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An Analysis of Long Term Yearly Water Flow Trend and Its Impact on Sediment Yield in King Talal Dam

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Abstract

Water stress and scarcity are becoming a serious threat to economic growth, social cohesion, and political stability. In Jordan, the problem of water scarcity is further excerpted as a result of wide fluctuations in annual rainfall, population growth, urbanization and a dramatic increase in refugees' numbers. All these factors affect the sediment yield in King Talal Dam (KTD) which is one of the largest dams in Jordan. Accumulation of sediment in KTD influences the storage capacity, operational life and water quality of the dam, thus affects the water uses for irrigation purposes. Hence, quantifying sediment loads, as well as the rainfall and water flow trends, are of high significance for understanding the sediment accumulation and the watershed management of sediment. This study demonstrates an analysis of the long term yearly water flow and sediment yield trend in KTD in the period between the years 1980 to 2017. The distribution of annual water flow and rainfall in the KTD area indicated a high variation and a significant correlation between them. Annual water flow and sediment yield exhibited a corresponding general trend over the study years. Based on the results of this study, the estimated annual sediment yield at KTD for the years 1980-2017, ranged between 0.10 to 2.90 MCM with an estimated sedimentation rate of about 0.393 MCM per year. The estimated total volume of sediment at KTD in 2017 after 39 years since its operation is about 15.32 MCM, which indicates that about 20.4% of the dam's storage capacity of 75 MCM has been lost due to the sediment accumulation. KTD is expected to be completely filled up with sediments in 2208 with an expected life span of about 230 years from the start of the dam's operation. The application of land use management practices for the KTD in the watershed of Zarqa River Basin will reduce soil erosion and accumulation of sediment in KTD, as well as enhance the infiltration rate, groundwater recharge and maintain enough irrigation water downstream to the Jordan valley. Measures on land use management practices in a sustainable manner have to be implemented by decision makers to manage water flow of Zarqa Basin, such as improving rangelands and recharging groundwater.

Keywords: Water Flow; Sediment Yield; Rainfall Trend; Decision Makers; King Talal Dam.

1. INTRODUCTION

Rainfall is a principal element of the hydrological cycle; therefore it is of interest to understand its behavior and profound social and economic significance. Recording and studying the historical yearly rainfall amounts is important information for understanding the changes in the rainfall trend. However, rainfall changes are particularly hard to gauge, because rainfall is not uniform and varies considerably from place to place and from time to time, even on small scales [[1],[2]]. Nevertheless, understanding trends and variations of the current and historical hydro-climatic variables is pertinent to the future development and sustainable management of water resources of a particular region. Global climate changes may influence long-term rainfall patterns impacting the availability of water, along with the danger of increasing occurrences of droughts and floods [[3],[4]]. Many previous studies have analyzed the rainfall trends in several parts of the globe, [[5]] described the fluctuations of rainfall in Europe using a time series of annual areal precipitation totals [[5]]. Positive and negative trends have also been observed in the USA [[6]], and Italy [[7]].

The yearly rainfall trend and river discharge affect the amount of sediment delivered via the river to the dam located down streams [[8]]. The accumulation of sediment in dams is highly influenced by many factors such as land-use, vegetation cover, river discharge and rainfall variability [[9]], where poor land-use practices will cause high rates of soil erosion and thus an increase in sediment yields. Several previous studies have suggested various recommendations on land use and water resources management e.g. [[10]] and to reduce the sediment yield e.g. [[8]]. According to the previous studies, the influence of the sediment accumulation has received a lot of attention since the consequence of high sediment yield is causing the siltation of dams and loss of their storage capacity which affects the economic life. Moreover, loss of storage capacity hampers the dams' ability to fulfill their functions which include; irrigation supply, flood control, and domestic water supply [[11]].

Jordan is considered among the most water-stressed countries in the world with an annual per capita 140 m3 of renewable water resources, which is far below the minimum water per capita in the severe water-scarce countries; 500 m^3/year

[[12]]. Water stress and scarcity are becoming a serious threat to economic growth, social cohesion and political stability. Water in Jordan is usually used for many purposes including domestic use, irrigation, industry, livestock watering, recreation, etc. The climate of the country is characterized by long dry and hot summer, rainy winter and spring drier than autumn. The temperature increases towards the south of the country, with the exception of some southern highlands. Rainfall varies considerably with location, mainly due to the country's topography.

Precipitation in Jordan ranges between 50 to 500 mm yearly depending on the location and topography, but over 90% of the country receives less than 200 mm/year. 94.7% of the rainfall is exposed to evaporation, whereas 2.3% flows into the rivers and other catchments (e.g. dams) and 3% infiltrates into underground aquifers. The long-term average rainfall is about 8200 MCM [[13]]. Rainfall fluctuation restricts surface water supplies, making water a key issue for the country [[14]]. Hence, the construction of dams on the side wadis and the river flows is one of the important water harvesting projects for the development of the country.

Dams located across the country involve 10 major dams and more than 143 large ponds to collect floodwater. The country's 10 major dams are King Talal Dam, Wadi Al Arab Dam, Sharhabil Dam, Kafrein Dam, Wadi Shuaib Dam, Karameh Dam, Tannour Dam, Waleh Dam, Mujib Dam, and Wihdeh Dam. Momentarily, All these dams hold 60 percent of their total capacity of 325 MCM [[15]].

King Talal Dam (KTD) is the largest dam and one of the main sources of water in Jordan, **Figure 1**; it was originally constructed in Zarqa River Basin in 1977 to provide a storage capacity of 55 MCM. In 1988, the dam was raised and enlarged to a storage capacity of 75 MCM to meet the country's increased water demands. The main purpose of this dam is to supply agricultural irrigation water to the Jordan Valley. Meanwhile, the water from KTD is used to irrigate lands within the middle and southern zones of the Jordan Valley [[16]]. Zarqa River is the main artery flow to the KTD. The streamflow of Zarqa River is being impounded at KTD at the south-west of Jerash town at an elevation of 120 m. The flow characteristics have been further modified by the discharge to the river of treated domestic wastewater that composes nearly all of the summer flow and causes substantial degradation in the water quality of the dam [[17],[18],[19]]. Water quality from the KTD is dramatically deteriorated after the establishment of the largest wastewater treatment plant in Jordan in 1985 which was named Khirbet es-Samra Wastewater Treatment Plant (KSTP); it is located about 42 km upstream of the dam. The effluent from KSTP discharged through the Zarqa River to KTD and spilled out downstream until it reaches the Jordan Valley area which is mainly used for irrigation purposes. Therefore, any pollution in the river will lead to pollution in the KTD, which in turn may affect the quality of agricultural produce in the Jordan Valley [[20]] .

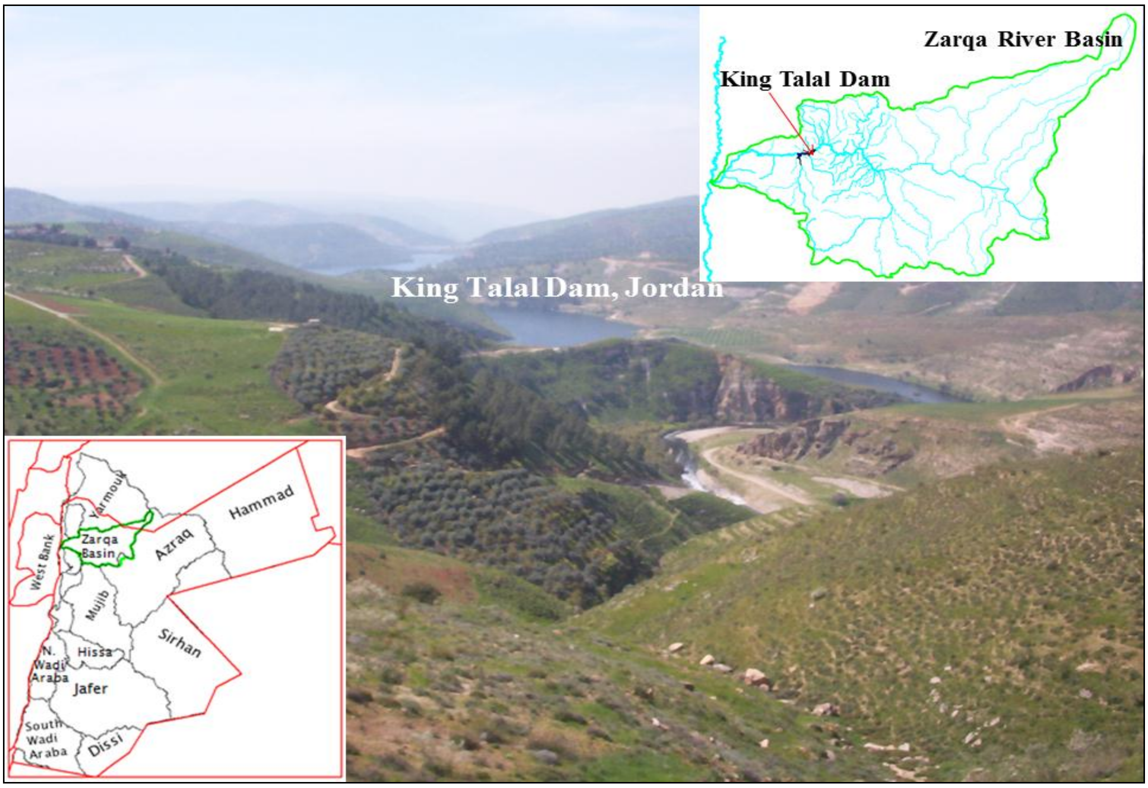

Figure 1. Location Map of King Talal Dam - Jordan.

KTD is selected in this study because it suffers from accelerated annual sedimentation and a staggering annual loss of storage capacity due to the sediment carried by surface runoff of the Zarqa River Basin. It is worthwhile to mention that the runoff gauge station at Jerash Bridge on the Zarqa River is the only gauge in the whole Zarqa Basin, which has the continuous long recorded database and possibly enough to be suitable for rainfall analysis as it is located at the entrance of the KTD from the east. Therefore, the aim of this study is to assess the impact of the rainfall and water flow trends on the sediment yield of KTD. This is an essential key for controlling the sediment yield accumulation in the KTD. The specific objectives of this study are (1) to analyze the long term yearly rainfall trend for the period of 1980-2013 for 33 rainy seasons, (2) to assess the impact of rainfall and water flow trends on the yearly sediment yield based on data availability between the years 1980 to 2017, (3) to propose land use practices that may reduce KTD sediments.

2. MATERIALS AND METHODS

A. Rainfall and water flow

Historical rainfall and water flow trends were analyzed using all available data of the rainy seasons 1980-2013 for rainfall and 1980-2017 for the water flow. The records of the Zarqa river flow were from the only gauging station located at the New Jerash Road Bridge and named Jerash gauge station, where the records are available on a daily basis. Jerash gauge station is the most essential station with a complete record for measuring the Zarqa river discharge. The data of historical rainfall based on a daily record was obtained from the Ministry of Water and Irrigation [[21]], whereas, the rainfall intensity is not continuously recorded at the Jerash station. Thirty-three (33) rainy seasons were studied in this paper in terms of counting the rainy days of each year compared to the amount of annual rainfall of the targeted year. **Table 1** shows the analysis of the historical annual rainfall and rainy days per each year in mm at the Jerash Gauge station for the years (1980-2013).

B. Sediment loads of King Talal Dam

Data regarding the characteristics of past and current sediment load on the location of KTD were collected from the Jordan Valley Authority (JVA) [[22]] for the years 1980-1985, 1988-1989, 1990-1992, 1993-1994, 1996-1997,2008-2009 and 2014-2015 and from [[23]] for the years (1985-1988 and 1989-1990) as shown in **Table 2**. Nevertheless, there is missing data for many years such as 1992-1993, 1994-1996, 1997-2008, 2009-2014 and 2015-2017. The values of sediment yield for the missing years were calculated based on the available historical recorded data [[22]], by plotting the relationship between cumulative annual flow in MCM and cumulative sediment yield in MCM over the years of available record. Depending on the analysis of the correlation results, it was found that the following power function equation fits perfectly with the historical data and was used to calculate and predict the sediment yield for the years (1992-2017).

$$\sum S_y = 0.6042 \times \sum W_f^{\,0.3694} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where;

S_y: is the cumulative sediment yield of the KTD and W_f: is cumulative water flow into KTD.

The cumulative sediment values for the years 1992-2017 were firstly calculated using equation (1), and then the expected actual sediment yield for each year was obtained from the difference between the cumulative value of sediment (S_y) for the target year and the cumulative value of a year before as shown in **Table 2**. For example, the actual sediment yield of KTD in the year 2000 is the difference between cumulative sediment values in years 1999 and 2000.

3. RESULTS AND DISCUSSION

A. Historical rainfall, water flow and rainy days

The data of the historical annual rainfall and water flow at the Jerash Gauge station as shown in **Table 1 and Figure 2**, where the variability of the rainfall and water flow over the studied area is high. Unfortunately, there are not enough records of rain intensity over the studied years, but it can be seen from **Table 1 and Figure 2** that the highest values of the annual rainfall and water flow were recorded in the rainy years 1991-1992, 2002-2003 and 2012-2013 and the lowest values were recorded in 1985-1986. Whereas the highest numbers of rainy days were recorded in the rainy years 1987-1988, 1991-1992 and 2002-2003 and the lowest numbers were in 1983-1984 and 1998-1999.

A large number of rainy days do not certainly mean a large amount of rain, and the low number of rainy days does not mean a low amount of rain. The amount of rain depends on other factors such as the intensity of rain, it is possible that the number of rainy days is low and gives a large amount of rain this can be attributed to the heavy rains during the low days of rain: For example, the case in the year 2012-2013, where the rainy days was 31 days and the annual rainfall was the highest of about 709 mm compared to the year 1985-1986 which the number of the rainy days was 36 and the annual rainfall was the lowest of about 189.5 mm as shown in **Table 1**.

The analysis of the data in **Table 1 and Figure 2** shows a weak relationship; R2=0.32 between rainy days and annual rainfall with an increase in the annual rainfall over the targeted years. Further studies are needed regarding the analysis of rainfall intensity. To understand and analyze the rainfall intensity pattern, the hourly rainfall data should be analyzed.

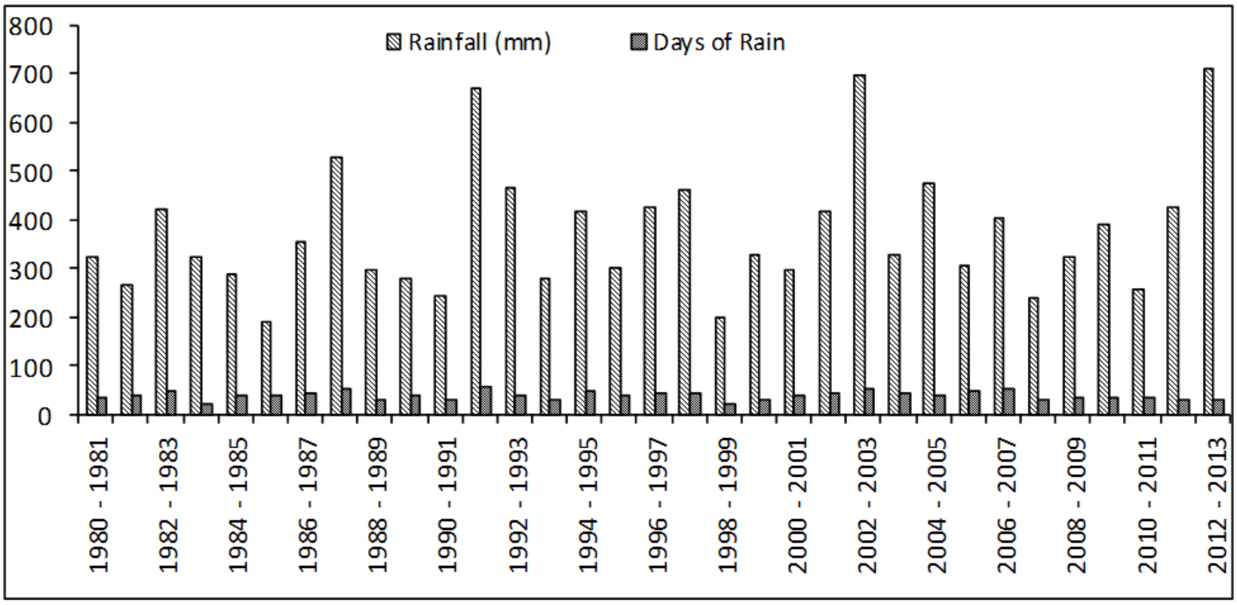

Figure 2 Characteristics of the average annual rainfall trend in mm and rain days for the years 1980-2012 for Jerash Gauge station [[21]].

Table 1 Historical annual rainfall in mm, water flow in MCM and rainy days at Jerash gauge station.

Year	Days of Rain	Rainfall mm	Water Flow MCM
1980 - 1981	34	324.0	65.0
1981 - 1982	40	266.3	61.3
1982 - 1983	45	421.9	90.2
1983 - 1984	19	323.6	42.1
1984 - 1985	37	285.0	74.8
1985 - 1986	36	189.5	40.8
1986 - 1987	42	352.2	57.9
1987 - 1988	53	526.8	123.7
1988 - 1989	27	297.2	65.1
1989 - 1990	37	277.8	61.5
1990 - 1991	27	241.5	56.3
1991 - 1992	55	668.7	190.1
1992 - 1993	39	462.9	128.4
1993 - 1994	31	279.7	83.8
1994 - 1995	48	414.2	126.3
1995 - 1996	39	298.5	81.4
1996 - 1997	42	423.1	101.5
1997 - 1998	44	460.0	78.2
1998 - 1999	19	196.8	66.0
1999 - 2000	30	327.2	76.6
2000 - 2001	39	297.7	65.6
2001 - 2002	41	416.2	97.5
2002 - 2003	53	696.7	108.5
2003 - 2004	41	325.8	75.1
2004 - 2005	40	472.2	176.9
2005 - 2006	45	306.2	82.3
2006 - 2007	50	402.5	83.2
2007 - 2008	27	237.6	61.7
2008 - 2009	34	321.5	75.9
2009 - 2010	33	389.0	94.3
2010 - 2011	32	254.9	91.4
2011 - 2012	31	422.4	102.9
2012 - 2013	31	709.0	128.2
2013 - 2014	---	---	116.8
2014 - 2015	---	---	127.2
2015 - 2016	---	---	115.4
2016 - 2017	---	---	115.8

The data of plotting diagram of annual water flow and annual rainfall over the studied years **Figure 3,** showed that a significant relationship with a value of R2=0.58, which shows that the variation of the annual rainfall data is responsible for about 57.8% of the variation in the data of the annual water flow. Consequently, this indicates that other factors affect the water flow other than rainfall. The other factors may be related to land use/ cover changes in the study area. The main changes that altered the character of land use/cover were the expansion of urban areas and the recession of forests [[24]]. The impact of these land use/cover changes reflects the amount of water flow over the years. Thus, the flow management upstream of King Talal Dam is highly needed to minimize sediment accumulation in terms of land use management practices.

B. Sediment loads of King Talal Dam

Sedimentation is one of the most important problems facing the majority of the dams in the world; it is of great importance due to its impact on storage capacity, operational life and water quality of the dams. KTD receiving annual variable and irregular sediments [[23]], where these sediments contain high concentrations of heavy metals and nutrients [[17],[25]].

The values of measured and estimated annual sediment yield at KTD (**Table 2)** for the rainy years 1980-1981 to 2016-2017 ranged between 0.10 to 2.90 MCM with an estimated sedimentation rate of about 0.393 MCM per year. The analysis of **Table 2 and Figure 4** showed a significant relationship between the annual rainfall and water flow on annual sediment yield. For example, the highest sediment yield occurred during the year 1991-1992, which was about 2.9 MCM, where the resulted data showed that the year 1991-1992 witnessed many rainfall days of 55 days compared with other years as shown in **Table 1**, and the water flow in that year was the highest of about 190.09 MCM among the study years. The lowest annual sediment yield occurred during the rainy year 2007-2008, which was about 0.10 MCM resulted from 27 rainy days, where the recorded water flow in that rainy year was one of the lowest recorded values in the all studied years.

Figure 4 shows more or less a generally similar trend between the annual sediment yield and water flow but it is clear that the annual sediment yield has generally decreased and stabilized over the last years, which can be attributed to artificial barriers and terraces and land-use management practices that located before the dam as well as the increased effluents from KSTP; the largest wastewater treatment plant in Jordan, which constitutes a significant portion of the water flow to the KTD, especially since the improvement of the efficiency of KSTP has been increased during the last study years. The relationship between annual sediment yield and water flow needs to be investigated using detailed rainfall intensity records (hourly data), flow and sediment data at the basin outlet.

The data of the present study **Table 2 and Figure 5,** showed that the estimated value of the total volume of sediment at KTD in 2016-2017 after 39 years since its operation is about 15.32 MCM, which indicates that about 20.4 % of the dam's storage capacity (75 MCM) has been lost due to the sediment accumulation. Based on these calculations, KTD is expected to be completely filled up with sediments in 2208 with an expected life span of about 230 years from the start of the dam's operation.

It was agreed that the land use management practices need to be supported by decision-makers to allow minimizing the sediment accumulation in dams [[9],[10],[8]].

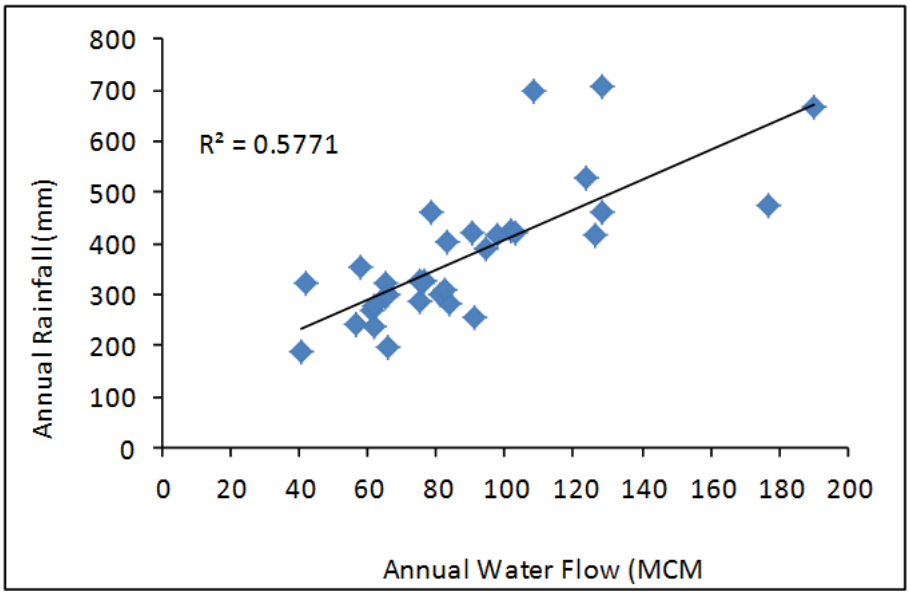

Figure 3 Correlation between annual rainfall in mm and annual water flow in MCM.

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Table 2. The measured and estimated sediment load at King Talal Dam (KTD) of the years 1980-2016.

Year	Annual Rainfall in mm	Annual Water Flow in MCM	Actual and Estimated Values of The Annual Sediment Yield in MCM	Available data of the Total Sediment accumulation in MCM obtained from JVA	Estimated Values of of the Total Sediment accumulation in MCM. This Study
1980 - 1981	324.0	65.0	0.691*	3.842	3.84
1981 - 1982	266.3	61.3	0.788*	4.630	4.63
1982 - 1983	421.9	90.2	0.444*	5.074	5.07
1983 - 1984	323.6	42.1	0.334*	5.408	5.41
1984 - 1985	285.0	74.8	0.351*	5.759	5.76
1985 - 1986	189.5	40.8	0.259**	6.018**	6.02
1986 - 1987	352.2	57.9	0.384**	6.401**	6.40
1987 - 1988	526.8	123.7	0.660**	7.061**	7.06
1988 - 1989	297.2	65.1	0.370*	7.431	7.43
1989 - 1990	277.8	61.5	0.209**	7.640**	7.64
1990 - 1991	241.5	56.3	0.203*	7.843	7.84
1991 - 1992	668.7	190.1	2.903*	10.746	10.69
1992 - 1993	462.9	128.4	0.370***	---	11.06
1993 - 1994	279.7	83.8	0.226***	10.996	11.29
1994 - 1995	414.2	126.3	0.322***	---	11.61
1995 - 1996	298.5	81.4	0.197***	---	11.81
1996 - 1997	423.1	101.5	0.235***	12.492	12.04
1997 - 1998	460.0	78.2	0.174***	---	12.22
1998 - 1999	196.8	66.0	0.143***	---	12.36
1999 - 2000	327.2	76.6	0.161***	---	12.52
2000 - 2001	297.7	65.6	0.134***	---	12.66
2001 - 2002	416.2	97.5	0.194***	---	12.85
2002 - 2003	696.7	108.5	0.208***	---	13.06
2003 - 2004	325.8	75.1	0.140***	---	13.20
2004 - 2005	472.2	176.9	0.317***	---	13.51
2005 - 2006	306.2	82.3	0.142***	---	13.66
2006 - 2007	402.5	83.2	0.140***	---	13.80
2007 - 2008	237.6	61.7	0.102***	---	13.90
2008 - 2009	321.5	75.9	0.123***	13.537	14.02
2009 – 2010	389.0	94.3	0.150***	---	14.17
2010 - 2011	254.9	91.4	0.142***	---	14.31
2011 - 2012	422.4	102.9	0.156***	---	14.47
2012 - 2013	709.0	128.2	0.190***	---	14.66
2013 - 2014	---	116.8	0.168***	---	14.83
2014 - 2015	---	127.2	0.179***	15.025	15.01
2015 - 2016	---	115.4	0.158***	---	15.16
2016 - 2017	---	115.8	0.155***	---	15.32

* [[22]], **[[23]], and *** Estimated values using Equation (1) in the present study.

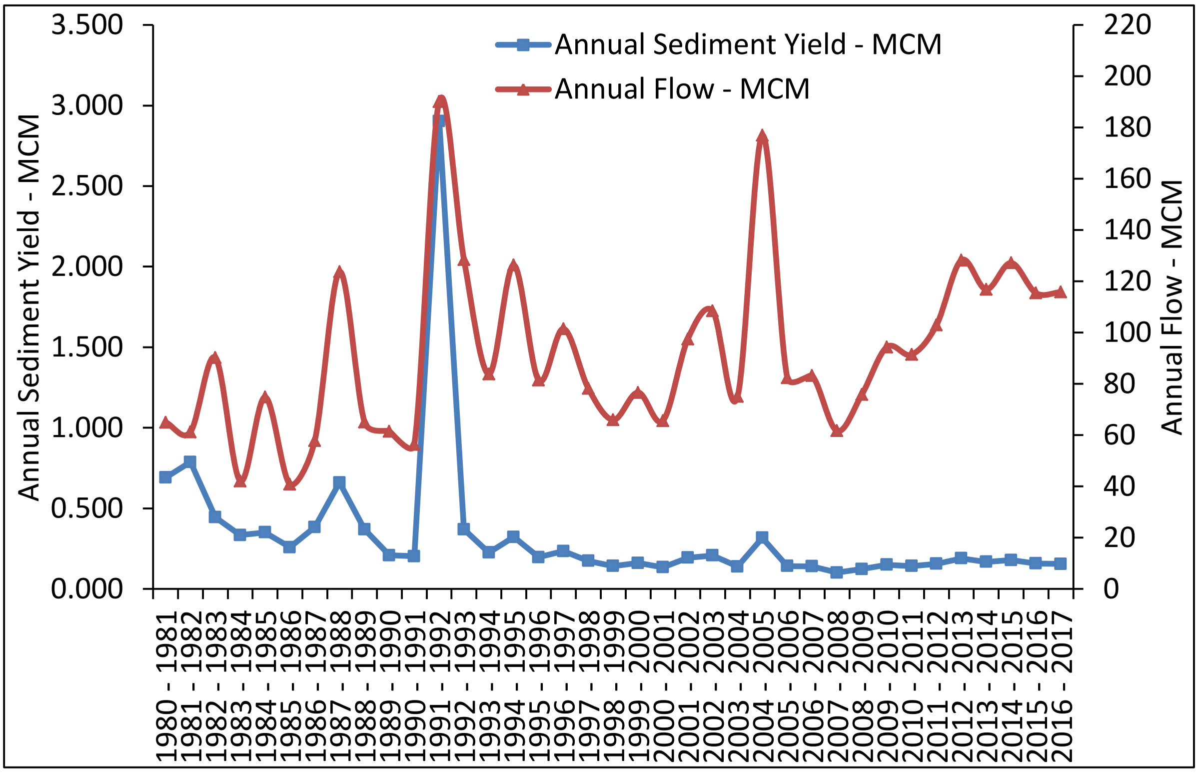

Figure 4 Annual sediment yield in MCM and water flow in MCM at King Talal Dam over the study years.

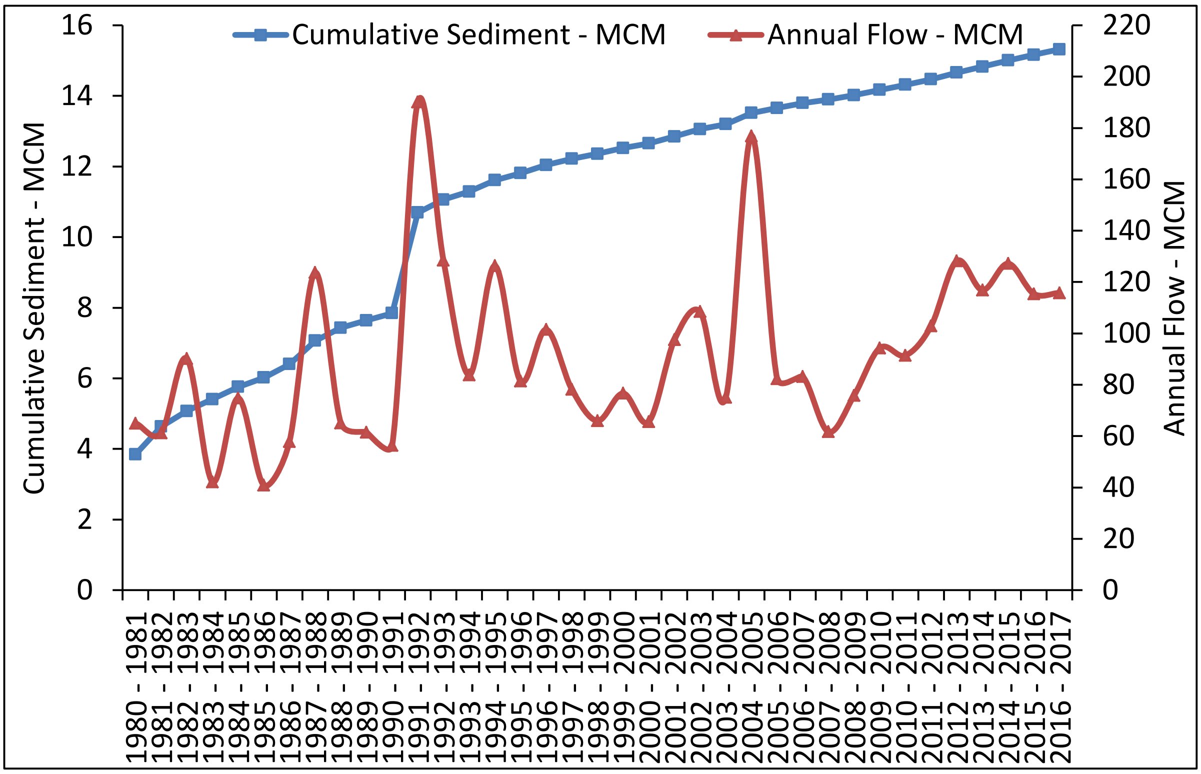

Figure 5 Total sediment accumulation in MCM at King Talal Dam over the study years.

C. Land-use management practices in the upper stream of King Talal Dam

The main cause of accelerated annual sedimentation and loss of KTD capacity is land degradation, which is from land fragmentation, rainfall fluctuation, and poor enforcement of legislation. But, it is clear from **Table 2** and **Figure 4** that the sediment yield dropped from 2.9 MCM in 1991/1992 to 0.15 MCM in 2016/2017. Moreover, **Figure 5** showed a steady status of sediment yield after the year 1992/1993. This is because of land use management practices upstream of KTD which have been supported by Jordanian's decision-makers to reduce soil erosion and accumulation of sediment in KTD such as construction of stone walls, contour cultivation; conservation of soils on steep slopes by terraces on the slope, plantation crops and trees which lead to soil and water conservation, deforestation and rangeland management [[26]]. These practices reduce sediments while at the same time maintain enough flow to reach KTD, thus maintain enough irrigation water to the Jordan valley. Therefore, Moreover, the land management practices will enhance the infiltration rate, which will contribute to more recharge of the groundwater that could be also used for irrigation. The involvement of farmers and related actors is highly needed to get their support and to facilitate more implementation of measures on land management practices in a sustainable manner [[27],[26]].

4. CONCLUSIONS

Sediment accumulation in dams is of great importance due to its impact on storage capacity, operational life, and water quality. The highest value of annual sediment yield in KTD was recorded in the year 1991-1992, which was about 2.9 MCM, where that year witnessed many rainfall days 55 days and the value of annual water flow was the highest of about 190.09 MCM among the study years.

The values of measured and estimated annual sediment yield at KTD (**Table 2)** for the rainy years 1980-1981 to 2016-2017 ranged between 0.10 to 2.90 MCM with an estimated sedimentation rate of about 0.393 MCM per year.

The values of annual sediment yield and water flow exhibited a corresponding general trend from 1980 to 2017, but it is obvious that the annual sediment yield has generally decreased and stabilized over the last studied years, which can be attributed the construction of stone walls, artificial barriers and terraces and land-use management practices that located before the dam.

The data analysis of the present study showed that the estimated value of the total volume of sediment at KTD in 2016-2017 after 39 years since its operation is about 15.32 MCM, which indicates that about 20.4 % of the dam's storage capacity (75 MCM) has been lost due to the sediment accumulation. Based on the calculations and analysis of data in the present study, KTD is expected to be completely filled up with sediments in 2208 with an expected life span of about 230 years from the start of the dam's operation.

Land use management practices that performed upstream of KTD are supported by Jordanian's decision-makers in order to reduce soil erosion and accumulation of sediment and to maintain enough water flow to KTD, thus secure enough irrigation water to the Jordan valley. Moreover, the application of land use management practices will enhance the infiltration rate and recharge of the groundwater. The involvement of farmers, actors, and related stakeholders is highly needed to get their support and to facilitate more implementation of the management practices on a sustainable manner. The results of the research could be useful for planners, related institutions and decision-makers for the future management of the dams in Jordan.

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