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Assessment of sedimentation in Pong and Bhakra reservoirs in Himachal Pradesh, India, using geospatial technique

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ABSTRACT

All water storage structures constructed on natural rivers are subjected to reservoir sedimentation. The reservoir sedimentation is filling of the reservoir behind a dam with sediment carried into the reservoir by streams. The sediment particles which originate from erosion processes in the catchment are propagated along with the river flow. When the flow of a river is stored in a reservoir, the sediment settled down in the reservoir and reduces its capacity. Decrease in the storage capacity of a reservoir beyond a limit hampers the purpose for which it was constructed. Therefore, assessment of sediment deposition becomes very important for the management and operation of such reservoirs. Some conventional methods, such as hydrographic survey and inflow-outflow approaches, are being used to estimate the sediment deposition in a reservoir, but these methods are tedious, time-consuming and costly. Consequently, in this study, a remote sensing data based digital image processing technique was used to assess the sedimentation in Pong and Bhakra reservoirs, located in foothill of Western Himalayas, India. Seven dates of IRS-(P6) LISS-III satellite data from maximum to minimum reservoir level were used to assess temporal and spatial patterns of reservoirs. The water spread areas of the reservoirs were assessed by using a band rationing technique i.e. Normalized Difference Water Index (NDWI). Furthermore, the revised capacities of the reservoirs between minimum and maximum levels were computed using the trapezoidal formula. From the analysis, it has been observed that the live storage capacity of Pong Reservoir, due to sedimentation, was estimated as 632.84 Mm^3 in last 35 years (1974–2009), whereas it was determined as 802.34 Mm^3 for Bhakra reservoir in the span of 46 years (1963–2009). Further, the sedimentation rate in the Pong reservoir was calculated as 18.08 Mm^3/year, while for the Bhakra reservoir it was 17.46 Mm^3/year. These sedimentation rates are comparable with the hydrographic survey analysis.

1. Introduction

Soil erosion is a serious problem in India. Soil erosion and sediment transport in a river basin are largely governed by topographical, meteorological, land cover, soil and drainage characteristics in the basin (Durbude and Purandara, 2005). The procedure of watershed erosion, sediment transport and its subsequent deposition in reservoirs is a widespread occurrence. Sediment is originated in the form of erosion due to natural as well as anthropogenic activities in the catchment and propagates along with the river flow. A large number of dams have been constructed in India since independence for hydroelectric power generation, irrigation, flood mitigation and domestic water supply, etc. Most of these reservoirs have been designed for a life period of 100 years or more. However, excessive siltation due to rapid erosion in the catchment is threatening to reduce the storage capacity of these reservoirs (Morris et al., 2008). The useful life and capacity of some of the reservoirs are being depleted faster than the projected rate, because of extensive soil erosion in their catchments. Despite more than six decades of research, sedimentation is still a most serious technical problem faced by the dam authorities of India. The suspended sediments or eroded sediments settle down in the reservoir bed and reduce the volume or storage capacity of that reservoir (Shalash, 1982; Fan and Morris, 1992; Durbude, 2014).

Annual sediment inflow into many of the reservoirs in India varies from 0.8 to 172 t/ha from the catchment (Dos et al., 1969), excluding few well protected catchments. Analysis of sedimentation survey details in respect of 43 major, medium and minor reservoirs in the country indicates that the sedimentation rate varies between 0.3 and 27.8 ha m/100 km^2/yr for major reservoirs to 1.0–2.3 ha m/100 km^2/yr for minor reservoirs (Shangale, 1991). On the basis of various soil loss studies from different land units and land uses, reservoir sedimentation data and river sediment discharge Narayana and Babu, 1983, estimated the

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magnitude of total soil erosion occurring in India. They reported that, on the country scale, approximately 5,334,000,106 t of soil (1640 t/km^2) is being annually eroded. The country's rivers carry an approximate quantity of 2052000106 t (626 t/km^2) of sediment annually. However, nearly 480,000,106 t are deposited in various reservoirs and 1,572,000,106 t are washed into the sea every year. In other words, about 29% of the total eroded soil is permanently lost to the sea, 10% is deposited in reservoirs resulting in loss of storage capacity of 1% – 2% per year, and 61% of eroded soil is being transported from one place to another (Narayana and Babu, 1983). Although these rates are approximations. However, soil erosion is a serious problem and integrated measures of soil erosion control are needed. On the basis of screening analysis of available data, Morris (1995) reported that some of the reservoirs in India have lost about 50% of their capacity till to date. By 2020, it is expected that 27 out of 116 reservoirs will have lost half of their original capacity and by the year 2050, 20% of existing reservoirs will have lost 50% of their capacity (Durbude and Purandara, 2005).

The periodic evaluation of sediment deposition pattern, its inflow-outflow analysis and the assessment of available live storage capacity are essential components of the optimum utilization of water. The conventional techniques of sediment quantification in a reservoir, i.e., hydrographic surveys and inflow-outflow methods are cumbersome, costly and time consuming. Further, prediction of sediment deposition profiles using empirical and numerical methods requires a vast data and the results are still not accurate (Jain and Goel, 2002). With the introduction of remote sensing techniques in the last few years, it has become very economical and easier to quantify sedimentation in a reservoir, to assess its distribution and deposition pattern. Remote sensing techniques are superior to the existing conventional methods, as it offers data acquisition over a long time period with a broad spectral range, (Jain et al., 2002). The remote sensing techniques provide a synoptic view of the reservoir in a different form which obtain surface data and sample. By using the digital analysis techniques and the geographic information system in conjunction, the temporal change in water spread area is analyzed to evaluate the sediment deposition pattern in a reservoir. Various studies have been carried out in the past, related to reservoir sedimentation, modelling of soil erosion etc. (Manvalan et al., 1991; Gupta, 1999; Mukherjee et al., 2007; Jain and Kothyari, 2000; Garg and Jothiprakash, 2009, 2010, 2013). But, No study has been made as such for estimation of reservoir sedimentation in these both the reservoirs using IRS based remote sensing data. The remote sensing based approach can be cost effective, easy to use and requires less time in analysing the data, compared to the conventional methods as discussed above. Keeping in mind the above mentioned problems and suitable solutions, the present study estimation of sediment deposition in Bhakra and Pong reservoirs, located on the Satluj and Beas Rivers in the foothills of the Himalayas, Himachal Pradesh, India, was carried out using remote sensing approach. In this study, multi dates of IRS P6 LISS-III satellite imageries were used to calculate the water spread area of these reservoirs.

2. Study area

The Pong and Bhakra reservoir, also known as Rana Pratap Sagar and Govind Sagar reservoir, which were constructed on River Beas and on river Satluj, respectively. Both of the reservoirs were constructed in the low foothills of Himalaya on the northern edge of the Indo Gangetic plain, located in the Kangra and Bilaspur districts of Himachal Pradesh, India. Pong reservoir lies between 31°59′02″ North Latitude and 76°03′12″ East Longitudinally, whereas Bhakra reservoir lies between 31°24′39″ North Latitude and 76°26′0″ East Longitudinally (Fig. 1). The climatic variability of the study area is erratic and it separates between dry (October-May) and wet (June to September) seasons. According to Indian Meteorological Department (IMD), the average annual rainfall of Kangra district is about 1800 mm, however it is about 1258 mm for Bilaspur district. Major land use types consist of forest, degraded forest, cropland, grassland and orchard. Forests are degraded in low mountain areas because of easy accessibility of the settlement areas located in lowlands (Shrestha et al., 2014). The characteristics and salient features of both the reservoirs are given below in Table 1.

2.1. Pong reservoir

The Pong Dam Lake, the highest earth-fill dam in India was constructed in year the 1975 on Beas River in the wetland zone of the Siwalik Hills of Kangra district, Himachal Pradesh, India. It named on the honor of patriot Maharana Pratap (1572–1597). The reservoir or the lake is a well-known wildlife sanctuary, and one of the 25 international wetland sites in India. The reservoir covers an area of 24,529 ha (60,610 acres) and the wetlands portion is about 15,662 ha (38,700 acres) (Raina and Petr, 1999). The Pong Dam impounds the Beas River just before the river descends to the plains at Talwara. It is an earth core gravel shell dam of 435 ft (132.6 m) height above the deepest foundation and is stated to be the highest earth fill dam in India. The Maharana Pratap reservoir has a storage capacity of 8570 M.cum. The designed maximum flood discharge of 4,37,000 cusecs (12,401 cumecs) is discharged through a gated chute spillway located on the left abutment of the dam (http://www.mcllo.com/pongdam.html).

2.2. Bhakra reservoir

Bhakra Dam is a concrete gravity dam, constructed in 1963, on the Satluj River in Bilaspur district, Himachal Pradesh, India. Bhakra dam controls the devastating floods and benefits to the irrigation and hydropower power generation. A huge lake has been created on the upstream side of the dam, called Gobindsagar reservoir, on River Satluj at Bhakra. It has enormous water spread area, extending over 168.35 km^2 at full reservoir level (515.11 m). Its head touches a point about 12.87 km above Slapper village near Kasol. The designed dead storage of this dam is about 2431.81 Mm^3, whereas live storage is about 7436.03 Mm^3. The total storage capacity of Bhakra dam is about 9867.84 Mm^3.

The Bhakra reservoir is fed by the consisting flows contribution from rain and melting of snow. Singh and Kumar (1997), have studied the precipitation distribution in various Himalayan river basins and found that the maximum contribution to annual rainfall is received during monsoon season (42–60%), whereas the minimum (5–10%) is received in post-monsoon season. Consequently, the reservoir attains its maximum water level just after the monsoon season. The water level of the reservoir gradually depletes due to various types of uses and reaches lower levels before onset of the subsequent monsoon. The Satluj River transports heavy amount of sediment, which diminishes the life of the reservoir. The massive siltation in the reservoir is occurred from this basin due to deforestation, over-grazing in the pasture lands, unscientific agricultural practices, farming at elevated terraces etc. (BBMB, 1997). This region is also very prone to landslides and slips, which is one of the major sources of sedimentation in this river. Further, the natural factors which attribute to high levels of sediment production in this region are steep topographic gradient, poor structural characteristics of soils; clay rich rocks such as Spiti shales and schists; and the widespread existence of limestone deposits (Sharma et al., 1991).

3. Material and methods

3.1. Data used

In this study, multi-dates, multispectral satellite images of IRS (P6) LISS-III sensor (Spectral bands: 0.52–0.59 (Blue); 0.62–0.68 (Green); 0.77–0.86 (Red); 1.55–1.70 (Near Infra-Red)) were used to estimate the water spread area of the reservoir at different reservoir levels. The