it will provide the chance for residents to rescue their property from flood hazards during the rainy season, and they will have enough water for irrigation purposes during the summer season.

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Keywords

Contour map, dam site, reservoir capacity, surface runoff

1. Introduction

Naturally, the water flowing in the rivers is not uniform throughout the year; the water level sometimes reaches extreme levels along those rivers that do not have hydraulic structures for water control and management. In addition, climate change has also adversely affected important parts of the hydrological cycle. In the last two decades, the temperature has increased significantly, while in many regions of the world, the amount of precipitation has decreased and the groundwater table has dropped. The timing of rainfall has shifted [1] and the possibility of floods and flood hazards has increased more than ever before. The dangerous waves of climate change have already hit Afghanistan. In the last two years (2022 and 2023), floods have caused severe damage in the southern and southeastern regions of the country. Therefore, the study aims to work on floodwater harvesting of the Arghastan River basin with the help of GIS and remote sensing data. The problem of lack of sufficient water for agricultural lands is increasing in many regions of the country. Thus, floodwater harvesting is a good solution for reducing flood risk and water scarcity in arid and semi-arid regions [2]. We can say that floodwater is the main source of surface water and groundwater for many arid and semi-arid regions [3] because it is needed to control and manage floodwater for later use. Besides the washing of agricultural land, soil erosion, and floods also contaminate drinking water sources by collapsing wells or leaking the pipes of the water supply system [4]. Moreover, it is necessary to control the flow of floodwater for two main reasons, first, the demand for water for agriculture and drinking purposes is constantly increasing at the regional level, and second heavy and continuous floods have been predicted due to climate change.

Geospatial techniques, particularly Geographical Information Systems (GIS) and Remote Sensing (RS), have garnered considerable attention in recent times for identifying optimal locations for water recharging and harvesting [5]. The utilization of remote sensing and GIS proves to be a highly efficient and cost-effective approach for flood management, with the Digital Elevation Model (DEM) playing a crucial role in flood hazard mapping. With the availability of advanced remote sensing techniques and more intricate climatological and process models, there are now enhanced opportunities for comprehensive modeling of small reservoirs. This enables the accurate estimation of their surface areas, providing a clear understanding of their storage capacities and available water resources [6]. The application of Remote Sensing techniques directly yields information about the water spread area of a reservoir at a specific elevation during satellite passes [7]. Site suitability for various water harvesting structures can be determined by taking into account spatially varying parameters such as runoff potential, slope, fracture pattern, and micro-watershed area [8].

1.1. Problem Statement

Most of the residents of this region are engaged in agriculture and their agricultural products are an important source of livelihood. There is no regular system for irrigation in this area; the deficiency of surface water due to climate change has made the lives of the residents very difficult. Floods in the rainy season and lack of sufficient water for the agricultural lands in the dry season have made their lives in this region face severe challenges, therefore, there is a need to take necessary steps for floodwater harvesting in this area.

1.2. Research Objectives

Arghastan is a district located in the south of Kandahar, most of its residents are engaged in agriculture and livestock. The lack of sufficient water for their agricultural land is one of the main problems of their lives and this problem has become more serious with the increase of climate change. During the rainy season, the Arghastan River has enough water, and sometimes the property of the local people is washed away due to the floodwater. The main goal of this research is the floodwater harvesting of this area. We will try to mark the points along the river that are suitable for the construction of the dam and we will find the annual flow of this river basin up to the marked point.

1.3. Site Description

Afghanistan is a mountainous country and is included in the list of Asian countries that are not connected to the sea. This country has five important river basins, which include the Helmand River Basin, the Kabul River Basin, the North River Basin, the Amo River Basin, and the Harirod River Basin as shown in Fig.1. Out of these river basins, Helmand is the only river that flows completely within the country and covers the biggest area of the country related to others. The Helmand River consists of two main tributaries (Helmand and Arghandab) and both tributaries are almost the same in area. Arghandab tributary, which has an area of approximately 75000 km2, is mostly formed in the southern part of the Helmand River basin, it is divided into three other tributaries (Arghandab, Trunk, and Arghastan), and its geographical location is 31.33 to 33.57 N and longitudes 66.46 to 69.34 E as illustrated in Figure 2. The Arghastan River, which is the longest sub-river of this river basin, has a length of about 715 km and an area of 34,000 km2. It joins the Arghandab River in the west of Kandahar city.

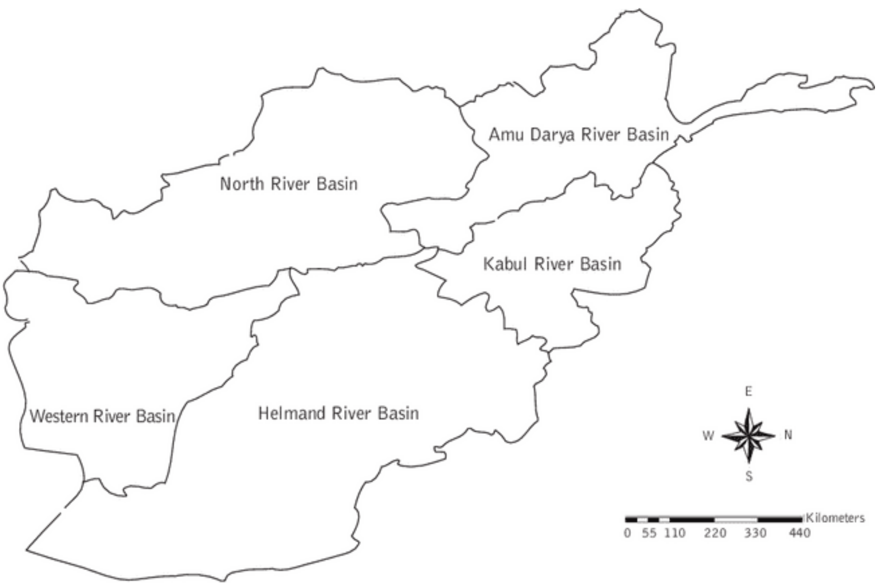

Figure 1. Five main River basins of the Afghanistan

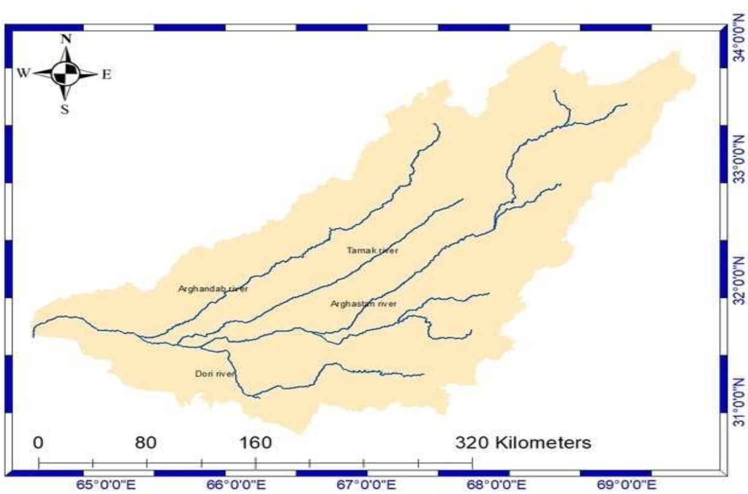

Figure 2. Location of the Arghastan River

2. Material and method

Floodwater harvesting is the main objective of the study, so the works of this research are divided into two phases. First is the need to find out the annual runoff of this river basin, to do so requires the data of DEM, Land used/land cover, Soil map, and meteorological data of the region. After the estimation of the annual yield of the basin, it is needed to identify the suitable location of the dam for maximum water harvesting in the region, the flow charts of the method are illustrated in Figure 3.

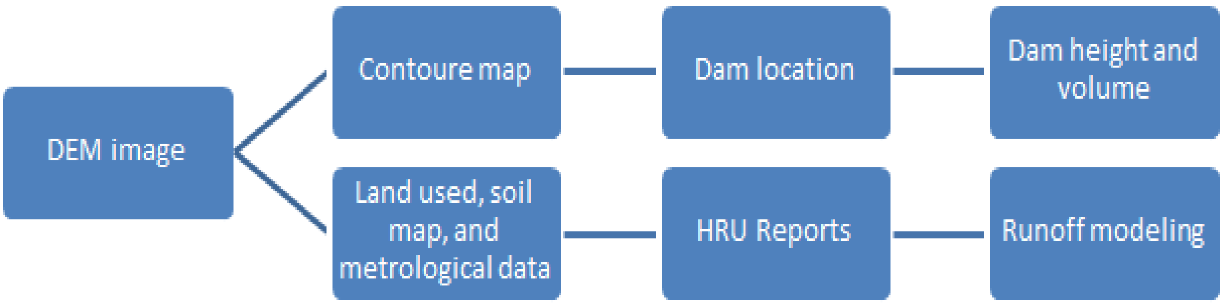

Figure 3. Methodology flow chart

To pinpoint an optimal location for the dam and determine the reservoir's volume capacity, Digital Elevation Model (DEM) images with a 5m resolution were acquired from the Ministry of Energy and Water. Figure 3 displays the contour map of the entire basin created using GIS, with contours at 10m intervals. Subsequently, a suitable dam location on the Arghastan River was identified through zooming and visual judgment. For the 3D analysis, the surface volume option in GIS was utilized to estimate the reservoir's size and water spread area at different dam elevations. This involved calculating the projected area, surfaced area, and establishing a Level-Volume-Area relationship dataset. Various data, including the DEM image, soil properties map, land cover/land use map, and climate data, were sourced from different providers. The 5-meter resolution DEM image from the Ministry of Energy and Water served for creating the contour map and estimating the reservoir volume. Additionally, around 18 ASTER 30-meter resolution DEM images were downloaded from the USGS site for runoff modeling across the entire watershed. Due to the absence of specific land use/land cover data for the country in the Soil and Water Assessment Tool (SWAT), a global land use/land cover map spanning 2004 to 2006 was obtained from the http://due.esrin.esa.int/page_globcover.php website. This comprehensive dataset compilation enabled a thorough analysis and modeling process for identifying the ideal dam location and assessing reservoir characteristics. Same case for soil data, no appropriate soil map was found for the country therefore, the world soil map was downloaded from http://www.isric.org/data/isric-wise-derived-soil-property-estimates-30-30-arcsec-global-grid-wise30sec website In. Other data that is needed for runoff modeling is meteorological data, around 36-year meteorological record for the study area was downloaded from https://globalweather.tamu.edu/.

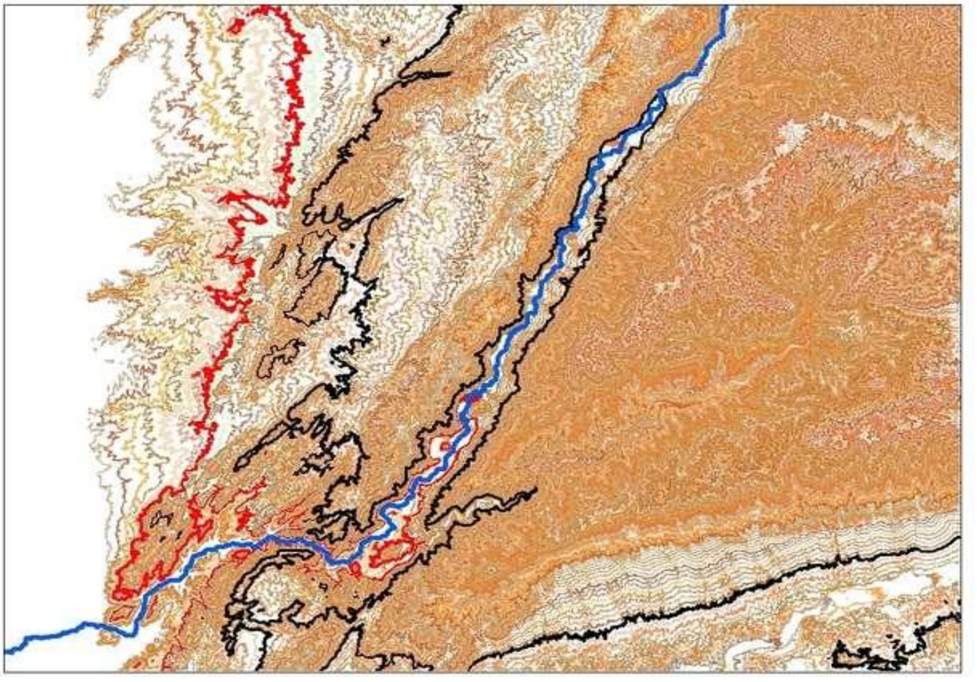

Figure 4. Contour map of the study area

3. Results and Dıscussıon

The main object of the study is the harvesting of thousands of cubic kilometers of floodwater that are flowing in this river yearly, with no hydraulic structure along the river to regulate the water for later use. To control and manage this water, an attempt is made to study the suitable site location for the dam along the river.

3.1. Dam site

As mentioned earlier 5-meter resolution, digital elevation model image was used for constructing a contour line to find out the location of the dam to harvest the water. Several points are there along the river that were suitable for the check dams, but the most important point, which is elected in the study has the coordinate of 66°48'34.468"E 31°35'4.512"N, and illustrated in figure 5. The red contour line that is attached to the bed of the river at that point has zero elevation while the block contour line is 170m in height from the streambed at that point. It specifies that there is a possibility to build a dam up to 170 meters in height. For economical consideration, the length of the dam should be as small as possible to increase the stability of the dam and decrease the volume of constructed material. The width of the river at this point that is selected for the dam is only 95 m at the bed of the river, while it has a width of 485 m in height of 170 m from the bed of the stream.

Moreover, the least amount of public property will submerge at the upstream side of the dam once if built is another worthy feature that is considered during selecting the site for the reservoir. A dam also needs to have a safe passage of floodwater downstream of the river, which is known as a spillway, the location and discharge capacity of the spillway is very important for the stability of the dam. The spillway will be a part of the dam or a separate structure far from the main body of the dam, so it is important to consider during the site selection of the reservoir. Because it has a great effect on the cost of the dam construction, as illustrated in Figure 16 the point that is suggested for building the dam has an appropriate site for the spillway construction on the right bank of the river.

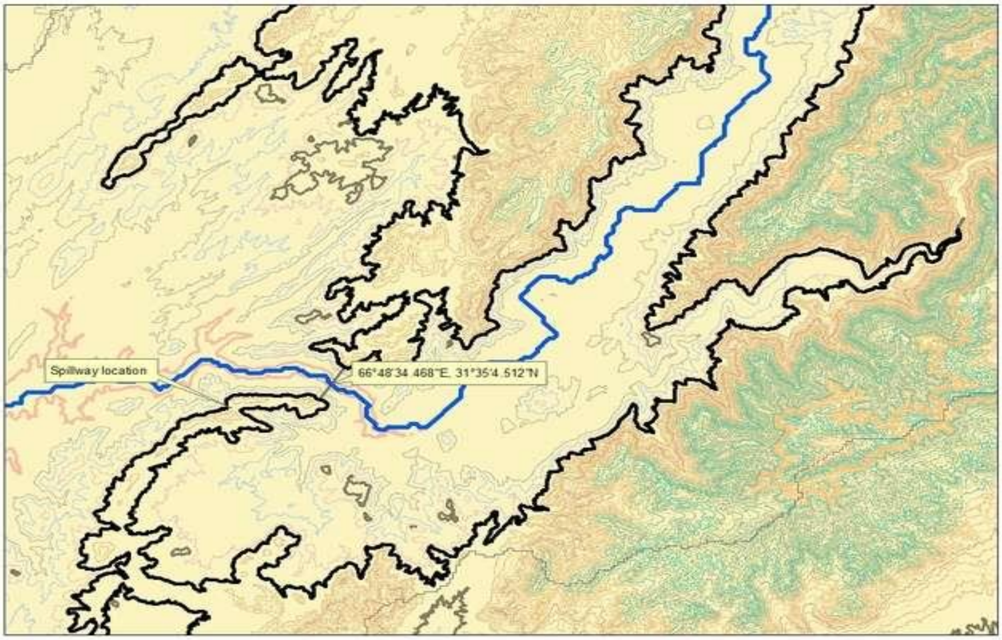

Figure 5. location of the elected site for the dam and spillway on the Arghastan River

3.2. Reservoir capacity

Table 1. Elevation, water spread area, and corresponding volume of the purposed dam

Arghastan dam area-volume				
NO	Elevation of the dam from the riverbed in m	Elevation of the dam from mean sea level in m	Reservoir water spread area kilometer sq.	Reservoir volume in million cubic meters
1	0	1450	0.00	0.00
2	10	1460	0.12	0.46
3	20	1470	0.55	3.53
4	30	1480	1.24	12.19
5	40	1490	2.15	28.68
6	50	1500	3.19	55.26
7	60	1510	4.72	94.06
8	70	1520	6.16	148.25
9	80	1530	7.64	217.32
10	90	1540	9.20	301.43
11	100	1550	10.81	401.22
12	110	1560	12.68	518.54
13	120	1570	14.95	656.28
14	130	1580	17.39	817.73
15	140	1590	20.10	1005.06
16	150	1600	23.12	1221.05
17	160	1610	26.19	1467.73
18	170	1620	28.81	1744.43

Calculating the volume of the reservoir for the point selected for the dam is an important part of the research because the capacity of a reservoir and the area of water spread are important factors that play a special role in the selection of the area for the reservoir. In this research, 3D analysis tools within GIS were employed to estimate the volume of the reservoir and the water spread area on the upstream side of the dam. A contour map of the site was generated, and calculations were conducted at various elevations along the contour lines to determine both the volume and water spread area. Table 1 summarizes the results obtained from 18 different elevations, ranging from zero at a specific dam location up to 170 meters above the riverbed. The storage volume and water spread area at different elevations were then plotted, resulting in storage-elevation and area-elevation curves, as depicted in Figure 6. The analysis reveals that, at dam heights of 160 and 170 meters, the reservoir has the capacity to store up to 1467 and 1744 million cubic meters of water, respectively. This substantial capacity is deemed adequate for effectively managing water for agricultural purposes downstream of the dam, particularly during dry seasons.

3.3. Compression of the reservoir volume with runoff

As per evaluation, the average stream flow of the Arghastan River up to the point where the reservoir is supposed to be built is around 38.6 m3/s, if calculated the total cumulate stream flow for a year is equal to somewhat about 1200 million cubic waters. So, if all water that is flowing in the stream throughout the year is stored, is needed to build the dam up to 150 meters in this specific location. From this, it appears that we have sufficient volume at this point, and can even hold the water of this river completely for a year. In addition, if 35 cubic meters per second of water from this reservoir is normally released for other purposes such as (electricity, agriculture, etc.) about 130 million cubic meters of the reservoir is needed to keep this amount of water flowing at critical times throughout the year as shown in Fig 6. A dam with a height of 70 meters is needed to build a reservoir of 130 million cubic meters in this area as indicated in Table 1.

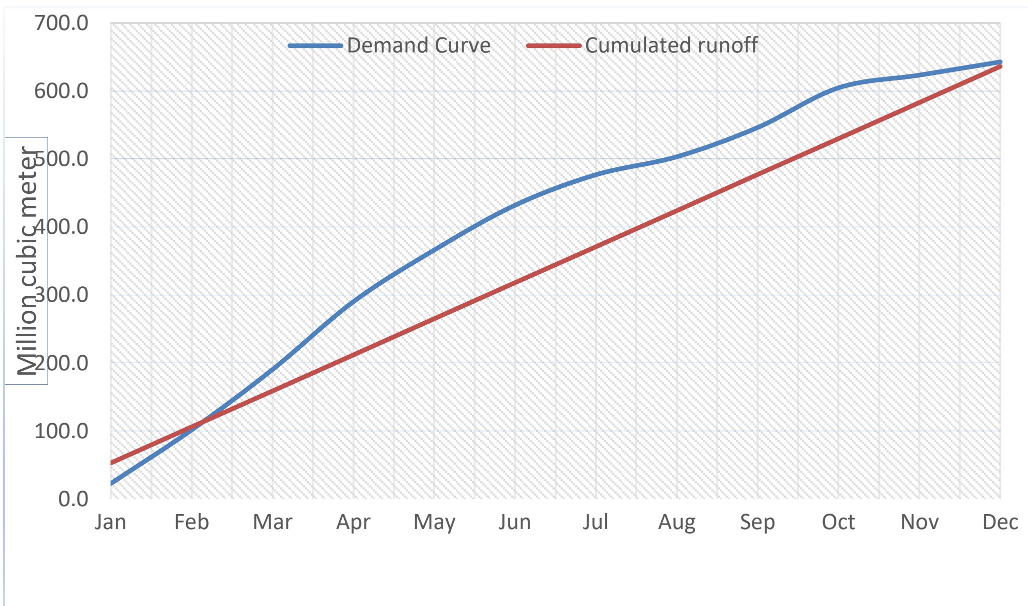

Figure 6. Storage and area elevation curve of the reservoir

3.4. Runoff modeling beyond the year 1980

Metrological data of 34 used in GIS for monthly-based river flow modeling of the Arghandab River basin at a specific location that was investigated for dam construction. The 34-year average River flow of the Arghastan River basin up to the specific point is about 38.6 m3/year. The stream flow hydrograph of the Arghastan River basin indicates that the discharge of this river has reached a peak point between the years of 1998 to 1999, while it reached to lowest point within the years of 2001 to 2002 for this specific period of estimation as shown in figure 7. Overall, the hydrograph shows that the discharge of the river basin has been slightly decreased year to year for the entire period of the study.

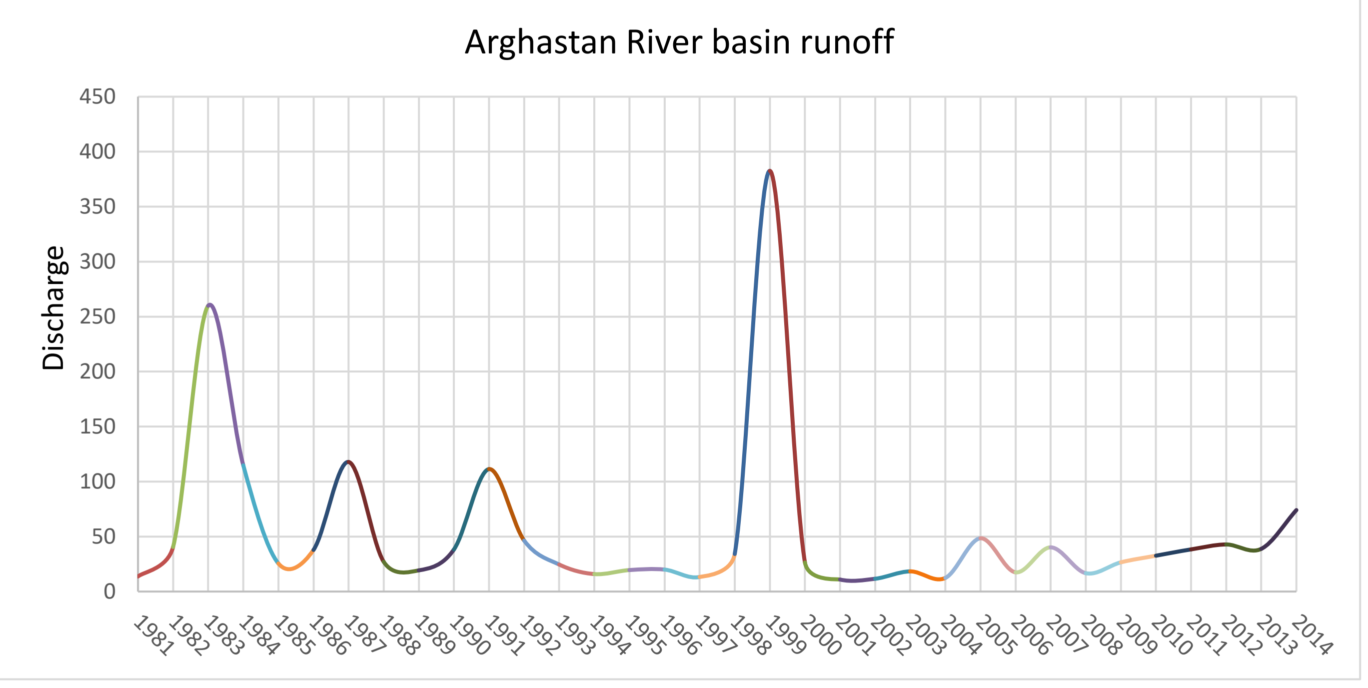

Figure 7. 34-year annual hydrograph of the Arghastan River basin

4. Conclusion

For the adaptation of climate change, which is a global concern issue, floodwater harvesting is a basic task. In this study, it has tried to work on water resource management of the Arghastan River basin which covers about 34,050 sq. km, area and is located to the southeast of Kandahar City. Several points along the River of Arghastan were suitable for water control on small scales, among them the most important site was the coordinate of 66°48'34.468"E 31°35'4.512" N, which can build a dam in this location up to 170 meters height. Furthermore, there is an excellent site for a spillway on the right bank of the river. The average monthly discharge of the Arghastan River basin that is estimated by Arc-SWAT up to the specific point of the investigation is about 38.6 m3/s. Overall; the hydrograph shows that the discharge of this river has slightly decreased year by year as an inverse effect of climate change. In addition, if 35 m3/s of water is released for agricultural and other purposes, in this case about 130 million cubic meters of the reservoir is needed to keep this amount of water flowing at critical times throughout the year.

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