Evaluation of Development and Land Use Change Effects on Rainfall-Runoff and Runoff-Sediment Relations of Catchment Area of Simly Lake Pakistan

Muhammad Shahid [1], Hamza Farooq Gabriel [2], Amjad Nabi [3] Sajjad Haider [4], Shaukat Ali Khan [5], Syed Muhammad Ali Shah[6]

[1] Postgraduate Student at National University of Sciences and Technology (NUST), Islamabad, Pakistan
[2] Associate Professor at National University of Sciences and Technology (NUST), Islamabad, Pakistan
[3] Principal River Engineer at Ministry of Water and Power, Pakistan
[4] Associate Professor at National University of Sciences and Technology (NUST), Islamabad, Pakistan
[5] Assistant Professor at National University of Sciences and Technology (NUST), Islamabad, Pakistan
[6] Postgraduate Student at National University of Sciences and Technology (NUST), Islamabad, Pakistan
shahidbaloch@ymail.com

Abstract: Evaluation of land use changes and their effects on hydrology of a watershed is necessary for excellent planning and management of water resources. The present study gives information to determine the effects of land use changes on rainfall-runoff relation and runoff-sediment relation in humid subtropical zone. For this study Simly watershed has been selected which has experienced fast land use changes due to development activities. Simly watershed is located in Margalla Hills Islamabad, the capital of Pakistan. Based on rainfall-runoff relation two periods1983-1994 and 1995-2012 were selected for comparison of land use changes effects. The objectives of the study were to determine land use changes during 1992, 2000 and 2010 and analyse the effects of these land use changes on Rainfall-Runoff relation and Runoff-Sediment relation. Double Mass Curve with trend curve was used to determine land use changes effects on Rainfall-Runoff relation and Runoff-Sediment relation. . It can be observed from the results that in humid subtropical zone where the change in rainfall can be ignored land use changes may be deemed as major factor for increase in runoff and sediment. Due to changes in land use the rainfall-runoff relation and runoff sediment relation were changed. The slope trend curves of annual and monsoon moths' rainfall-runoff mass curves and runoff-sediment mass curves were higher for period 1995-2012 as compared with period 1983-1994. It indicates more runoff and sedimentation occurred during 1995-2012. If development activities continue with this pace the reservoir will be silted up to its designed dead storage much earlier than the expected life of 63 years. In order to reduce sedimentation deforestation and urbanization should be reduced in the Simly catchment.
[Shahid M, Gabriel, H.F, Nabi Amjad, S.Haider, S.A.Khan. **Evaluation of Development and Land Use Change Effects on Rainfall-Runoff and Runoff-Sediment Relations of Catchment Area of Simly Lake Pakistan.** *Life Sci J* 2014;11(7s):11-15]. (ISSN:1097-8135). http://www.lifesciencesite.com. 2

Keywords: Land Use Change; Double Mass Curve; Sediment, Rainfall, Runoff

1. Introduction

Water resources are affected by development activities and land use changes are important part of these activities. These change can alter hydrology of a watershed by changing the hydrological cycle. Due to human alteration and development activities in a catchment area, changes occur in the process of runoff generation because the infiltration rate is reduced. Due to urbanization ground water recharge decreases and runoff volume increases. Sedimentation also increases due to deforestation which affects the life of a water reservoir (Tali 2011). Studies using different climate models have shown that land use alters the global hydrological cycle by affecting the pattern of precipitation and temperature. Small basin can be significantly affected by land use change impacts (Jones and Grant, 1996).

This study was carried out on Simly reservoir which is the largest reservoir of drinking water for people living in the Islamabad capital of Pakistan. Up to 2.5 cubic meters/second water is supplied to the Capital Development Authority from Simly Dam. The Current storage capacity of Simly Dam is 32219 acre-feet. Comparing it with actual storage capacity of Simly Dam it can be observed that 2.36 % storage capacity of Simly Dam is lost which is due to land use changes (IUCN PAK, 2005). Therefore it is important to evaluate land use change impacts on sustainable management of water resources.

2. Material and Methods

Simly Dam is located in 30 kilometers East of Islamabad and Rawalpindi 33^0 43' 8" N and 73^0 20' 25"E it is constructed on Soan River. It was constructed in 1982 its storage capacity was 28370082.67 cubic meter when developed, which was increased up to 40704901.22 cubic meter in 2005. The location map of Simly catchment is given

in Figure1. Its watershed size is 153.5 km^2 rhomboidal "in shape about 18990.25 meter long and about 8046.72 meter wide at average. Its watershed is located in Margalla Hills which exists in north of Islamabad Capital of Pakistan. The elevation of Simly catchment ranges from 643-2274 meter. Simly Dam receive heavy precipitation in the form of snow and rainfall most of which occurs in December to January and July to September respectively and Annual precipitation in its catchment area is 1788 mm (Pakistan Metrological Department).

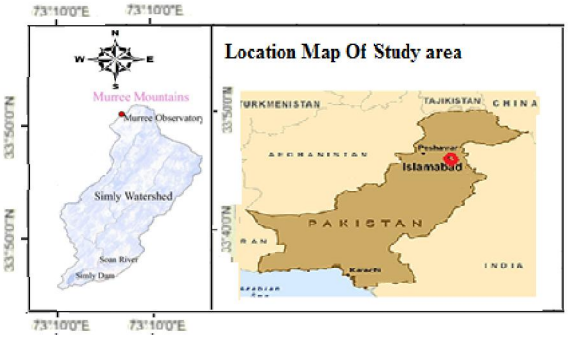

Figure 1. Location Map of Study Area (Landsat - 2010)

The topographic sheets of scale 1:50000 were obtained from Survey of Pakistan to delineate catchment area, using Planimeter catchment area was computed as 153.5km2. Murree observatory is the only rainfall observatory station in the catchment area of Simly Dam and its location is mentioned in Figure 1. The rainfall ,runoff data of Simly Dam for the period 1983-2012 and sediment data for the period 1983-2005 were collected from Pakistan metrological department and Water and power development authority. Landsat Thematic Mapper (TM) and Enhance Thematic Mapper (ETM+) data for 1992, 2000 and 2010 were selected for land use classification. The digital elevation model (DEM) was taken from ASTER G DEM 30.

Land use changes effect on runoff of a catchment can be evaluated using statistical methods, hydrological modeling and study of an experimental catchment. In present study land use changes effect on rainfall-runoff relation and runoff sedimentation relation were evaluated using double mass curve. In Double mass curve Cumulative values of one variable are plotted against the Cumulative values of other quantity keeping time period same for both variables. 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. In general it is a rule that if the break in slope persists for the duration less than five years then the breaks in slope is ignored also if breaks are for more than 5 years then it can be considered a trend and it can be analyzed and investigated (Albert 2004). Merriam in 1937 used double mass curve to check the consistency of precipitation data in Susquehanna watershed USA. Recently Chinese scholars used using double mass curve for analyzing the effect of soil & water conservation also for detection of land use change effect on runoff and sedimentation and got good results (Zaho, et al., 2010). Rainfall runoff relationship for Simly catchment is shown in Figure 2 based on this relationship Double mass curve was drawn for two periods 1983-1994 and 1995-2012 and Landsat TM and ETM+ data for 1992, 2000 and 2010 was selected for land use mapping.

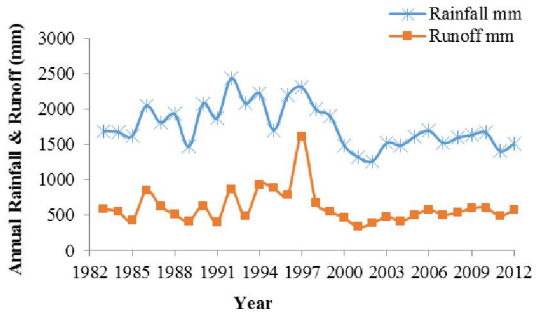

Figure 2. Rainfall runoff relationship for Simly catchment

3. Results

Rainfall is one of the main contributing factor which have significant impact on a catchment's hydrology. To evaluate the rainfall runoff relation of study area annual, average monthly and monsoon period's rainfall and runoff data of Simly catchment for the period 1983 to 2012 were plotted. It can be observed from the results that rainfall-runoff relation and runoff-sedimentation relation were affected by land use change and a swift change in land use was observed from 1995-2012. Based on rainfall-runoff relationship land use maps were prepared for 1992, 2000 and 2010. The Unsupervised classification of satellite images was done. Six land use classes i.e. Water bodies, Forest, Vegetation & Agriculture, Range land, Built-up area, and bare land were developed. It was observed that in Simly Dam catchment from 1992- 2010 water bodies' area, forest area, vegetation and agriculture area decreased and range land area, built up area and bare land area increased. The results of land use classification for 1992, 2000 and 2010 is shown in Figure 3 and the changes are tabulated in Table 1.

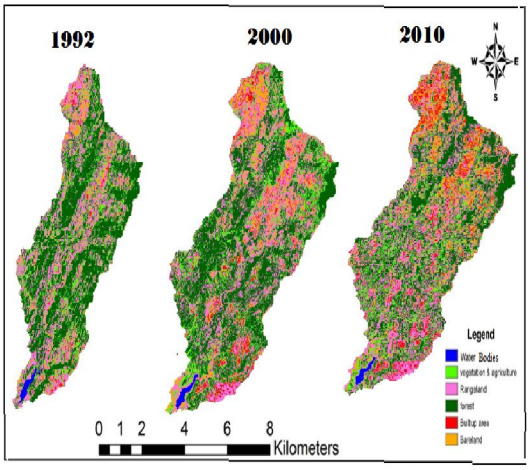

Figure 3. Land Use Classification Maps

Table 1. Land Use Change in Simly Catchment 1992-2010

Land use	1992	2000	2010	1992-2010
	Area km^2	Area km^2	Area km^2	Change km^2
Water bodies	1.3	0.8	0.7	-0.6
Forest	71	61.9	52.3	-18.7
Vegetation & Agriculture	25.9	24.2	21.8	-4.1
Rangeland	45.1	46.7	51.9	6.8
Built-up area	2.4	6.5	8.9	6.5
Barren land	7.8	13.4	17.9	10.1
Total	153.5	153.5	153.5	

4. Discussion

The annual and average monthly rainfall runoff relationship for Simly catchment is given in Figure 2 and Figure 4 respectively. It can be observed that with the increase of rainfall runoff is also increasing and from 1998 an increase in the volume of runoff was evident from the plots, although the amount of rainfall was almost same as before. It emphasize the fact that during same period due to land use changes runoff volume has increased with constant rainfall amount. Figure 4 shows the relationship between mean monthly precipitation and the resultant runoff. It can be inferred from Figure 4 that July, August and September are the months with highest amount of rainfall and runoff.

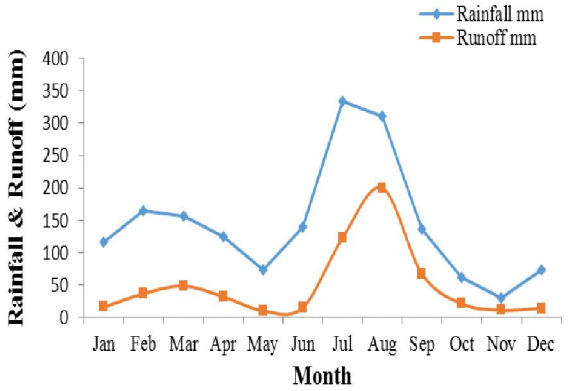

Figure 4. Average Monthly Rainfall & Runoff for Simly Catchment (1983-2012)

To check consistency of rainfall-runoff relationship and land use change effects annual double mass curve of rainfall runoff was plotted which is shown in Figure 5. Break in slope is significant in Figure 5 from 1995. It can be observed in Figure 5 that with the increase in rainfall runoff is also increasing and this trend can be clearly observed during period 1998-2008 and 2009-2012. To compare the land use changes during period 1983-1994 and 1995-2012 Double Mass Curves were plotted for annual and monsoon months which are shown in Figure 6 and Figure 7, 8,9 respectively. From these figures it can be observed that with the increase in rainfall runoff is also increasing and this trend can be clearly observed during period of 1998-2008 and 2009-2012. From regression coefficients of linear equation it can be clearly observed that for annual and monsoon months Double Mass Curve the value of slope is more during period 1995-2012 as compared with the period 1983-1994. The ground realities reveal that the major development activities in the catchment area started from 1998 in which Islamabad-Murree carriage way constructed and this project completed in 2008. Nearly 19 km section of Islamabad-Murree carriage way runs through the catchment area of Soan River upstream of the Simly reservoir. Similarly during construction work over 10 million cubic feet earth/excavated material dumped along Soan River is silting up Simly reservoir. Large scale cutting of trees for the construction of the said highway also caused sedimentation in the reservoir.

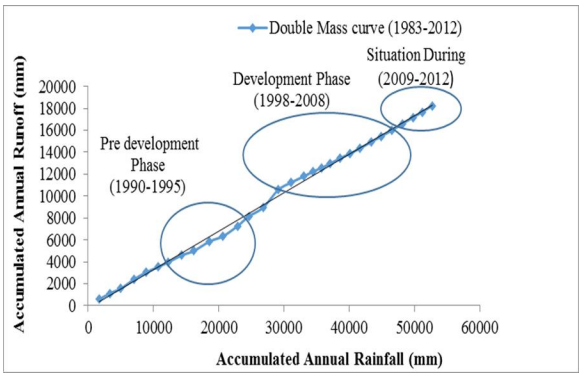

Figure 5. Double Mass Curve of Rainfall & Runoff for Period (1983-2012)

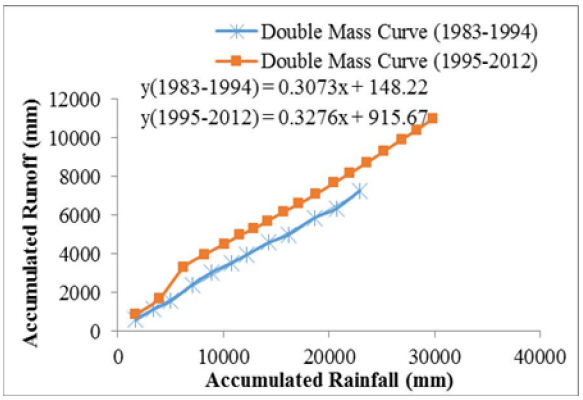

Figure 6. Double Mass Curve of Annual Rainfall & Runoff for Period 1983-1994 & 1995-2012

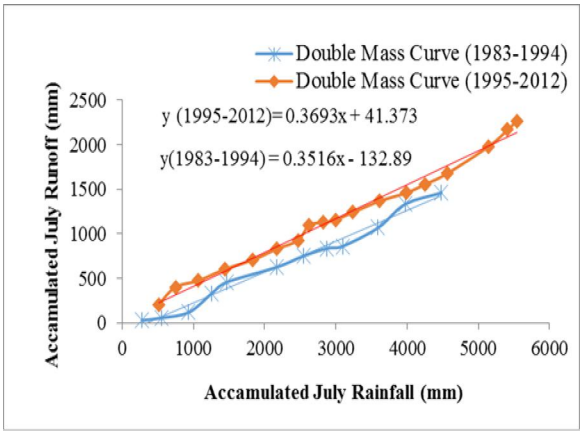

Figure 7. Double Mass Curve of July Rainfall & Runoff for Simly Catchment for 1983-1995 & 1996-2012

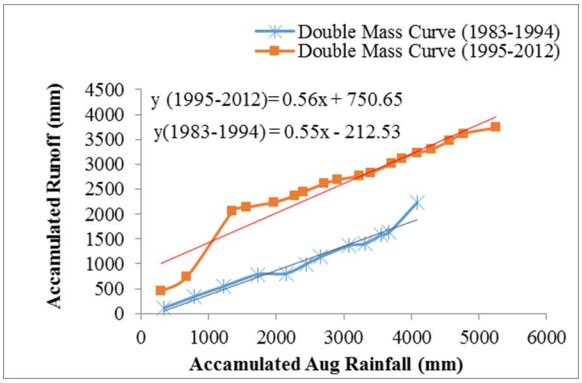

Figure 8. Double Mass Curve of Aug Rainfall & Runoff for Simly Catchment for 1983-1995 & 1996-2012

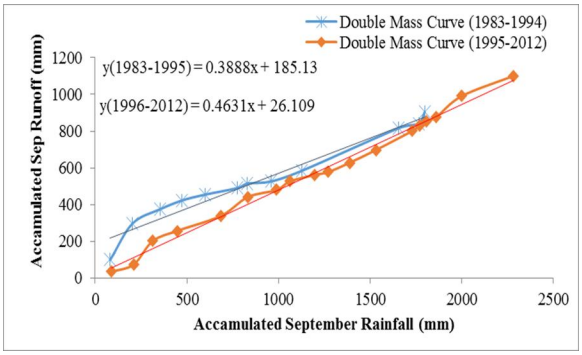

Figure 9. Double Mass Curve of September Rainfall & Runoff for Simly Catchment for 1983-1995 & 1996-2012

The biggest problem being faced in the Simly basin is the accelerated soil erosion causing sedimentation in the Simly Dam reservoir. The runoff-sediment relationship for Simly catchment and its Double Mass Curve is given in Figure 10 and Figure 11 respectively. It can be observed in the Figure 10 and 11 that sedimentation is increasing with the increase in runoff and double mass curve regression equation coefficients show more value of slope for period 1995-2008.

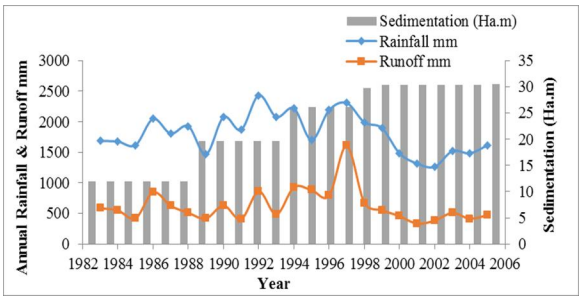

Figure 10. Annual Runoff & Sedimentation in Simly Catchment (1983-2008)

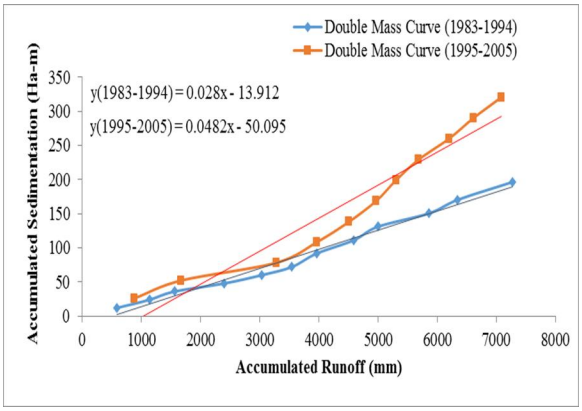

Figure 11. Double Mass Curve Annual Runoff & Sedimentation for Simly Catchment (1983-1994, 1995-2005)

In the study area land use pattern has changed from 1995-2012 as compared with 1983-1994. More runoff and sedimentation occurred during 1995-2012, which is statistically significant from slope trend curves of Double mass curve. The value of slope for period 1995-2012 is greater than 1983-1994, which shows the rainfall-runoff relation and runoff-sediment relation in Simly catchment are changed due to land use changes. From the Remote Sensing analysis it can be concluded that 18.7 km^2 forest area, 4.1 km^2 vegetation and agriculture area and 6.6 km^2 water bodies' area decreased for Simly Dam catchment. Similarly 6.8 km^2 range land area, 6.5 km^2 built up area and 10.1 km^2 barren land area increased for Simly Dam catchment. If development activities continue with this pace the reservoir will be silted up to its designed dead storage much earlier than the expected life of 63 years. In order to reduce sedimentation deforestation and urbanization should be reduced in the catchment area.

5/2/2014

Acknowledgements:

Authors are grateful to the National University of Sciences and Technology (NUST) Pakistan for financial support to carry out this work.

Corresponding Author:
Muhammad Shahid
NUST Institute of Civil Engineering
National University of Sciences and Technology Pakistan
Email: Shahidbaloch@ymail.com

References

1. International Union for Conservation of Nature and Natural Resources Pakistan (IUCN-Pak), 2005 "Rapid Environmental Appraisal of Developments in and Around Murree Hills".
2. Jason M.A, 2004 "Hydraulic Analysis and Double Mass Curves of the Middle Rio Grande from Cochiti to San Marcial, New Mexico", M.Sc. Thesis, Colorado State University Fort Collins, Colorado, USA.
3. Jones, J. A. and Grant, G. E, 1996 "Peak Flow Responses to Clear-Cutting and Roads in Small and Large Basins, western Cascades, Oregon" Water Resource. Res. 32, Vol 4, pp. 959-974.
4. Tali, P A 2011, "Land use/Land covers Change and its Impact on Flood Occurrence: A Case Study of Upper Jhelum Floodplain", M.Phil. Thesis, Department of Geography & Regional Development, University of Kashmir
5. Zaho W.W, Fu B.J, Meng Q.H, Zhang Y.H, 2004 "Effects of land-use pattern change on rainfall-runoff and runoff-sediment relations: a case study in Zichang watershed of the loess plateau of China" Journal of Environmental Science Vol 16 pp. 436-442.