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Use of Hydrological Modeling Techniques to Evaluate, Develop and Enhance Irrigation Potential of a Humid Subtropical Watershed

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Hamza Farooq Gabriel and Amjad Nabi

Additional information is available at the end of the chapter

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1. Introduction

Water is essential and basic necessity of life. Water utilization can be categorized for domestic/municipal consumption, industrial usage and irrigation purposes, notwithstanding its necessity for ecological systems. Globally 69% of fresh water is withdrawn for agriculture purposes, 23% for industry and 8% for domestic use (J.Van.H et al 2002) [1]. Water has become a scarce natural resource whose equitable management for all socio-economic development is essential. Irrigation is essential component for agriculture production and all developing countries are dependent on it. During 1997-1999 in developing countries two fifth of crops were provided by irrigated land (FAO, 2002a) [2]. Similarly during 1997-1999 in developing countries 59% of cereal production was obtained through irrigation (Burke et al, 2003) [3]. All over the world excluding Europe and North America agriculture sector is the largest user of water (FAO, 2002c) [4]. During 2000 worldwide 70% of water withdrawals and 93% of water consumption was done for agriculture whereas water consumption for industry and municipality use is elaborated in Figure 1 (FAO, 2004) [5]. Three liters of water per day are required for human body, approximately 30-300 liters per person are required for domestic use which reveals water requirement for agriculture is more as compared with human needs (FAO, 2003c) [6].

Agriculture is the backbone of Pakistan's economy, according to 2013-2014 economic survey agriculture generates 21% of total output of GDP. The livelihood of more than 67% of the country's population is linked with agriculture (Arif. M, 2004) [7]. Pakistan's water resources are under stress due to large extent of agriculture activities. To meet the crop water require-

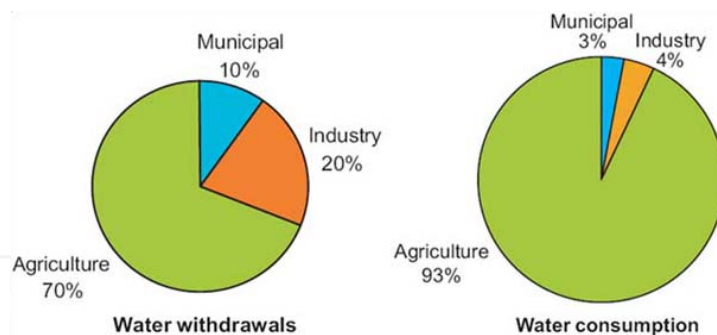


Figure 1. Water Withdrawals and Consumption (FAO, 2004)

ments scientific use of water resources is strongly needed. The present study was carried out on watersheds of Rawal Dam and Simly Dam located in Margalla hills, Pakistan. Both of these dams are the main source of municipal and irrigation water for Rawalpindi and Islamabad areas. The actual storage capacity of Rawal Dam was 47230 acre-feet when developed and its present storage capacity is 31000 acre-feet. Similarly the actual storage capacity of Simly Dam was 33000 acre-feet when developed and its present storage capacity is 32219 acre-feet.

2. Methodology

2.1. Study area

The study area comprises Rawal and Simly Dams located in Islamabad, the capital of Pakistan. The catchment areas of Rawal and Simly Dams are adjacent and located in Murree Hills. The Rawal Dam is located in Park area of Islamabad and Simly Dam is located 30 km east of Islamabad. The location map of the study area is given in Figure 2.

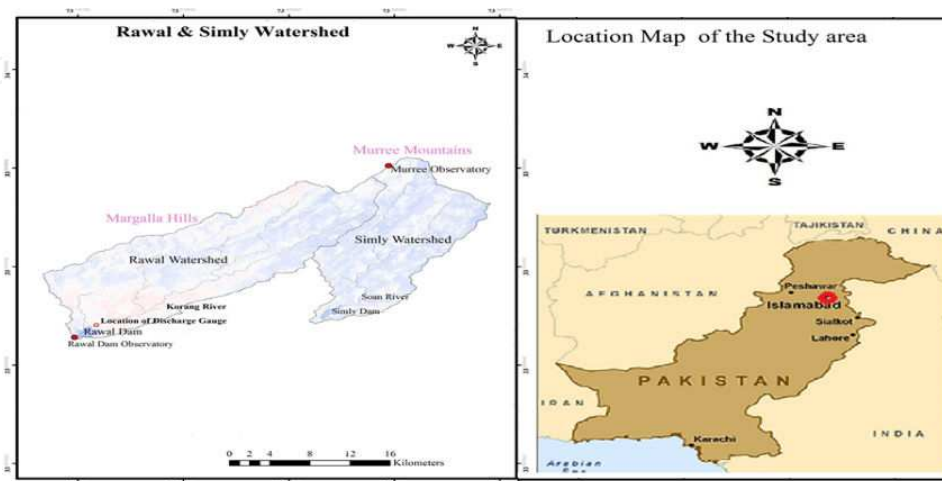


Figure 2. Location Map of Study Area (Landsat 2010).

The catchment areas of Rawal Dam and Simly Dam are contiguous and co-located as shown in Figure 2. The location of installed metrological stations i.e. Rawal Dam observatory and Murree observatory is also shown in Figure 2. The location map of Rawal Dam and Simly Dam is shown in Figure 3 and salient features of Rawal and Simly Dams are given in Table 1 and Table 2 respectively.

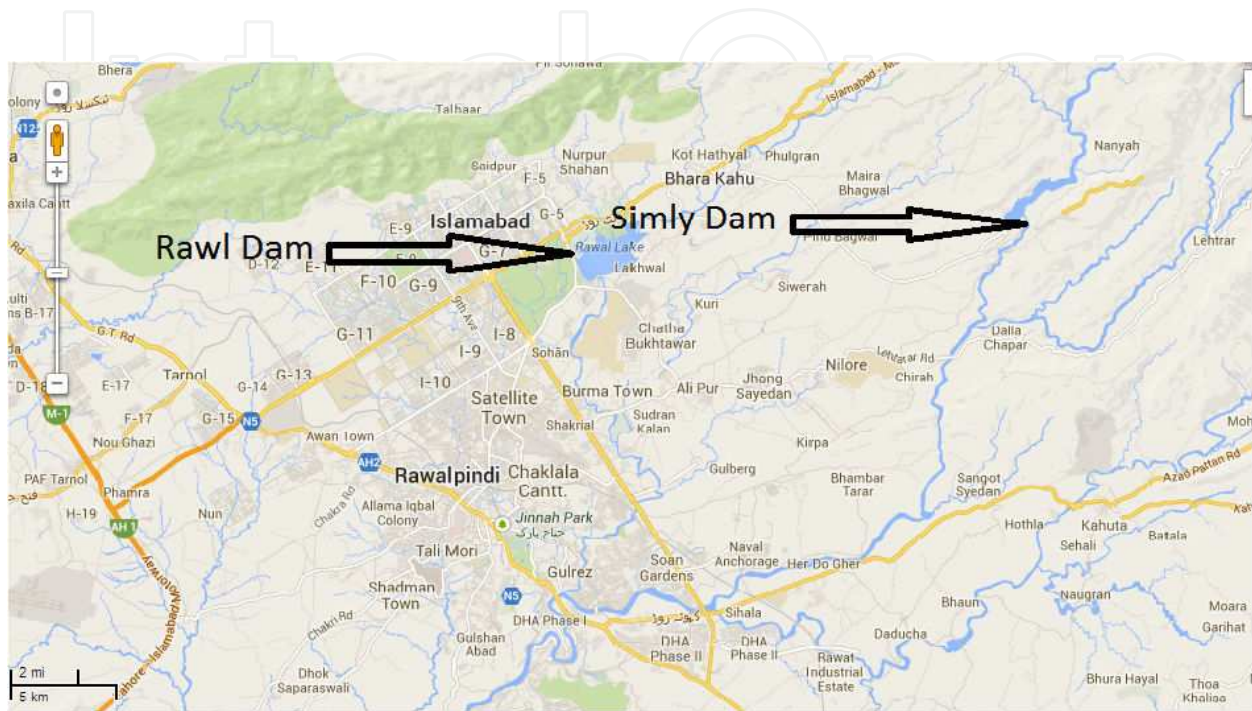


Figure 3. Location Map of Rawal Dam and Simly Dam.

Name of Dam	Rawal Dam
Location of Dam	Longitude 73°-7' E , Latitude 33°-41' N
Constructed in	1962
Name of River	Korang River
Catchment Area	106.25 sq. miles
Length of dam	700 ft.
Spillway discharge capacity	82,000 cusecs
Water supply	14 million gallons per day
Right bank canal	Capacity 72 cusecs. Length 5 miles. Cultivable commanded area 50,101 acres.
Left bank canal	Capacity 40 cusecs. Length 5 miles. Cultivable commanded area 3,380 acres

Table 1. Salient Features of Rawal Dam

Name of Dam	Simly Dam
Location of Dam	Longitude 73°-20' E , Latitude 33°-43' N
Constructed in	1982
Name of River	Soan River
Catchment Area	59 sq. miles
Water Supply Tunnel Length	590 ft.
Spillway discharge capacity	80,800 cusecs
Water supply	47 million gallons per day

Table 2. Salient Features of Simly Dam

2.2. Meteorological conditions

The climate of study area can be divided into four seasons as are experienced over the whole of Pakistan. These are the winter monsoon (December-February), the hot weather (March-May), the summer monsoon (June-September) and the transition period (October-November). It is summer monsoon rainstorms that give rise to the major floods. In study area Average Annual Precipitation is 1817mm, Average Annual Humidity is 61.90%, Average Annual Maximum Temperature is 16.90 °C and Average Annual Minimum Temperature is 8.7 °C (Pakistan Metrological Department).

2.3. Data collection

Rainfall data of Rawal and Simly catchment for the period 1975-2012 and 1983-2012 were respectively collected from Pakistan Metrological Department (PMD). The discharge data of Rawal Dam for the period 1975-2012 and Simly Dam for the period 1983-2012 were collected from Small Dams Organization Punjab and Capital Development Authority (CDA) respectively. The sediment data of Rawal catchment for the period 1975-2005 and sediment data of Simly catchment for period 1983-2008 were collected from Small Dams Organization Punjab and Capital Development Authority respectively. The temperature data of both catchments for the period 1975-2012 were collected from Pakistan Metrological Department.

2.4. Double mass curve

A Double Mass Curve is defined as the plot of cumulative value of one variable against the cumulative value of other quantity while the time period should be the same. The slope of the line will show the constant of proportionality between two quantities and the break in the slope of line will show the change in the proportionality constant between quantities. The Double Mass Curve can give us the significant information about the time in which changes occurred in those variables for which Double Mass Curve is plotted (Searcy and Hardison,

1960) [8]. The aim of this curve is to check the data consistency with respect to time and to detect the changes in trends by changes in the slope (Chow, 1964) [9]. (Kosmas, et al. 1997) [10], (Shahid. M, et al. 2014) [11] used Double Mass Curve for Hydrological studies. The Figure 4 is an example of double mass curve. The break in slope can be clearly observed from this figure.

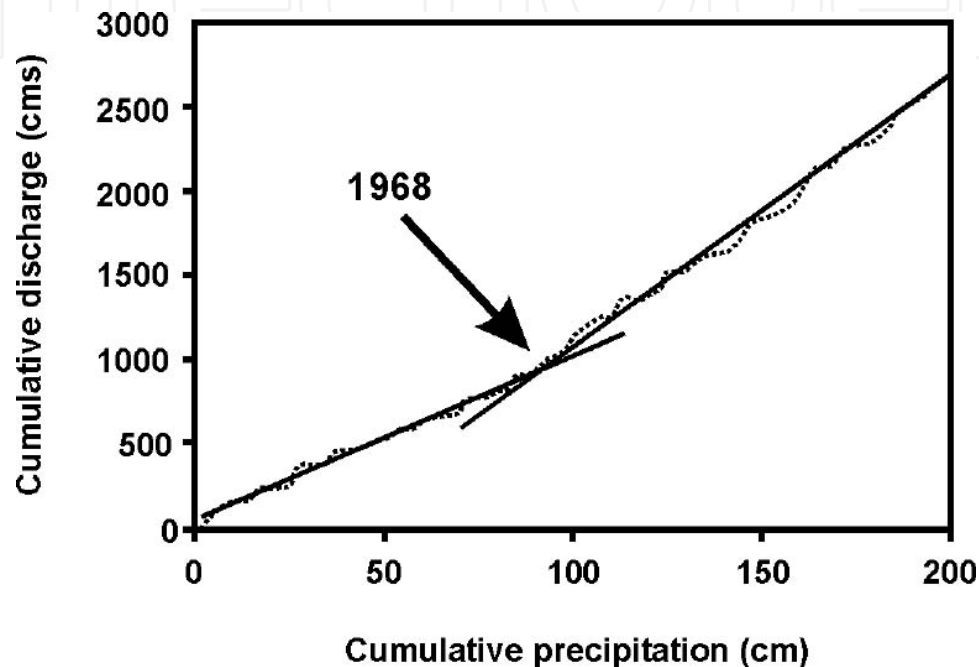


Figure 4. Example of Double Mass Curve Analysis.

3. Data analysis

3.1. Rainfall-Runoff relationship of Rawal catchment

The Hydrology of a region is controlled by precipitation. The annual rainfall and runoff relationship for Rawal catchment is shown in Figure 5. It can be observed in rainfall-runoff relationship of Rawal catchment that with the increase of rainfall runoff is also increasing. Annual Double Mass Curves of rainfall-runoff were plotted for Rawal catchment which are shown in Figure 6 and Figure 7. These figures show that runoff is increasing with the increase in rainfall. Figure 7 shows the Double Mass Curve and slope trend curves of Rawal catchment for 1975-1994 and 1995-2012. It is clear that for 1995-2012 slope trend curves are greater, which reveals that runoff is increasing during 1995-2012.

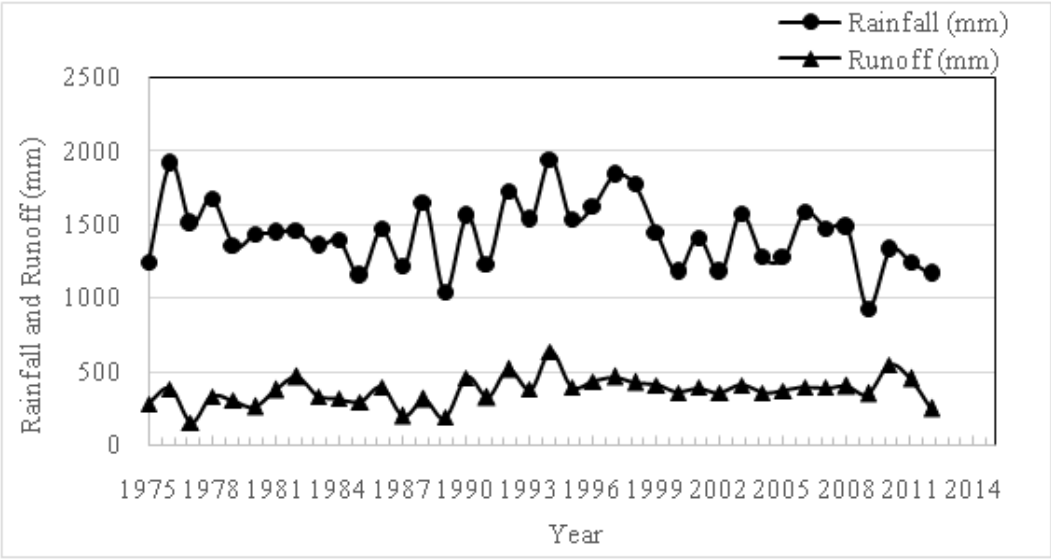


Figure 5. Annual Rainfall-Runoff Relationship of Rawal Catchment.

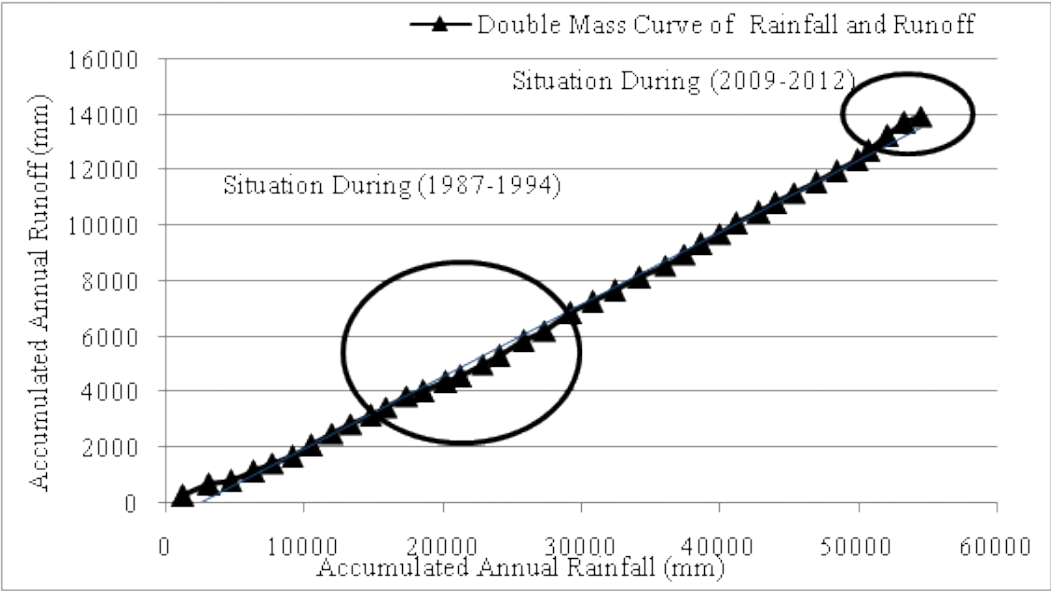


Figure 6. Annual Double Mass Curve of Rawal catchment (1975-2012).

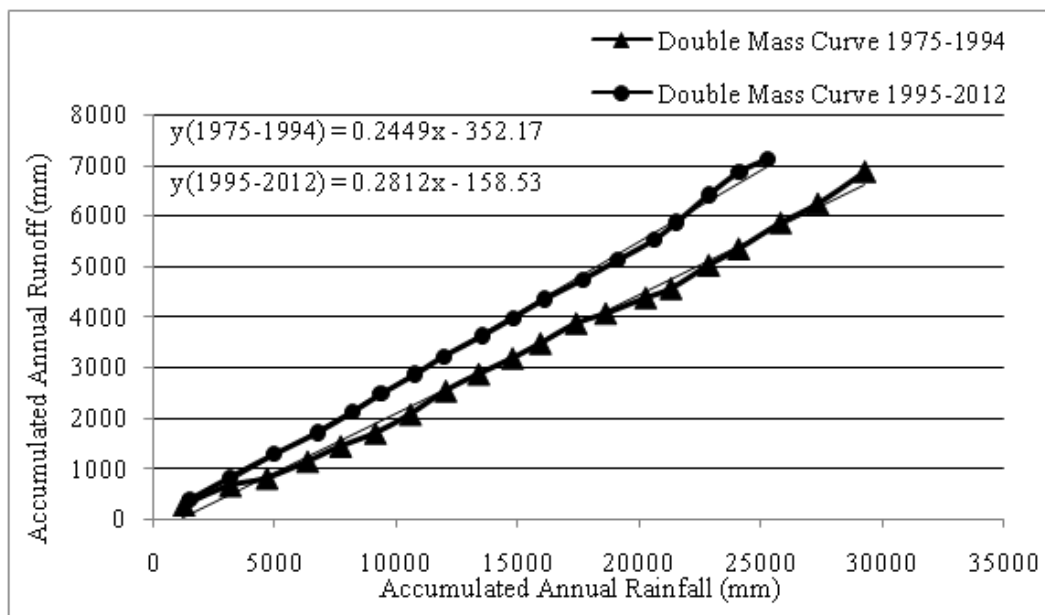


Figure 7. Rawal catchment Rainfall-Runoff Double Mass Curve (1975-1994) & (1995-2012).

3.2. Runoff-Sediment relationship of Rawal catchment

Rawal catchment runoff-sedimentation relationship using relevant organization data is given in Figure 8 and its Double Mass Curve is given in Figure 9. It is clear from Figure 8 that sedimentation rate is increasing with the increase in runoff and in double mass curve the value of slope is greater during period 1995-2005 which reveals that sedimentation is increasing with increase in runoff.

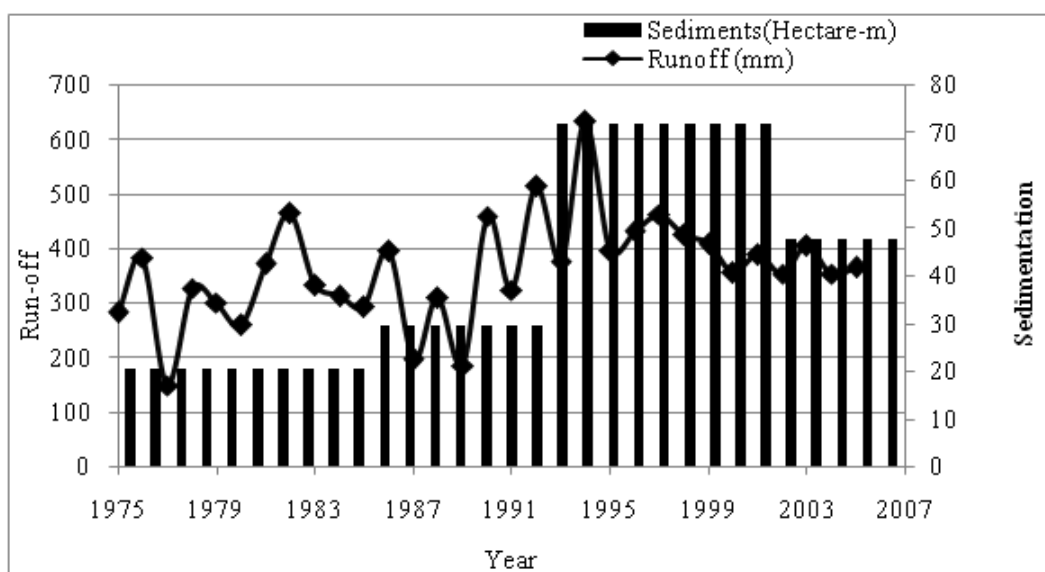


Figure 8. Runoff-Sediment Relationship for Rawal Catchment (1975-2005).

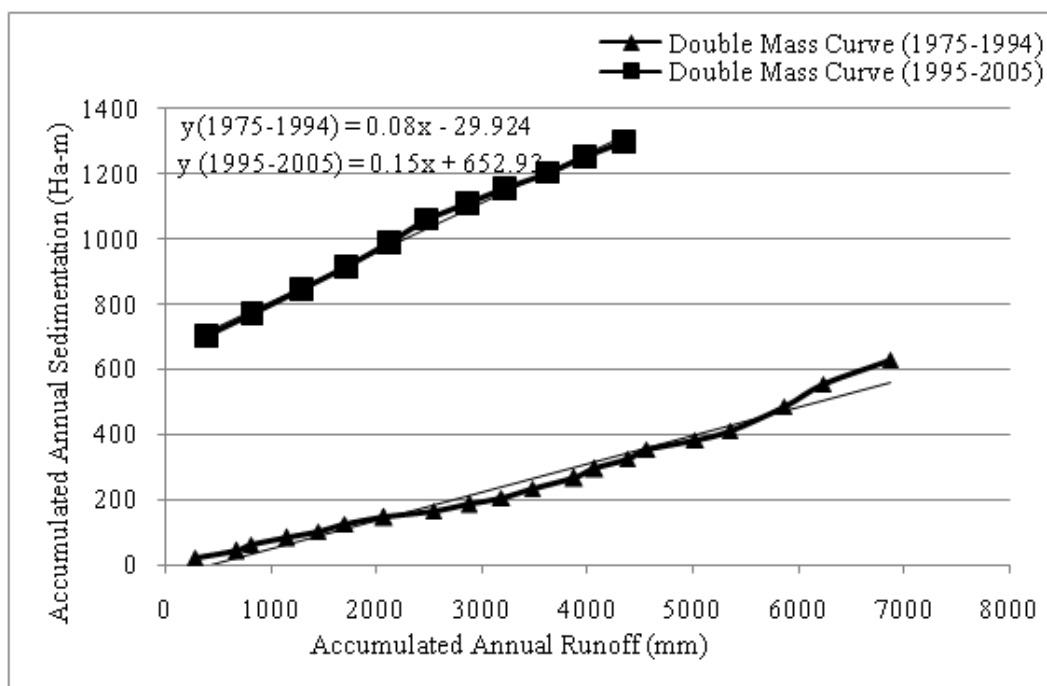


Figure 9. Rawal catchment Runoff-Sediment Double Mass Curve (1975-1994) & (1995-2005).

3.3. Rainfall-Runoff relationship of Simly catchment

The annual rainfall and runoff relationship for Simly catchment is shown in Figure 10. It can be observed in rainfall-runoff relationship of Simly catchment from 1995-2012 there is an increase in runoff from almost the same amount of rainfall which emphasize the fact that runoff amount has increased due to land use change.

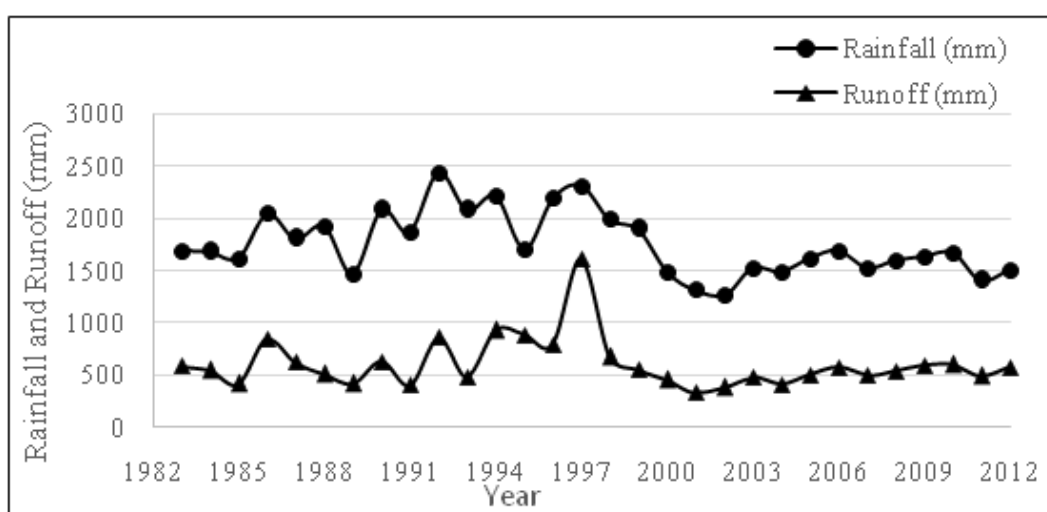


Figure 10. Annual Rainfall-Runoff Relationship of Simly Catchment.

Annual Double Mass Curves of rainfall-runoff were plotted for Simly catchment which are shown in Figure 11 and Figure 12. These figures show that runoff is increasing with the increase in rainfall. It is clear from the Figure 11 that with the increase in rainfall runoff is also increasing. Figure 12 shows the Double Mass Curve and Slope Trend Curves of Simly catchment for 1983-1994 and 1995-2012. It is clear from Figure 12 that slope trend curves and values of slopes from regression coefficients are greater during 1995-2012 which reveals that runoff is increasing during 1995-2012.

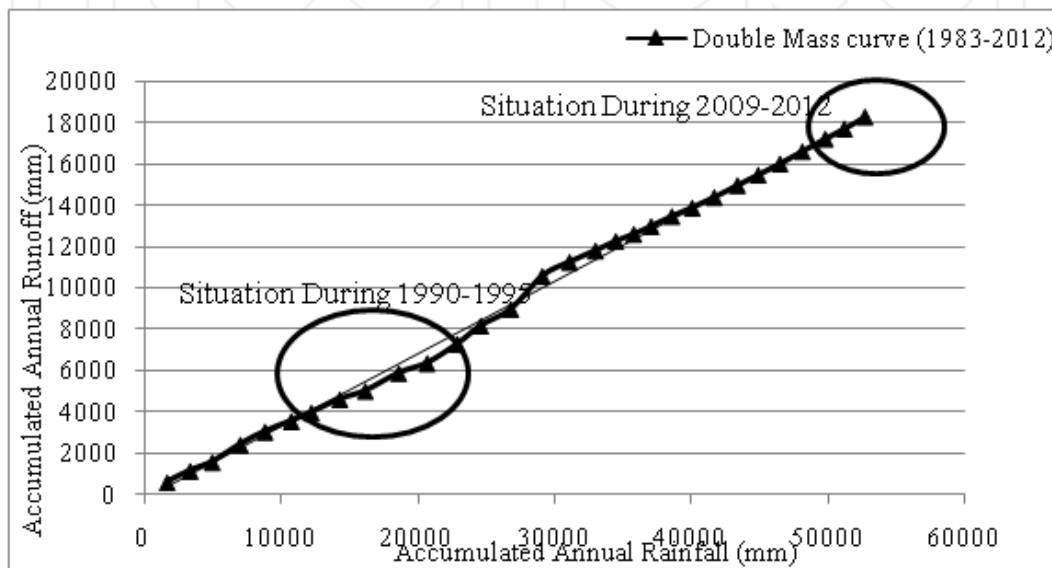


Figure 11. Annual Double Mass Curve of Simly catchment (1983-2012).

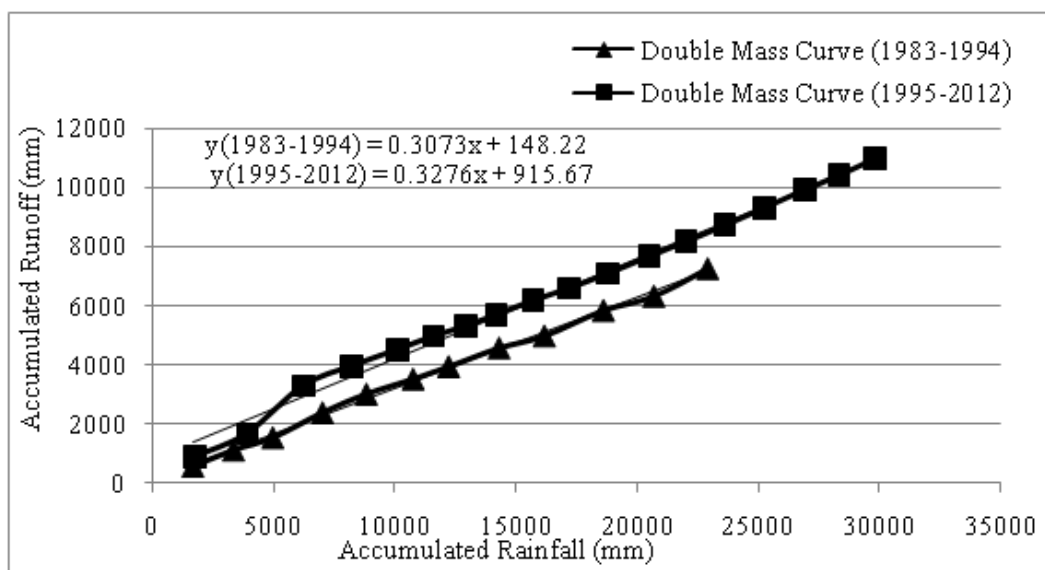


Figure 12. Simly catchment Rainfall-Runoff Double Mass Curve (1983-1994) & (1995-2012).

3.4. Runoff-Sediment relationship of Simly catchment

Simly catchment runoff-sedimentation relationship using relevant organization data is given in Figure 13 and its Double Mass Curve is given in Figure 14. It is clear from Figure 13 that during1995-2005 more sedimentation occurred as compared with sedimentation during 1982-1994. Figure 14 is Double Mass Curve which shows the value of slope is greater during period 1995-2012 which reveals that more sedimentation occurred during 1995-2012.

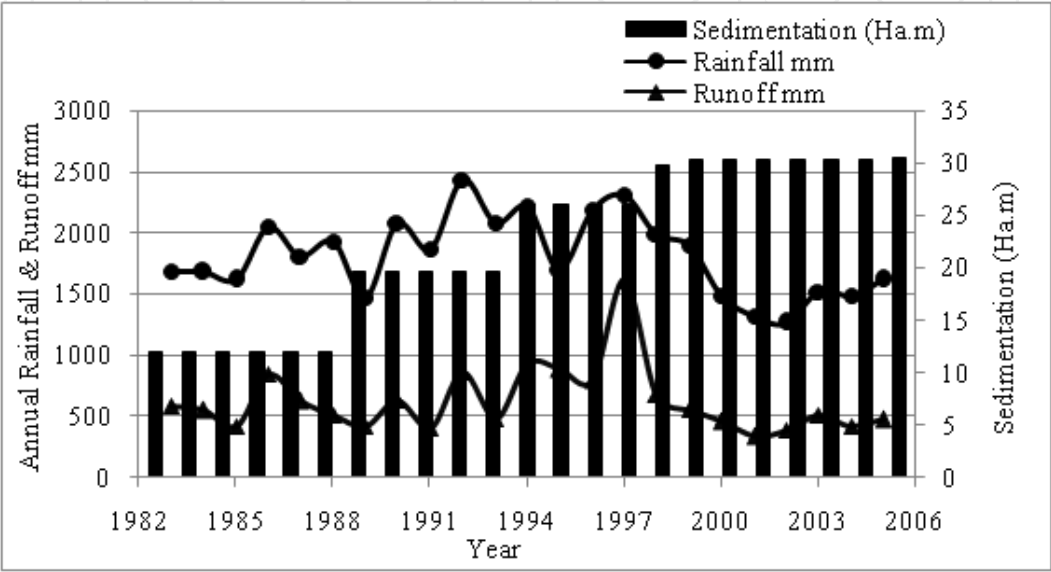


Figure 13. Runoff-Sediment Relationship for Simly Catchment (1983-2012).

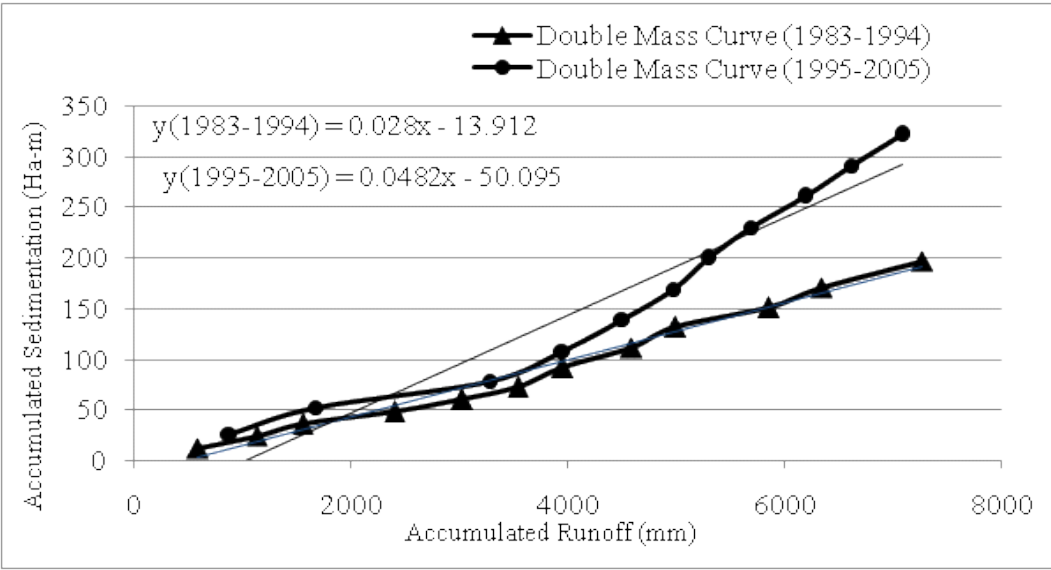


Figure 14. Simly catchment Runoff-Sediment Double Mass Curve (1975-1994) & (1995-2012).

3.5. Methods practiced for irrigation in study area

In Rawalpindi out of 25,000 acres an area of 820 acres are irrigated from Rawal dam and 16000 acres are irrigated by tube wells. Similarly 35 acres nurseries of CDA and private farms are irrigated from Simly Dam. The crops cultivated in study area are wheat, corn, maize and rice. Currently the surface (flood) irrigation methods are being used to irrigate the fields. Flood irrigation method is one of the oldest and obsolete methods for irrigation. In flood irrigation method a field is essentially flooded with water where the water submerges the soil. In flood irrigation too much care is required to avoid water losses. In flood irrigation water losses are more mostly due to seepage, runoff, deep percolation and evaporation. The flood irrigation is shown in Figure15.



Figure 15. Flood Irrigation Method.

The flood irrigation method is least efficient method and its efficiency is between 40-70% (Gill. A.M, 2010) [12]. Even the fruit orchards and vegetable gardens are being irrigated on the same pattern and methodology. The surface irrigation techniques (furrow, strip or basin) are really not beneficial to the crop productivity but their poor performance often results in wastage of water and at times in excessive water application. This also causes the root decay and decline in crop productivity.

In the current irrigation practices the water regulation is least under the control of the farmer. Water is applied when it is available with disregard to the crop demand and other hydrological

and metrological inputs. In addition to all of this, losses due to evaporation also put a lot of stress on the system.

More regulated and controllable irrigation systems like sprinkler and drip irrigation systems are difficult to install and may not be initially viable because of exhaustive costs. However these have proved to be more efficient in water management and financially beneficial over life cycle cost analysis. A comparison of various water management practices and system efficiencies is given in Figure 16.

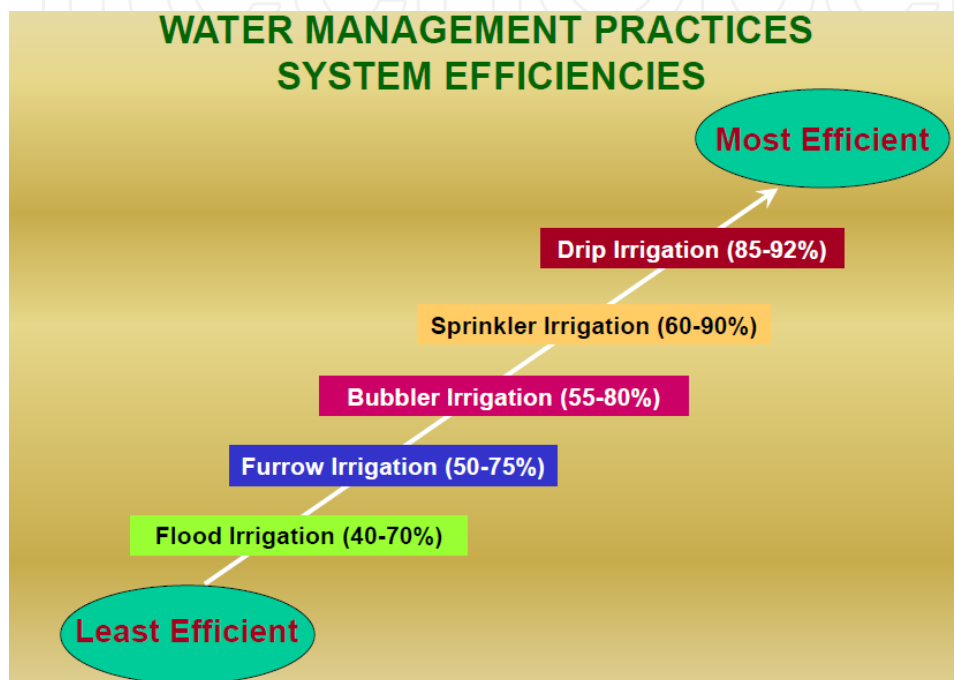


Figure 16. Water Management Efficiencies.

From Figure 16 it is clear that Drip irrigation method is most efficient. By remodeling of Rawal Dam and Simly Dam their storage capacity can be increased and by lining of the Rawal Dam Left Bank Canal seepage losses can be reduced thus increasing the velocity of water which will increase the efficiency of drip irrigation system whenever installed.

4. Conclusions

- a. From Double Mass Curve analysis it can be concluded that during 1995-2012 the slope trend curves were more which shows in both Rawal and Simly Dam catchment runoff increased with the time.
- b. Double Mass Curve analysis showed that in Both Rawal and Simly Dam catchment sedimentation increased with the time as the slope trend curves were more during 1995-2005 which shows more sedimentation occurred in both catchment during 1995-2005.

- c. Due to increase in runoff, sedimentation increased in both catchments thus reducing the storage capacity of both dams.
- d. The irrigation methods practiced in study area are least efficient and mostly water losses are due to obsolete irrigation methods.

5. Recommendations

- a. In study area mostly water losses are due to seepage and evaporation. The lining of canals will reduce seepage losses and it will increase velocity of water so canal lining is strongly recommended.
- b. The irrigation methods practiced in the study area are old and obsolete. To achieve a better efficiency it is strongly recommended that for irrigating the fields and orchards, drip irrigation method should be installed in the study area.
- c. The increase in runoff and sedimentation may be due to land use changes in the catchment areas. It is strongly recommended to evaluate the impact of land use changes in both Simly and Rawal catchments.

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