IMPACT OF RAINFALL AND VEGETATION ON RESERVOIR CAPACITY AND IDENTIFICATION OF EROSION PRONE AREA USING GIS & RS

Mahboob Alam [a] and Mohsin Jamil [b]

[a] Room No.6, Al-Umar Plaza, G-7 Markaz, Islamabad, Pakistan
malam.pwp@gmail.com
[b] Department of Meteorology, COMSATS Institute of Information Technology, H-8 Islamabad, Pakistan

KEYWORDS:
Reservoir Capacity, Sedimentation, Erosion, GIS, Remote Sensing

ABSTRACT

Most of the water reservoirs in Pakistan face the problem of sedimentation. The Mangla dam's capacity has been rapidly decreasing since it construction in 1967. The land cover changes, whether natural or man made as well as vegetation cover and rainfall have an immense effect on the sediment load. The traditional techniques to analyze the problem are time consuming and spatially limited. Remote sensing provides a convenient way to observe the landcover changes and gis provide tools for geographic analysis. This study demonstrates a GIS oriented methodology to calculate the impact of vegetation and rainfall on sediment load by using remotely sensed data. MODIS data is used to observe the temporal change in vegetation-covered area in Mangla watershed. The total drainage area for the Mangla is calculated from SRTM data. Annual rainfall is used to compute the annual available rainwater for the watershed. The impact of annual available rainwater on vegetation-covered area is computed in this study. In addition, certain areas are also identified which are causing sedimentation to the reservoir. An inverse relation between vegetation cover and rainwater is observed.

1 Introduction

Water is a very important resource for any country, especially for an agrarian one like Pakistan. It is a resource, which cannot be generated but can be preserved. Every country is doing its best to manage the water resources for the fulfillment of its needs. Water resources are affected by many natural hazards like sedimentation, earthquakes, floods etc. The anthropogenic activities lead to the increase in sedimentation (Des E. Walling., N.D). World's 13 large rivers carry 5.8 billion tons of sediments to the reservoirs every year (Nasir et al., 2000).

Pakistan is situated in a geographical location that leads to its rivers and their tributaries to get water from mountainous regions. Summer monsoons cause heavy rainfall in south-east Asia. During the rainy season the sediment load is very high due to flash floods in rivers. The watersheds in Pakistan are facing this sedimentation problem. Most of the reservoirs in Pakistan have their source of water at the north of the country.

The intensity of rain is very high in summers as compared to the winter season. The erosion rate grows higher with growing rain fall intensity (Wischmeier & Smith., 1978). The second factor that affects the erosion rate and due to which Pakistan's reservoirs face heavy sediments is steepness of the slopes. The water source for larger mountainous watersheds like Mangla and Tarbela are from higher mountains. The third important factor, causing sedimentation problem, is vegetation cover. Vegetation protects the soil from disintegrating and reduces the sediment delivery to dams (Alejandro et al., 2007). The River Indus and its tributaries in Pakistan carry 431.55 million cubic meter (mcm) of sediments load in a year. With such sediment intake rates the Indus basin ranks third in the world (Indus Basin).

The study area for this research is Mangla Watershed shown in Figure 1. Mangla dam was constructed in 1967 across the Jhelum River. It is situated 60 Km in south-east of Islamabad. The storage capacity of the Mangla dam was 7250.04 mcm when it was constructed and now it is reduced to 585675 mcm. The sedimentation rate is so high that the reservoir has lost 19.2% of its capacity since 1967.

Erosion around the catchments area of the reservoir contributes the sediment load that reduces the capacity of the dam. To prevent soil loss from the catchments areas there is a need for proper planning. The very first step in this planning is to uncover the main factors that contribute to sedimentation. The traditional methods of planning are time consuming and spatially limited. Geographic Information System (GIS) has reduced the effort involved in surveys and sampling. This study uses simple GIS and remote sensing based methodologies to identify the effects of Vegetation and Rainfall on reservoir capacity. Annual rainfall is interpolated spatially in GIS environment to compute annual available rainwater. Remote sensing technology serves best for the land cover assessment and topographic information. For Geo-visualization, Shuttle Radar Topographic Mission (SRTM) elevation data is used. Moderate Resolution Imaing Spectroradiometer (MODIS) sensor data is used to find out the changes in the vegetation covered area across watershed. The effect of both vegetation and rainfall parameters on sediment load is observed and the erosion prone areas are also identified in this research.

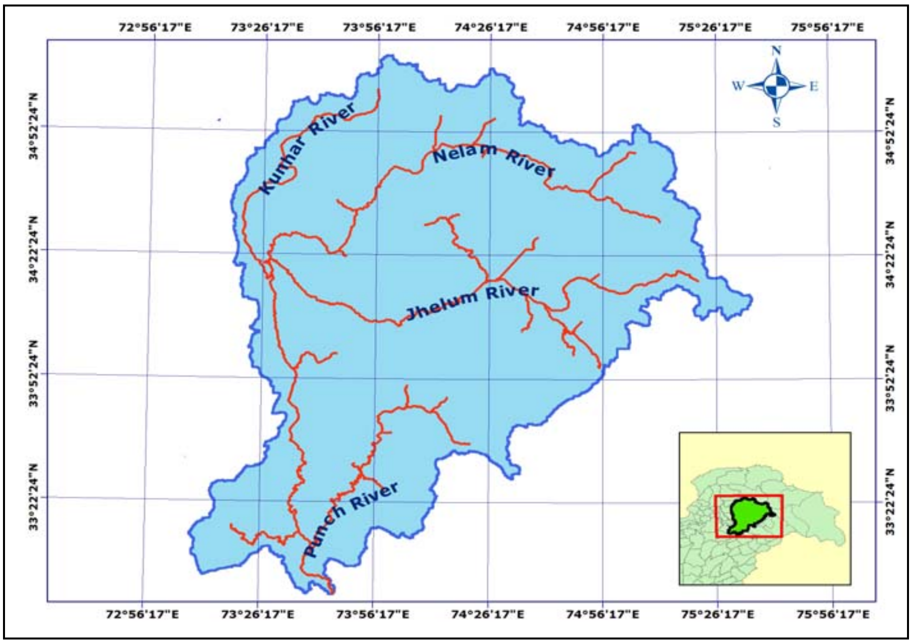

Figure 1: Mangla watershed

2 Material and Methods

There are four types of data which is acquired for this research.

1) Satellite Data
2) SRTM Data
3) Annual Rainfall Data
4) Sediment Load Data.

MODIS images are used to classify the landcover features in the study area. Indeed, the temporal images of MODIS are used in change detection. Six images with one year interval from 2000 to 2005 are selected for this study. The SRTM data is used to generate watershed area of the Mangla dam. Eight tiles of SRTM data are used to generate watershed. The total annual rainfall data from 2000 to 2005 is used in this study to compute the available water for the watershed and to identify the area of heavy rains. Fourteen meteorological observatories are selected to collect rainfall data. Sediment load data for Mangla dam is used to observe the vegetation and rainfall effect on sediment load.

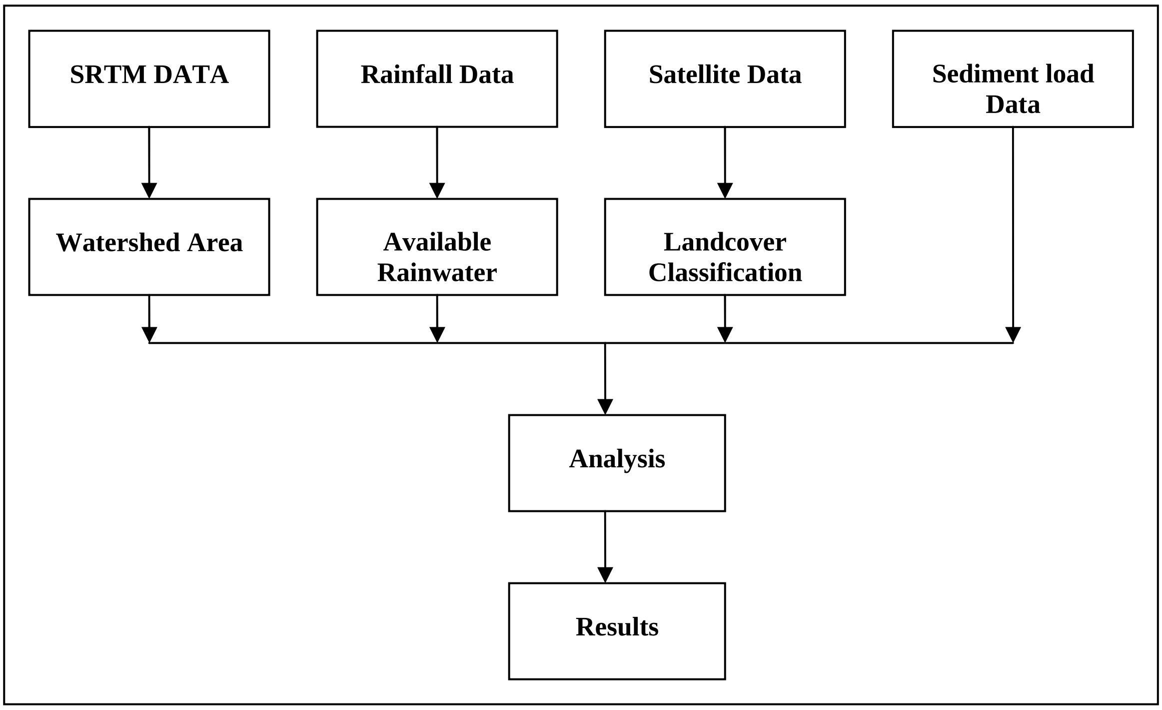

Figure 2: General methodology of research

2.1 Watershed Area

The SRTM data is downloaded in height files. The SRTM height file contains the topographic information of the earth. To generate the digital elevation model (DEM), the SRTM data need processing. By using Landserf software the height tiles are first converted into landserf format (“.srf”) and then voids in data (due to sensor defect) are removed with the help of the software,. The eight Landserf files are converted to text files.

The text files contain latitude, longitude and elevation information for each and every pixel. Triangular irregulated network is generated from the text files in ArcGIS 9.1. Triangulated Ire-regular Network (TIN) raster files are then converted to DEM raster files and then converted into single Dem file using Mosaic tool.

ESRI’s ArcHydro tool is used for extracting the watershed area from digital elevation model. The first step in this processing is to *fill sinks* in the DEM. Sinks are sudden change in pixel height values.

Using hydrological modeling the *flow directions* raster is generated from DEM. The flow direction raster actually shows the direction of water flow. Each and every pixel in flow direction raster is assigned a slope value.

The next process is the *flow accumulations*. The flow accumulation is computed from the flow direction raster. The flow accumulations raster contains the accumulated number of cells upstream of a cell.

By using this flow accumulation raster the stream definition raster is generated. The *Stream Definition* function takes a flow accumulation raster as input and creates a stream raster for a user-defined threshold. This threshold is defined either as a number of cells (default 1%) or as a drainage area in square kilometers. In this data processing for stream definition the default 1% is selected.

To get the stream network in the area, *stream segmentation* raster is generated from stream definition raster. This function links the stream definition raster to make the streams networks for the area.

The catchments delineation raster is computed from stream segmentation. The catchments raster delineation function creates a raster in which each cell carries a value indicating cells belonging to catchments. The value corresponds to the value carried by the stream segment that drains that area, defined in the stream segment link raster.

To extract catchments polygon shape file the *catchments polygon processing* is done on catchments delineation raster. The adjacent cells in the raster that have the same raster code are combined into a single area, whose boundary is vectorized. The single cell polygons and the "orphan" polygons generated as the artifacts of the vectorization process are dissolved automatically, so that at the end of the process there is just one polygon per catchment.

The drainage lines are generated from the stream definition raster and flow accumulation raster using Archydro tool *drainage line processing*. The drainage line processing function converts the input stream link raster into a drainage line feature class. Each line in the feature class carries the identifier of the catchments in which it resides.

Lastly the watershed extraction is done by *adjoint catchments processing* function. The Adjoint Catchment Processing function generates the aggregated upstream catchments from the "Catchment" feature class. For each catchment which is not a head catchment, a polygon representing the whole upstream area draining to its inlet point (reservoir) is constructed and stored in a feature class that has an "Adjoint Catchment" that is basically the watershed of Mangla Dam The Mangla Watershed and its stream network is shown in Figure 1.

2.2 Available Rainwater

Annual available rainwater for the watershed is calculated from the annual rainfall data. From 2000 to 2005 total rainfall for 14 stations are collected.

Six raster files for each year from 2000 to 2005 are generated from annual rainfall data having projected coordinate system “WGS 84 North UTM zone 43”.

To calculate the available rainwater the watershed area is clipped from the rainfall interpolated raster files. So the rainwater is calculated using function “Area and Volume” from the rainfall raster files. The available rainwater for the watershed for each year from 2000 to 2005 in million cubic meters is given in Table 1.

Sr.#	Year	Available Rainwater (mcm)
1	2000	22853.14
2	2001	19850.58
3	2002	18533.38
4	2003	21982.79
5	2004	22696.98
6	2005	21741.84

Table 1: Computed annual available rainwater

2.3 Landcover Classification

The landcover classification to monitor the vegetations cover in the watershed area is performed with MODIS data. Seven MODIS images are used for landcover classification.

To observe landcover changes over a six year period, supervised classification technique is adopted. Six images as discussed before are used for classification. As described before the band combination that was used for the interpretation is 7, 5, 3 of MODIS data. All the images are classified using supervised classification technique. In this classification user has to select the training area to specify one landcover feature. In this study, four classes are addressed i.e. vegetation, snow, water body, and bare land. All six MODIS images are classified having these four classes. In the first instance, spectral signatures are made for each image by selecting ten to fifteen training area for each landcover feature and then by using these signatures the images are classified using ERDAS Imagine 8.7. The results of the classification of the area covered by each landcover feature in square kilometers (km^2) for all six images are given in Table 2.

S#	LandCover Practice	2000	2001	2002	2003	2004	2005
		Area (km²)	**Area (km²)**	**Area (km²)**	**Area (km²)**	**Area (km²)**	**Area (km²)**
1	Vegetation	12543.09	18125.86	18228.45	17061.85	17827.73	16915.07
2	Bare Land	7230.39	6938.74	6578.05	5138.91	8095.24	9098.61
3	Water Body	1553.62	807.50	1009.48	486.90	767.96	494.21
4	Snow	7932.41	3390.78	3438.74	6555.21	2569.48	2753.79

Table 2: Landcover Classification Results

3 Results and Discussions

3.1 Impact of Rainfall on Vegetation

The vegetation trend is observed to be inversely proportional to rainfall. The vegetation covered area for year 2000 was 12543.09 km^2 with annual rainwater available for year 2000 as 22853.14 mcm. Rain water that was available for watershed in year 2001 was 19850.58 mcm and vegetation covered area in 2001 was 18125.86 km$^{2.}$ In 2002 the vegetation trend remains the same with decrease in available rainwater to 18533.38 MCM, while the vegetation increased to 18228.45 km^2. Again the available rainwater increased to 21982.79 mcm and vegetation decreased to 17061.85 km^2. The vegetation trend changed slightly in the year 2004 with increase in rainwater from 21982.79 MCM to 22696.98 mcm. An increment in vegetation was observed from 17061.85 km^2 for 2003 to 17827.73 km^{2}for 2004. Again in 2005 the vegetation and rainwater both decreased rainwater 21741.84 mcm and vegetation 16915.07 km^2. Graphical representation of rainfall impact on vegetation is given in Figure 3.

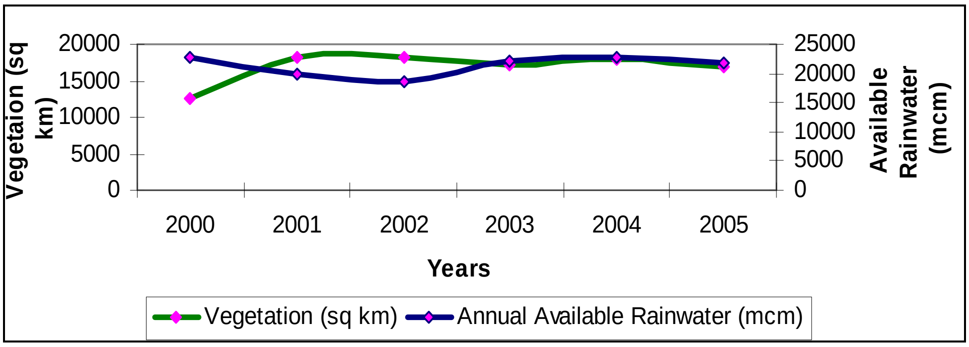

Figure 3: Impact of Rainfall on Vegetation

3.2 Impact on Reservoir Capacity

The comparison between sediment loads is performed differently because the data for sediment load is recorded as total load for two to three year rather than for a single year. The sediment load, vegetation covered area and rainfall water are given in Table 3.

S#	Name	2000	(2001-2002)	(2003-2005)
1	Vegetation (km^2)	12543.088	Average 18177.150	Average 17268.216
2	Annual Available Rainwater (MCM)	22853.140	Average 19191.980	Average 22140.550
3	Sediment Load (MCM) Data Source:(WAPDA)	34.524	Total 115.902	Total 73.98

Table 3: Rain water and Vegetation Impact of sediment Load

The sediment load for 2000 was 34.524 mcm with 12543.088 km^2 of vegetation covered area and rainwater 22853.140 mcm. The average vegetation covered area for the year 2001 and 2002 was 18177.150 km^2 and average rainwater for same two years was 19191.980 mcm with total sediment 115.902 mcm. The average rainwater available for three years from 2003 to 2005 is 22140.550 mcm and average vegetation covered area is 17268.216 km^2 while the total sediment load was 73.98 mcm.

3.3 Identification of Erosion Prone Areas

The erosion prone areas are identified for each year from 2000 to 2005. The identified erosion prone areas and rainfall distribution maps are given in figure 4.

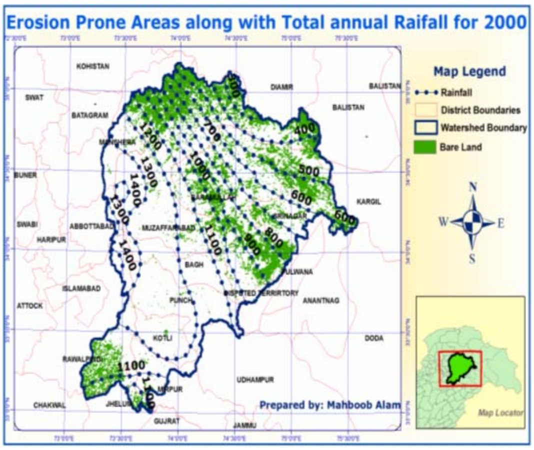

Figure 4(a): Erosion Prone Area's Maps for year 2000

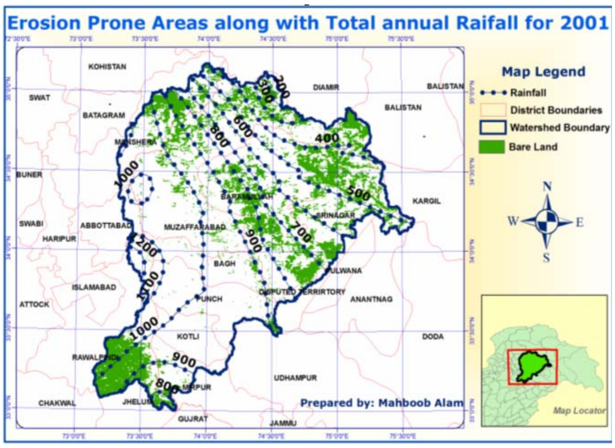

Figure 4(b): Erosion Prone Area's Maps for year 2001

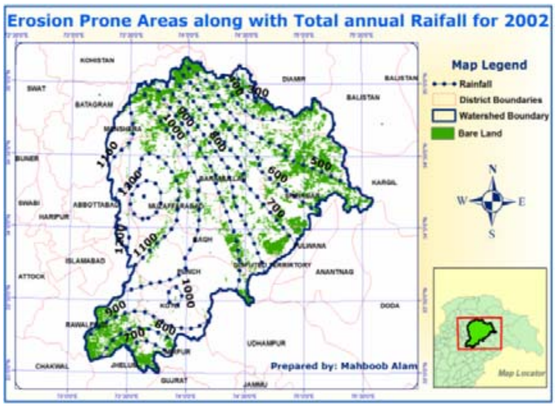

Figure 4(c): Erosion Prone Area's Maps for year 2002

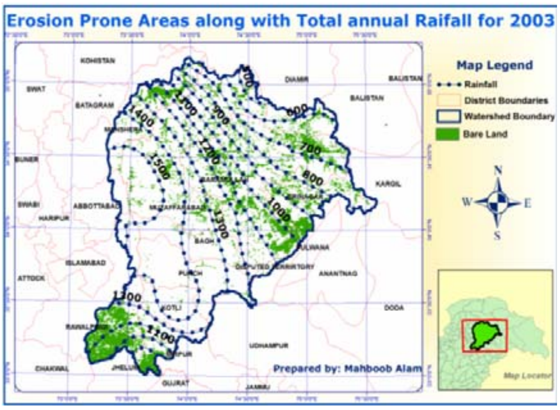

Figure 4(d). Erosion Prone Area's Maps for year 2003

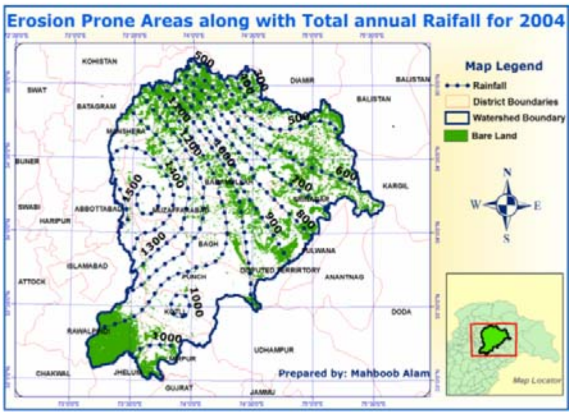

Figure 4(e): Erosion Prone Area's Maps for year 2004

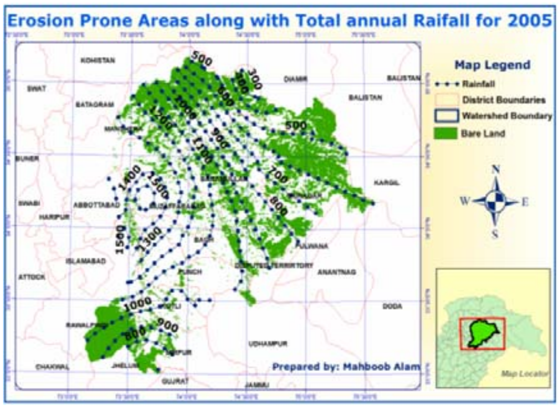

Figure 4(f): Erosion Prone Area's Maps for year 2005

4 Conclusions

Resource conservation has always been a critical issue as far as its efficient preservation and utilization is concerned. This study has helped enlighten the effects of different parameters that have majorly caused sedimentation in Mangla water reservoir. Incorporating the rainfall interpolation procedures have revealed the complex relationship between vegetation and available rainwater, depicting that decrease in vegetation along with heavy rainfall triggered the erosion process.

References

Alejandro, M. de Asis, Kenji Omasa., 2007. Estimation of vegetation parameter for modeling soil erosion using linear Spectral Mixture Analysis of Landsat ETM data. ISPRS Journal of Photogrammetry & Remote Sensing 62 309–324

Des E. Walling, N.D, Global Change and the Sediment Loads of the World's Rivers. Department Of Geography, University Of Exeter, Amory Building, Rennes Drive, Exeter, Devon, Ex4 4rj, Uk.

Nasir A, Uchida K, and Ashraf M, 2000, Estimation of Soil Erosion by Using RUSLE and GIS for small Mountainous Watershed in Pakistan. Pakistan Journal Of Water Resources, 10(1) :

Mangla Dam . N.D, Report by Pakistan Water and power Develoment Authority, Pakistan. http://www.waterinfo.net.pk/pdf/md.PDF (accessed 10.02.2008)

Indus Basin. N.D, Report by Pakistan Water and power Develoment Authority, Pakistan. http://www.waterinfo.net.pk/pdf/indusbasin.PDF (accessed 15.03.2008)

Wischmeier, W.H., Smith, D.D., 1978. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. US Department of Agriculture, Agricultural Handbook Number, vol. 537. Government Printing Office, Washington, D.C. Baver, L.D., 1956. Soil Physics, third ed. John Wiley & Sons Inc., New York.