Environmental Study of Water Reservoirs for the Watershed Management in Pakistan

Zulfiqar Ahmad[1] · Mohsin Jamil Butt[2]

Abstract

Water reservoirs in most parts of the world face the problem of sedimentation. Environmental impacts and land-use changes/ landslide have enormous potential to generate more sediment load in water reservoirs. Hence, the capacity of water reservoirs in Pakistan has been constantly reducing due to sedimentation. In this study, we have computed the environmental impacts on sedimentation load in Tarbela and Mangla water reservoirs using multi-satellite and ground-based data. The total drainage area of watershed is calculated using Shuttle Radar Topographic Mission data. Satellite data from NOAA-AVHRR are used to monitor urban development and changes in vegetation area, while MODIS data are used to estimate the snow area in the watershed region. Normalized Difference Vegetation Index is used to estimate the temporal changes in vegetation cover, whilst principle component analysis is applied to monitor urban changes in watershed region. Similarly, snow cover area in the study region is estimated using Normalized Difference Snow Index algorithm. Rainfall data obtained from Pakistan Meteorological Department are used to evaluate the relationship between sedimentation deposited in water reservoirs and annual rainfall amount. Results of the current study reveal that increase in urban development and high amount of precipitation has direct relationship with the load of sedimentation, while amount of vegetation has inverse relationship with the load of sedimentation in water reservoirs of the country.

Keywords NOAA-AVHRR · MODIS · NDVI · NDSI · PCA

1 Introduction

Watershed management has played a significant role in sustainable economic growth for many countries, especially for countries like Pakistan where the economy mainly depends on agricultural production (Nalbantis and Tsakiris 2009). For example, the wheat crop in winter is mainly irrigated through water stored in large reservoirs and dams. In addition to this, the runoffs from snow melt as well as from summer monsoon rainfalls need to be captured in large reservoirs to avoid flooding hazards in the downstream plain regions (Butt et al. 2010). To surpass these scenarios and other

challenges, like energy requirements, several dams have been proposed and constructed on major rivers in Pakistan, including Tarbela (on river Indus), Warsak (on river Kabul), and Mangla (on river Jhelum) dams. These water reservoirs, including several barrages, are the backbone of the country, and therefore, their management is highly mandatory. In this study, the sedimentation problem for water reservoirs would be addressed, and would provide general provision for other newly planned dams based on the results from this study.

Due to the highly elevated location of the watershed regions, snowmelt from mountains as well as the monsoon runoffs bring large amounts of sediments that keep on filling the water reservoirs regularly. This phenomenon has already filled the Warsak dam almost completely. According to Belaud et al. (1998), the rivers in Pakistan transport approximately 0.35 Million Acre Feet (MAF) of sedimentation load per year. Such a phenomenon is also quite common throughout the world, and a cumulative 4800 MAF of sedimentation is transported in various reservoirs in a year (Nasir et al. 2006). The rates of sediment deposition are different in every part of the world as it depends on several

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factors, like the amount of rainfall, extent of glacier melting, afforestation/deforestation, and the slope of the region (de Asis and Kenji 2007; Owens et al. 2004). Nevertheless, the objective of many researchers is to optimize the ways to reduce load of sedimentation in the dams. This has been discussed in several studies that emphasize the importance of watershed management (for example, Apitz and Power 2002; Apitz and White 2003; Wenning and Ingersoll 2002).

In the current study, we explore the combined effects of precipitation (snow melt and rainfall amount), vegetation, and urban growth on the sedimentation load in watershed regions for water store management. There are a number of large and small dams as well as barrages in Pakistan, and it is beyond the scope of this study to discuss sedimentation depositions in all of them (Butt et al. 2011). Therefore, in the current study, we have chosen two largest dams, that is, Tarbela dam and Mangla dam to analyze the sedimentation characteristics in the region. The codependence and sensitivity of precipitation, vegetation, and urban growth on sedimentation is obvious, and needs to be evaluated collectively (Ouyang et al. 2010; Zhou et al. 2008). These considerations provide stimulations for a comprehensive analysis of the regional characteristics of sedimentation load based on factors like urban growth, total vegetation cover, as well as precipitation amounts in the watershed region. For this study, sedimentation data from the year 1971–2015 are obtained from Water and Power Development Authority (WAPDA), while rainfall data for the same period are retrieved from Pakistan Meteorological Department (PMD). For the ground feature analysis, MODIS satellite data, which are used to estimate snow area by applying Normalized Difference Snow Index (NDSI), are retrieved for the year 2000–2015 (MODIS data are available since year 2000). Similarly, National Oceanic and Atmospheric Administration-Advanced Very High Resolution Radiometer (NOAA-AVHRR) satellite data for the same period are obtained to estimate vegetation area and urban development in the study area. Normalized Difference Vegetation Index (NDVI) and Principle Component Analysis (PCA) are applied to evaluate the amount of vegetation and urban growth development, respectively, in the study area.

2 Study Area

The study area selected for this research is the Tarbela and Mangla dams in Pakistan. The geographical extent of Pakistan is from 24°N to 37°N Latitude, and from 61°E to 75.5°E Longitude, which lies between Arabian and Indo-China peninsulas. The north east and northern region is bordered by Chinese territory of Sinkiang which has a border length of 592 km with Pakistan. The country gets separated from the Central Asian states due to the presence of the narrow arm of Afghanistan in the north-west, which

is mainly done by the low dry hills of the west. This border (Durand line demarcated in 1897 AD) has a length of 2240 km. Iran is located in the south-west share a common border of 800 km in length with Pakistan. Indian states of Punjab and Rajasthan share a border of about 1600 km in length along the East of Pakistan. However, in the south, Pakistan is mainly covered by the Arabian Sea (Raza 2001). Tarbela and Mangla watershed are the most important water resources in Pakistan. The geographical location of Tarbela dam is 34°05′23″N to 72°41′54.2″E, while location of Mangla dam is 33°08′31.50″N 73° 38′42.05″E. Both of these locations are in the downstream of mountainous regions of Hindukush, Karakoram, and Himalaya (HKH) situated in north Pakistan. HKH region, which includes not only snow covers, forest, and bare soils but also some permanent snow features in the form of glaciers that exists all year round. These glaciers and snow runoff are not only one of the main contributors of water reservoirs but also bring large amount of sedimentation downstream. In the current study, therefore, we have included the geographical range which extends from 33°N to 36°N latitude and from 70°E to 77°E longitude. The geographical location of the Tarbela and Mangla watershed is shown in Fig. 1.

The construction of Mangla dam started in the year 1961 and completed in 1965, while Tarbela dam project was started in the year 1968 and completed in 1976. Mangla dam is the first water storage reservoir constructed across the river Jhelum and Tarbela dam is the first water storage reservoir constructed across the river Indus. Both dams serve as the major water storage hubs for drinking, irrigation, and power generation needs for the country. The total catchment area of Tarbela dam is 169,600 km^2 with an annual flow of 64 MAF, while total catchment area of Mangla dam is around 35,000 km^2. The area of Tarbela Lake is 259 km^2 with a maximum depth of 137 m, while total area of Mangla Lake is 251 km^2 with a maximum depth of 115 m. Tarbela dam has 7 service spillways with 650,000 cusec discharge and 9 auxiliary spillways with 850,000 cusec discharge.

Both Tarbela and Mangla Dams are considered to be vulnerable for erosion due to the fact that the major soil type of the region is sand, silt and clay. Large amount of rainfall as well as snow melt runoff from HKH in the study region is responsible for loss in surface soil and consequently for sedimentation deposition in both the dams. This has been observed from the fact that due to sedimentation deposition, the capacity of one of the dams (Mangla) has been reduced from 7254.74 million m^3 to 5846.71 million m^3. Considering this, the authorities in the country decided to raise height of Mangla dam by 9.14 m in 2004. This increases the water storage capacity of the Mangla reservoir by 3577.10 million m^3 as well as 12% increase in the existing power generation capacity which will increase from 1000 MW to 1120 MW of electricity with four sets of power generation units. On the

Fig. 1 Geographical location of study area

other hand, Tarbela dam has 14 power units with a current capacity of 3840 MW electricity. Recently, extension of the Tarbela hydropower project is underway and expected to be completed in June 2021. This will further increase the capacity of the dam to produce electricity to around 4800 MW. The water from both the reservoirs is used for various irrigation purposes in different seasons in the country. Therefore, area of study is of highly importance, since it serves as a backbone for economic growth of the country.

3 Data

Moderate-Resolution Imaging Spectroradiometer (MODIS) onboard Terra (launched in 1999) and Aqua (launched in 2004) satellites has been providing environmental data including snow products to the scientific communities free of cost. MODIS orbiting the earth at an altitude of 705 km has a temporal resolution of 1–2 days with a variable spatial resolution depending upon bands. For instance, bands 1 and 2 have a spatial resolution of 250 m; bands 3–7 have a spatial resolution of 500 m, while remaining bands have 1 km spatial resolution. National Snow and Ice Data Center (NSDIC) has been distributing MODIS data to researchers free of cost. Various research groups have been using MODIS data for snow monitoring as well as to develop snow algorithms (Ault et al. 2006; Butt 2012; Riggs et al. 2006; Rodell and Houser 2004). In this context, Hall and Martinec (1985) proposed Normalize Difference Snow Index (NDSI) using bands 4 (highest snow reflectance) and 6 (lowest snow reflectance) from MODIS. Many researchers, for example, Butt 2013; Gao et al. 2010; Hall et al. 2010; López-Burgos

et al. 2013; Paudel and Andersen 2011, have shown that snow can be discriminated from other features more effectively by applying NDSI algorithm. Thus, NDSI is used in the current research to estimate snow in the northern region of the study area.

Similarly, data of AVHRR onboard NOAA satellite are used in this study to assess the vegetation and urban temporal changes in Tarbela and Mangla watershed region. NOAA-AVHRR is a series of satellites which is providing a historical data of reasonable spatial resolution (Chander et al. 2009). Since 1966, with the launch of the (NOAA) first polar orbiting satellite, which imaged the earth in the visible band, measurement of earth observation from space has been possible (Campbell 2002). The AVHRR has five channels spread over the red, near-infrared, and thermal infrared spectral ranges. The data from AVHRR channel 1 and 2 of visible and near IR, respectively, can be used in NDVI for the mapping and classification of vegetation/forested areas at large scale. In addition, AVHRR data are also very useful for monitoring urban growth changes at a large scale (Bajgiran et al. 2008).

We have also used the elevation data derived from Shuttle Radar Topographic Mission (SRTM) to make drainage area in the study region. On 11 February 2000, National Aeronautics and Space Administration (NASA) launched the SRTM mission which was onboard on Endeavor space shuttle collecting data from two radars with a spatial coverage of 60° north to 60° south and a temporal coverage of 1 arc second (Farr and Kobrick 2000; Jarvis et al. 2004). Organizations have been using SRTM data to prepare Digital Elevation Model (DEM) at 30 m and 90 m resolutions for North America and for other parts of the world, respectively. In current study, SRTM data

acquired from Global Land Cover Facility (GLFC) are used to generate DEM of the watershed region. The data from GLFC at global scale are not only much improved as compared to other data sets but also it can provide products to understand global environment systems (Dobos et al. 2005; Dobos and Daroussin 2005; Jarvis et al. 2004).

Beside remote-sensing data, we have also used the sedimentation data and rainfall data in this study. The sedimentation data are obtained from WAPDA (Water and Power Development Authority). WAPDA has been storing sedimentation data since the construction of both the dams; however, the data are retrieved from water reservoirs after different interval of times. Table 1 shows sediment deposition data in water reservoirs measured in MAF for a group of different years from 1971 to 2015. Similarly, Pakistan Meteorological Department (PMD) is responsible for collecting

and storing the meteorological data in the country. Thus, daily precipitation data from 17 stations are obtained from PMD and analyzed. Annual average rainfall amount of 17 ground stations in the study region are given in Table 2. Similarly, total annual average rainfall (sum of all the PMD stations) in the watershed region is shown in Fig. 2.

4 Methodology

SRTM data are used to demarcate the watershed region and its associated fluvial network. Jarvis et al. (2004) highlighted that, in the watershed region of a specific area, the locality of main stream networks (rivers, water channels, canals, etc.) can be generated from topographical data. Therefore, flow direction of the stream network in the current study has been

Table 1 Average annual sedimentation load and its corresponding rainfall for different groups of years (1971–2015) in study area

Years	Sedimentation in Tarbela (MAF)	Sedimentation in Mangla (MAF)	Total sedimentation (MAF)	Annual average rainfall (mm)
1971–1973	0.210	0.146	0.356	822.18
1974–1978	0.372	0.108	0.480	860.10
1979–1983	0.575	0.179	0.754	898.54
1984–1988	0.385	0.154	0.539	874.33
1989–1993	0.413	0.187	0.599	947.92
1994–1999	0.495	0.173	0.668	922.88
2000–2005	0.417	0.159	0.576	798.25
2006–2010	0.440	0.138	0.578	834.80
2011–2015	0.432	0.145	0.577	809.61

Table 2 Annual average rainfall for different groups of years on each stations in the study area

| Station name	Group of years with rainfall (mm)								
	1971–1973	1974–1978	1979–1983	1984–1988	1989–1993	1994–1999	2000–2005	2006–2010	2011–2015
Astore	517.33	435.62	467.2	481.56	542.16	575.88	440.96	430.6	398.9
Balakot	1626.83	1910.42	1867.44	1543.76	1737.28	1310.23	1401.69	1522.4	1383.3
Bunji	153.24	131.92	158.74	189.12	127.02	180.71	169.55	169.3	174.6
Chilas	178	68.82	223.94	224.14	205.6	254.33	173.86	194.4	152.3
Chitral	505.73	346.22	384.44	464.06	547.64	491	454.90	536.9	413.4
Dir	1225.1	1260.18	1588.7	1729.44	1547.26	1457.9	1189.40	1350.6	1322.6
Drosh	608.86	543.96	541.86	586.42	620.9	633.5	548.77	591.4	502.4
Garidopatta	1612.33	1469.1	1465.16	1412.14	1677.4	1513.83	1390.48	1357.3	1323.4
Gilgit	145.16	110.68	151.7	134.98	94.68	163.76	136.68	159.2	148.5
Gupis	115.39	96.38	78.52	78.42	184.48	394.5	353.05	154.5	171.0
Jehlum	743.43	980.64	977.28	808.48	948.64	1011.98	767.05	740.3	788.0
Kakul	1343.03	1489.34	1350.92	1387.68	1456.5	1365.4	1161.51	1229.8	1378.6
Kotli	1204.36	1216.02	1450.96	1330.8	1230.2	1345.55	1128.9	1235.2	1238.3
Murree	1548.26	1712.16	2026.64	1769.9	1813.66	2063.58	1861.7	1513.6	1715.0
Muzaffarabad	1324.63	1672.18	1398.42	1508.78	1744.34	1579.5	1308.2	1542.4	1435.7
Saidu Sharif	928.22	928.22	971.52	980.11	1412.192	1064.03	920.35	1152.1	987.6
Skardu	197.13	250	171.8	233.9	224.72	283.4	163.23	311.5	229.6
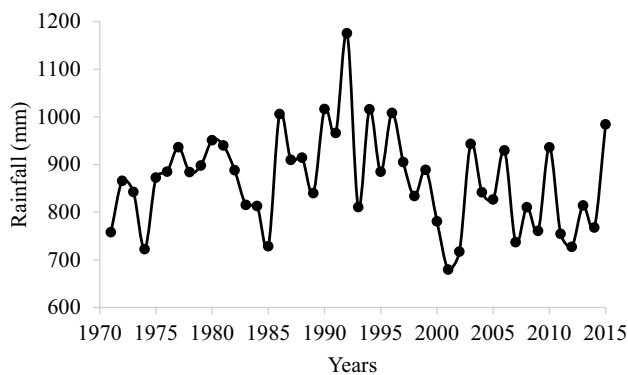
Fig. 2 Annual average rainfall data in the watershed region of study area from 1971 to 2015

generated from DEM (Digital Elevation Model) based on the SRTM data using Arc GIS software. First, we applied the fill tool in Arc GIS software to remove any sinks in the data, while sink-filled DEM is used to calculate the flow direction using flow direction tool. The accumulation of flow was calculated using flow direction grid file which is used to generate the stream channels by identifying the cells which are flowing in a unique cell by calculating the number of pixels that are contributing to that specific cell. Each stream segment is assigned a unique number which was generated in flow accumulation grid file. Finally, the watershed was delineated using 'watershed tool' from the hydrology toolbox of ArcGIS. Figure 3 shows Digital Elevation Model derived from SRTM data and water contours developed from DEM.

NDSI as given in Eq. 1 is used to estimate snow area in the study region. In addition, data from MODIS bands 21, 31, and 35 (emissive bands) are used to calculate brightness temperature, while data from MODIS bands 1, 2, 4, and 6 (reflective bands) are used to estimate reflectance. Similarly, MODIS LIB data product is used to estimate the radiance and reflectance values at Top of the Atmosphere (TOA). It is important to note that while applying NDSI for snow monitoring, a threshold value of 10% was used on MODIS band 4 to exclude dark pixels, while a threshold of greater than 11% was applied on MODIS band 2 to remove water pixels from the data. Another important issue is misinterpretation in snow monitoring due to ice clouds that may have similar values in NDSI estimation (López-Burgos et al. 2013). In current study, we have used a threshold of 0.40 on NDSI values as prescribed by Hall and Martinec (1985) to separate snow and ice features from other objects:

presented NDSI-based snow area for the year 2000 and 2015 in Figs. 4a and 4b, respectively. Figure 4 clearly demonstrates the change in snow area from the year 2000 to 2015.

Similarly, satellite data from NOAA-AVHRR with almost no cloud were acquired on-line from the satellite active archive (SAA). To define the study region, latitude and longitude values were assigned to define the region of interest. The data were requested and downloaded via FTP from SAA. The basic material consists of a set of AVHRR images covering entire Pakistan from years 2000 to 2015. Since all remote-sensing imageries are inherently subject to geometric distortions due to several factors, therefore, geometric registration of the imagery to a known ground coordinate system must be performed. The geometric registration process involves identifying the image coordinates (that is row, column) of several ground control points (GCPs), in the distorted image and matching them to their true positions in ground coordinates (e.g., latitude and longitude). The true ground coordinates are typically measured from a map either in paper or digital format or by registering one image to another image, called image-to-image registration. Analyses are made on digital number (DN) values to categorize the dissimilar structures in the watershed region using image processing techniques (Lillesand and Kiefer 2002). PCA technique is applied to estimate the urban changes in the watershed region. The watershed region of study area has a variety of vegetation for which we have applied the NDVI on satellite images to demarcate the area of vegetation in the study region. Previous studies showed that NDVI is very useful for the identification and estimation of the area covered by vegetation (Domeni-kiotis et al. 2002; Huete et al. 2002). NDVI-based estimated area of vegetation and PCA-based urban area estimation from NOAA-AVHRR from the year 2000 to 2015 in the study region are given in Table 3. The changes in the vegetation and urban areas are also shown in Figs. 5a, b and 6a, b, respectively. It is evident from Fig. 5a (year 2000) and b (year 2015) that vegetation area has decreased in the watershed region. Similarly, it is apparent from Fig. 6a (year 2000) and b (year 2015) that urban area has increased in the watershed region.

5 Results and Discussion

This study aimed at using physical data as well as remote-sensing techniques to explain the environmental impacts (precipitation, vegetation, and urban development) on load

$$\mathrm{NDSI} = \frac{\mathrm{MODIS4}\ (0.545 - 0.565\ \mu\mathrm{m}) - \mathrm{MODIS6}\ (1.628 - 1.652\ \mu\mathrm{m})}{\mathrm{MODIS4}\ (0.545 - 0.565\ \mu\mathrm{m}) + \mathrm{MODIS6}\ (1.628 - 1.652\ \mu\mathrm{m})}. \tag{1}$$

Results of NDSI-based snow estimation from year 2000 to 2015 are given in Table 3. In addition, we have also

of sedimentation in water reservoirs (Tarbela and Mangla) of Pakistan. Various data sets including SRTM, MODIS,

Fig. 3 a Digital elevation model (DEM); **b** contours drawn from DEM of SRTM data
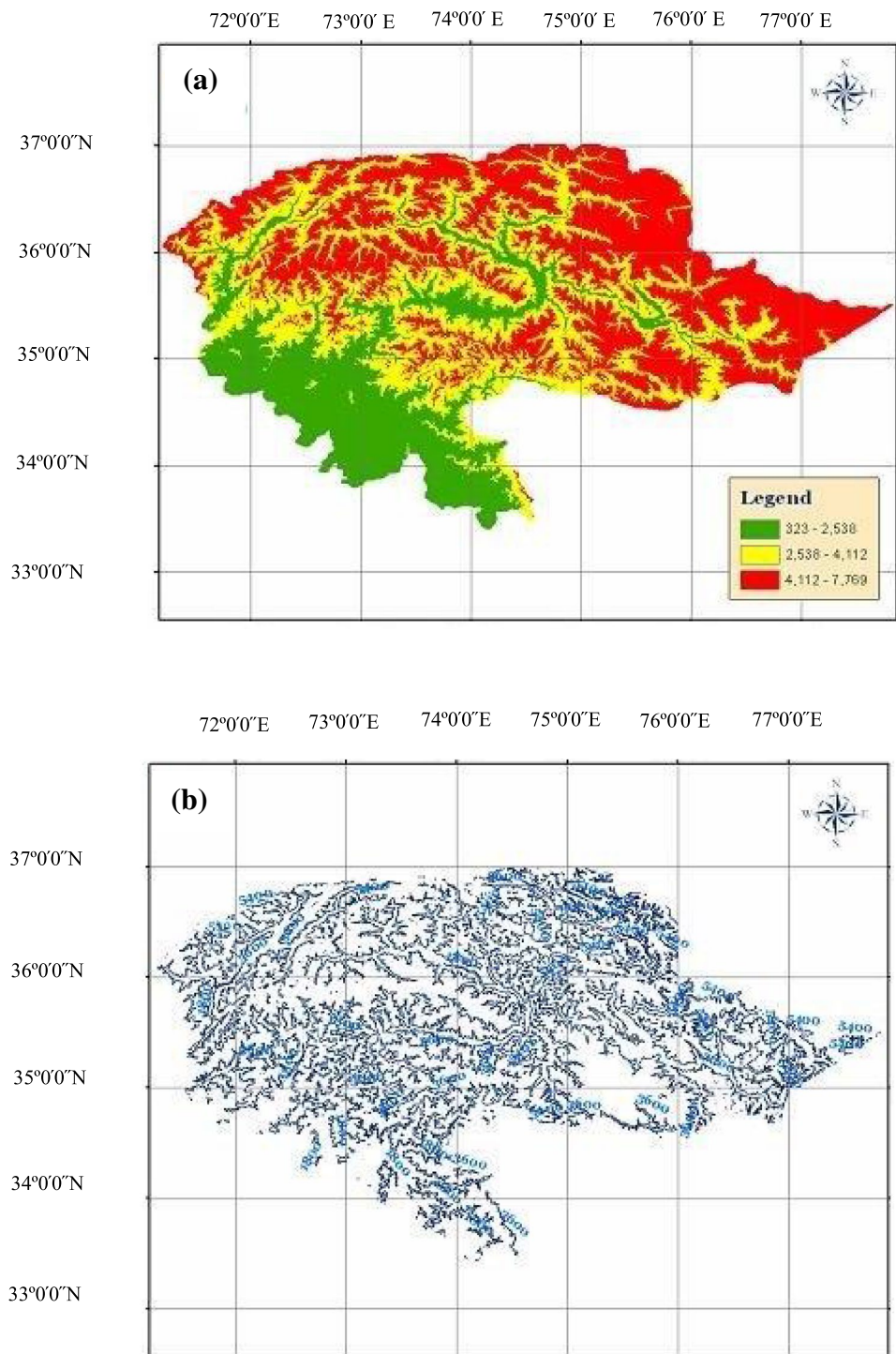
NOAA-AVHRR, rainfall, and sedimentation were used in this study. Snow cover in the HKH region of Pakistan is the main water resource for the water reservoirs. Thus, MODIS data from the year 2000 to 2015 were used to estimate change in annual snow area by applying NDSI algorithm. Similarly, NOAA-AVHRR data for the year 2000–2015 was used to highlight the vegetation growth as well as for the urban development in the catchment

area. NDVI algorithm is applied for vegetation monitoring, while PCA is used to highlight the urban development in the study region. The watershed region of study area comprises of rivers along with several small tributaries that are contributing in the dams. To see the impact of precipitation on rate of load of sediments, it is essential to delineate the boundary of the watershed. In this process, those areas which are contributing during the process of

Table 3 Area of vegetation and urban development estimated from NOAA-AVHRR data and snow cover estimated areas from MODIS data in watershed region for different years

| Years	Vegetation (km^2)	Urban area (km^2)	Snow area (km^2)
2000	39,476.89	647.12	55,982.63
2001	39,476.67	647.95	75,657.43
2002	38,231.53	648.46	62,665.70
2003	37,591.60	648.73	56,687.40
2004	37,007.46	649.84	65,140.53
2005	36,385.91	650.49	60,187.70
2006	35,792.82	651.38	63,489.87
2007	35,199.25	652.91	51,260.47
2008	34,784.38	653.84	53,628.94
2009	34,653.14	654.63	60,122.67
2010	33,968.56	655.52	72,690.23
2011	33,801.72	656.29	69,453.42
2012	33,195.59	657.06	65,287.43
2013	32,748.83	658.14	61,982.87
2014	32,692.63	659.31	59,987.99
2015	33,016.19	660.27	50,894.67

sedimentation are highlighted. This will also assist to identify the areas where possible impacts of precipitation on loss of soil and consequently load of sedimentation rate is higher. Thus, SRTM data were utilized to prepare the drainage area in study region.

For this study, we have acquired satellite data (MODIS and NOAA-AVHRR) from the year 2000 to 2015. Satellite data are processed to identify the changes in the land use and land cover in the watershed region of study area. The scope of current study is to monitor snow area, vegetation, and urban development. Annual changes in these features in study region are given in Table 3. Result of the study shows that estimated snow covered area using MODIS data has variation from year 2000 to 2015 (Table 3). For example, the maximum area covered by snow in study region is during the year 2001 (75,657.43 km^2), while the minimum area covered by snow in the study region is during the year 2015 (50,894.67 km^2). The study area has suffered a decrease of around 32% of snow surface from the year 2000 to 2015. Similarly, from NOAA-AVHRR data, we have focused only on two classes, that is, vegetation cover and urban area (mainly houses, buildings, road, and concrete structures). The separation of features into two classes can provide us a good understanding of the expansion of the watershed region of study area during the study period. Although urban development has no direct impact on load of sedimentation the increase in metropolitan area can cause serious environmental issues, which may indirectly has impact on sedimentation loss in the region and consequently increase in sedimentation in the water reservoirs. Temporal change in urban

classes from the year 2000 (Fig. 6a) to year 2015 (Fig. 6b) is quite evident. Analyzing Fig. 6a and 6b, it is apparent that from the year 2000 to 2015, the urban area has developed (though not much) in the study region. The increase in urban area is also evident from Table 3, which clearly indicate that the urban construction in study area has increased from 647.12 km^2 to 660.27 km^2 from the year 2000 to 2015; that is, there is an increase of 2% in the watershed region during 15 years. The growth in residential area during 15 years has definite influence on the regional environment, since concrete construction has high thermal capacity and conductivity and, therefore, can absorb high solar radiation, which can be one of the reasons in the increase in local temperature and consequently loss of permanent snow features in the study area.

In the watershed region, the vegetation growth varied from year to year, and the sedimentation accumulation rate also varied. Annual changes in vegetation area in study region are given in Table 3, while Fig. 5a shows vegetation area for the year 2000 and Fig. 5b indicates vegetation area for the year 2015. It is evident from Table 3 that the maximum area covered with vegetation is 39,476.89 km^2 for the year 2000 and the minimum area covered with vegetation is 32,692.63 km^2 for the year 2014. It is also evident from Table 3 that from the year 2000 to 2014, the area of vegetation is reducing in the study region, while it started increasing again in the year 2015. The increase in vegetation area in study region is due to the "Billion Tree Tsunami" program launched by KPK government in 2014. General analysis of Table 3 indicates that as the area of vegetation decreased, there is an increase in the load of sedimentation in the water reservoirs in the study region. However, for the years when there is an increase in the vegetated area, a slight decrease in sedimentation load is observed in the water reservoirs. More specifically, we have also analyzed the vegetation area according to the group of years for which sedimentation data are available. For example, going from the group of years 2000–2005 towards the group of years 2006–2010, the load of sedimentation is slightly increased although vegetation area is decreased from annual average of 38,028.34–34,879.63 km^2. This increase in sedimentation is very much due to the increase in rainfall amount in the study region (Table 3). For the next group of years, that is going from 2006 to 2010 towards 2011–2015, the load in sedimentation is decreased and so is the area of vegetation. From these results, it is safe to say that an inverse relationship exists between the area of vegetation and the sediment load rate. To sum up, it can be said that an increase in the estimated vegetation area may be a good reason in the reduction of sediment load in water reservoirs. As even though there is a decrease in vegetation, an exceptionally low amount of rainfall can be resulted in less water flowing down stream and thereby slight possibility of soil erosion,

Fig. 4 NDSI-based snow area from MODIS data for the year **a** 2000 and **b** 2015
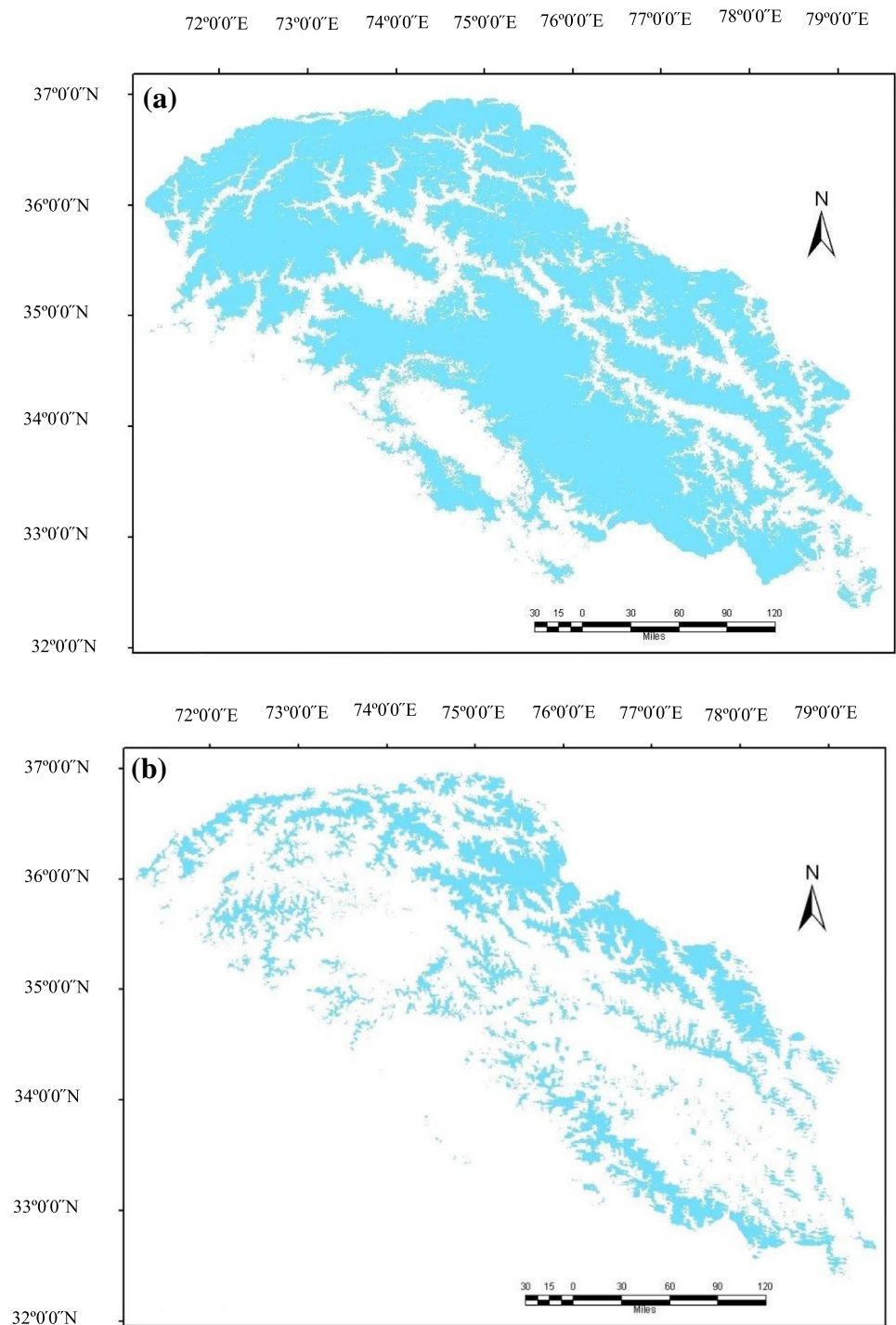
giving an unusual result of sediment deposition in the water reservoirs.

Finally, we will discuss rainfall in the study area and its relationship with sedimentation deposition in water reservoirs. Annual average rainfall and sedimentation load in study area for a groups of years as given in Table 1 indicate that for the group of years when there is less rainfall the load of sedimentation is also low, while for the group of years when

there is high amount of rainfall, the load of sedimentation is also high. For example, for the first 3 years (1971–1973) of study period, it is clear that the average annual amount of rainfall in the watershed region is 822.18 mm, while load of sedimentation for the same period is 0.356 MAF. For the next time period of 5 years (1984–1978), the average annual amount of rainfall in watershed region has increased by 42% and the load of sedimentation is also increased by 26%. For

Fig. 5 NDVI-based vegetation area **a** for the year 2000 and **b** for the year 2015
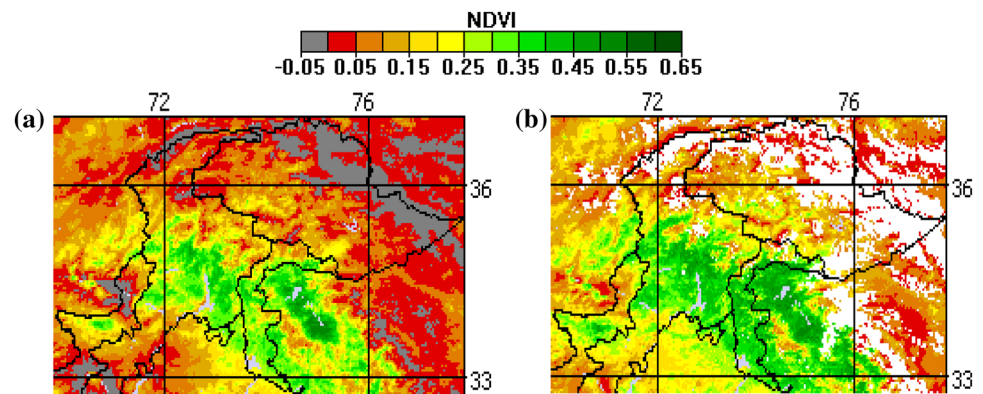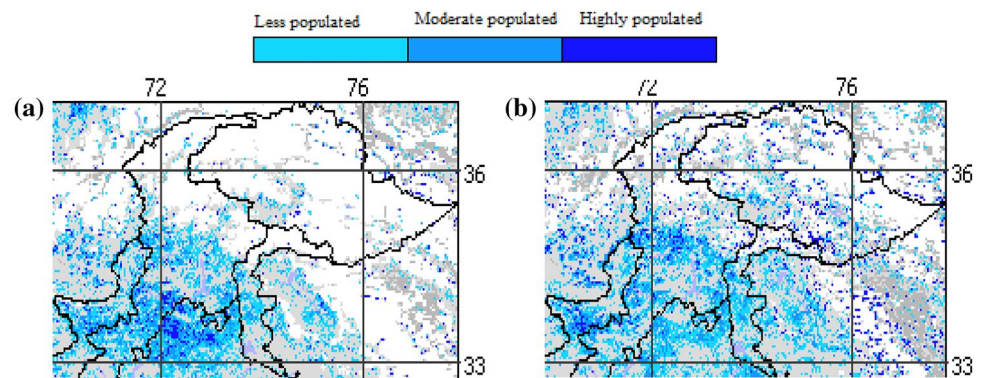

Fig. 6 PCA-based urban development **a** for the year 2000 and **b** for the year 2015

the third time period (1979–1983), total amount of average annual rainfall increased by 4.2%, while sedimentation load for this time period is increased by 36%. From 1984–1988 (fourth time period), the average annual amount of rainfall is decreased by 2.8% and the load of sedimentation is also decreased by 40%. For the next set of years (1989–1993), average annual amount of rainfall is increased by 8%, while the load of sedimentation is increased by 10%. In the set of years from 1994 to 1999, the average annual amount of rainfall is increased by 14% and a sedimentation load is increased by 10%. For the next time period (2000–2005), the average annual amount of rainfall in watershed region is decreased by 16% and the load of sedimentation is also decreased by 16%. For the set of years from 2006 to 2010 in this study, average annual amount of rainfall in watershed region is decreased by 15%, while total load of sedimentation is slightly increased by 0.35%. For the last set of years (2011–2015), the average annual amount of rainfall is decreased by 3.1% and the sedimentation load is slightly decreased by 0.2% in the water reservoirs. This analysis indicates that the sedimentation load varies with the amount of rainfall that occurs. A lower total rainfall means that there is a less occurrence of soil detaching, and, hence, a reduction in sedimentation load in water reservoirs.

The outcomes from this study indicate that the sedimentation load rate is greatly affected by the amount of rainfall

in the watershed region of study area. Heavy precipitation, especially during the monsoon, results in land sliding, causing a large amount of sedimentation in the water reservoirs. This can be well understood with the high value of the correlation coefficient (0.8) between annual loads of sedimentation with rainfall. It is noteworthy that rainfall alone is not the only contributor to the sedimentation load. Other factors are also known to impact the sedimentation load, and these include the intensity of rainfall, vegetation coverage of the area, as well as the geographical location of the region. For example, tributaries in the watershed region are fed by both seasonal snow melting and glaciers which eventually join the main river course that flow straight into water reservoirs. Several fruit trees and other vegetated areas are known to grow throughout the river path in the watershed region. The trees grip into the soil and keep it firm, reducing the process of any soil loss which can contribute to the load of sedimentation in the water reservoirs. Hanif et al. (1990) proved that a 78% reduction in the sediment load of the Mangla watershed area is possible simply with the plantation of trees in the region. It is significant to note that extreme rainfall can still impact the sedimentation load by causing a spike in the total sediment deposit value due to forced soil erosion. An extremely high correlation coefficient value of 0.8 suggests that an increase in total annual rainfall will increase the sedimentation deposit in the water reservoirs and vice versa.

6 Conclusion

This study sheds light on the effect of soil erosion on the deposition of sedimentation in water reservoirs as a result of precipitation, vegetation, and urban development. It is important to note that water resources are critical for developing countries, including Pakistan. A reduction in these resources may prove to be critical in the overall growth of the country, as well as for further development, and in some cases, even for survival. These water resources are becoming more and more limited with sedimentation deposits in reservoirs and rivers, including the Mangla, Tarbela, Warsak, Rawal, and Chashma. Several proposed projects, as well as ongoing dam constructions in Pakistan (which include the Munda dam, Akhori dam, and the Diamir dam) do seem to be a ray of light in the otherwise alarming situation, but eventually, these dams too will be plagued with sedimentation and lose their full capacities to merely fractions of their full capabilities. The paramount importance of these projects for the economy of Pakistan is the main reason that it is more than just vital to take steps to recognize the physiognomies of the region under consideration that can impact soil loss, which eventually can contribute in major problem of sedimentation. In addition, work has to be done to mitigate the sedimentation problem to prevent the reduction of the life of water reservoirs.

The current research is an effort to understand the impact of rainfall, vegetation, and urban development on load of sedimentation in water reservoirs as a result of the process of soil erosion. This implies more generally to some regions that are more vulnerable to problems such as land degradation, soil creep, landslips, and dangerous landslides. The main causes of these menacing issues are the summer monsoon rainfall, and the torrential rainfalls (July–September). With regards to the management of the areas more likely to be harmed by sedimentation, climate change is another important factor to take into consideration. The worries do not end there as the currently ongoing projects, as well as yet-to-be approved projects of water resource management and dams will all be impacted by the same problem of sedimentation. It is, therefore, important that immediate steps be taken to not only counter the current problem, but also to prevent it to the best possible extent in the future. This study concluded that knowledge of soil moisture is of high importance as it is one of the most important factors that can promote soil detachment. This information can also be very helpful for planning irrigation schedules, as well as for evaluating water and solute fluxes. To determine the soil moisture content, several different traditional techniques (gravimetric technique, radiological methods, and soil water dielectric), as well as some modern techniques (remote sensing) exist. Modern day techniques have a definite added advantage over the other outdated methods as remote sensing can provide almost real-time data, and, hence, is more efficient and effective.

Foreign exchange income is vital for most countries who want to either establish or maintain a strong economy, and this factor is of even more importance for developing countries such as Pakistan. Hence, even small alterations, better management, and an improved system for the water resource reservoirs can bear many fruits for the economy of Pakistan in terms of economic boost. The value of this study provides a better concept and insight on the complex link that exists between the area of vegetation, urban growth, and rainfall amount with the amount of soil detachment and sediment load in the reservoirs. With the passing time, burden may be placed on the current water resources of Pakistan due to an increasing population, which results in an increase in demand (Ahmed 2015; Hasan and Raza 2009; Singha et al. 2019). Hence, as discussed in this paper, the sedimentation problem that occurs in the water reservoirs can become a bigger hazard in the coming future. The results of the current research attest to the fact that sedimentation is decreasing when area of vegetation is increased (due to lesser soil erosion) in the watershed region. Unfortunately, a huge drawback in this current study was the unavailability of continuous satellite data for the area concerned with this study.

Further research and work is recommended to not only refine the understanding between vegetation, urban development, and rainfall with sedimentation load in the reservoir, but also to better grasp the concept of the relationship that exists between them. Efforts are being made in most parts of the world to extract the positive uses of water, while negating the destructive effects that this element of nature brings in our lives. This is being done extensively due to the firm belief that a country cannot grow successfully, and neither can poverty be eradicated properly, until the true potential of water resources of mother earth is utilized to its fullest. Hence, it is essential to make devise strategies that can counter the issue of sedimentation in the reservoirs. It can be concluded that vegetation growth is not only vital, but very effective for the reduction of sediment load in the watershed regions.

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