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ORIGINAL ARTICLE

Four decades of water and sediment discharge records in Subarnarekha and Burhabalang basins: an approach towards trend analysis and abrupt change detection

Sumit Das[1]

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Abstract
The outcomes of trend analyses, abrupt change detection of discharge, sediment load data of Subarnarekha River for the last four decades are presented in this paper and possible causes of these changes are discussed. Bivariate linear regression, Mann–Kendall non-parametric test, Pettitt test have been implemented on the daily discharge and sediment concentration data provided by Water Resources Information System of India (India-WRIS). A statistically significant decreasing trend of discharge is found in the Subarnarekha upstream, whereas other stations in downstream show an insignificant increasing trend during the past four decades. Sediment load shows a decreasing trend in the entire study area where the change is significant in downstream regions since last four decades. An abrupt downward shift on the discharge is found only in case of Muri station from the year 2000, located in the upstream of Subarnarekha main river. Abrupt changes on the sediment load were found in the downstream after the period of construction of dams on Subarnarekha River. More precisely, sediment load had started declining progressively from 1998 in the Subarnarekha River and since 2010 in its adjacent river, Burhabalang.

Keywords Water discharge · Sediment load · Mann–Kendall test · Trend analysis · Pettitt test · Subarnarekha · India

Introduction

Nowadays, water resource management is an increasing concern globally due to the rapidly expanding population growth and the anthropogenic effects on the river systems and other natural systems (Crutzen and Stoermer 2000; Meybeck 2001; Varis and Vakkilainen 2001; Maybeck 2003; Zhang et al. 2008; Das 2018, 2019; Das and Pardeshi 2018a, b). Several studies have been carried out since last few decades regarding the changes of river system, attributable to climate change and human activities (Nearing et al. 2005; He et al. 2008; Ghaffari et al. 2009; Li et al. 2009; Ouyang et al. 2010). Examination of a long-term trend of water discharge and sediment load can deliver an understanding of how climate change and human actions affect the drainage system (Walling 1997; Asselman 2000). Likewise, in future, water resource management will become easier by this understanding of changes in water and sediment flux through a long-term trend analysis (Walling and Fang 2003; Kundzewicz 2004).

The river geomorphology depends on its discharge and sediment load characteristics. The geomorphic attributes of a river can be affected due to the variations in the water discharge and sediment load. Several studies have reported such changes worldwide such as the Rhone River (Petit et al. 1996; Arnaud-Fassetta 2003), Wisloka River (Wyzga 1997), Cache Creek and Stony Creek (Collins and Dunne 1990; Kondolf 1997), the Yangtze River (Yang et al. 2003) and Pearl River (Zhang et al. 2008). There is a growing body of evidence pertaining to the significant reduction in sediment supply to the ocean due to the anthropogenic entrapments in dams and reservoirs which has resulted a noticeable change in geomorphological, hydrologic and ecological function of the river basins (Walling and Fang 2003; Chakrapani 2005; Syvitski et al. 2005; Panda et al. 2011). Zhang et al. (2008) demonstrated Mann–Kendall statistics to detect the long-term hydrological and sediment load change of Pearl River over a period of 1950–2004 by analyzing data from nine stations. Their study showed that there was a significant decreasing trend in sediment load which was mainly

✉ Sumit Das
sumit.das.earthscience@gmail.com

[1] Department of Geography, Savitribai Phule Pune University, Pune 411007, India

because of the construction of several numbers of reservoirs and dams. Decrease of sediment load with subsequent increase in coastal erosion appears to have severe inferences as coastal zones perform a vital role in economic activities.

Indian rivers can be categorized into two broad systems based on the tectonic origin (Himalayan and peninsular) and show a significant difference in the sediment production. The Gangetic system produces annual average sediment of 2390 t km^{-2} from constantly uplifting and erodible Himalayan range while the peninsular river systems produces 200–300 t km^{-2} sediment (Milliman and Meade 1983). The summer monsoon rainfall predominantly influences the stream flow, sediment transport and channel morphology of the tropical monsoon rivers (Kale 2002; Panda et al. 2011; Doke et al. 2018). The Himalayan rivers are perennial due to the glacial melts while the seasonal flow of peninsular rivers leads to construction of dams and reservoirs (Agarwal and Chak 1991). Although damming the rivers able to bring ample social benefits in terms of addressing water; the hydrological, geomorphic and ecological consequences have received scientific attention in these regions (Panda et al. 2011).

Subarnarekha can be considered as a distinctive tropical river. Many researchers have tried to understand the hydrological and sediment flux characteristics of many small tropical rivers, but an understanding of these characteristics of Subarnarekha River is still unknown. Therefore, an attempt has been made in this study to assess the changes in hydrological and sediment load trend of the Subarnarekha basin during the late Anthropocene period of last 40 years.

Study area

Subarnarekha–Burhabalang river basins are located in the eastern part of peninsular India, lying in Jharkhand, Odisha and West Bengal state, encompassing an area of 24,000 km^2 (Subarnarekha ~ 19,000 km^2 and Burhabalang ~ 5000 km^2) (India-WRIS 2012). Latitudinal and longitudinal extension of the study area is 21°15′–23°34′N and 85°08′–87°32′E (Fig. 1). The basins are bound by Chhota Nagpur plateau on the north and west. The ridges on the south are separating the Subarnarekha basin from Baitarani basin.

Subarnarekha and Burhabalang are the major river networks in the study area. Subarnarekha is a typical rejuvenated river having a length of about 450 km, experiencing a steady tectonic uplift (Guha and Patel 2017). All the streams within Subarnarekha basin are flow eastward and fall into the Bay of Bengal. Based on the elevation map, in the study area, elevation varies from 0 to 1172 m above sea level (Fig. 2). Prominent hills within Subarnarekha basin

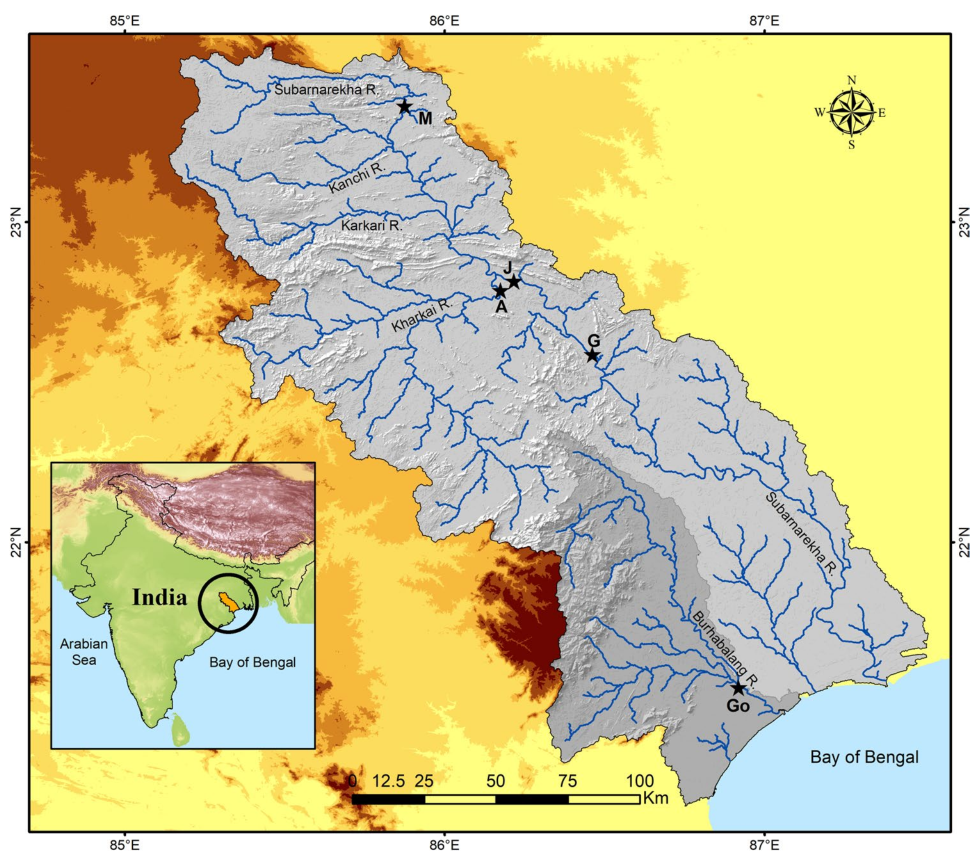

Fig. 1 Geographic location of Subarnarekha basin and the hydrological stations. (Hydrological stations: M. Muri; A. Adityapur; J. Jamshedpur; G. Ghatsila; Go. Govindpur.) Notice the darker shade of the Burhabalang basin which is a relatively small adjacent river basin of Subarnarekha

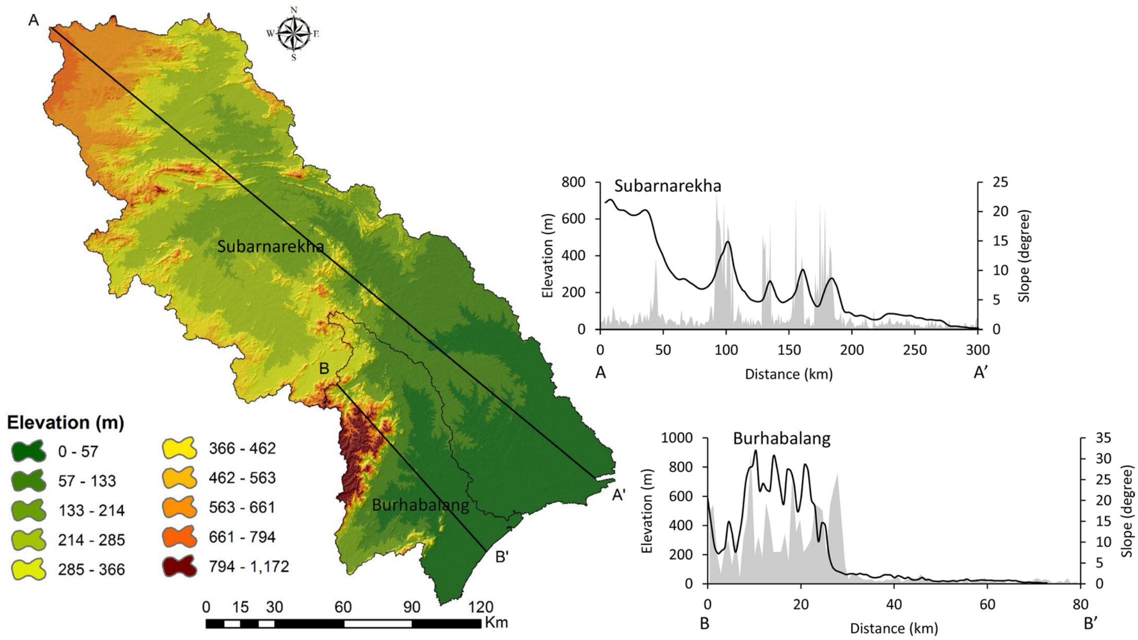

Fig. 2 Digital elevation model of the study area representing the altitudinal variation. The graphs indicate the longitudinal altitude and slope variation along the lines. The black line on the graph indicates elevation and the gray color represents slope

are located above an elevation of 450 m from mean sea level and flanked by denudation scarps situated at an elevation of 300–450 m (Guha and Patel 2017). From the geomorphic perspective, the study area can be categorized in three distinct broad physiography: the hilly region in the west from where the rivers originate, the undulating topography in the central and the coastal lowland with very low regional slope (Fig. 2).

Mainly three prominent geological formations in the study area are Archaean–Precambrian metamorphic rock, Tertiary, and Quaternary alluvium. In the upper Subarnarekha basin, major rock types are granite and quartzite and the lower section shows mainly vast deposition of sediments (Geological Quadrangle maps for Subarnarekha region, Geological Survey of India).

Climatically, the study area shows typical monsoonal characteristics where heavy rainfall occurs in monsoon months (June–Sept). During non-monsoon period rainfall is very less in the study area. The average annual rainfall in the study area ranges between 1100 and 1400 mm (Chatterjee et al. 2014).

Site description

Geomorphic characteristics of a river channel can easily be addressed through analyzing longitudinal profile of the river. Figure 3 presents the longitudinal profiles of Subarnarekha main channel and its tributaries on which hydrological stations are located. The transverse profiles on the longitudinal profile are representing the channel cross sections of each site. The Subarnarekha main channel shows higher relative steepness compared to the other two tributaries and all the hydro-observation stations are located below an elevation of 300 m.

Data and methodology

Hydro-geomorphic characteristics of Subarnarekha River have been assessed in this study by analyzing discharge and suspended sediment concentration data of five gauging stations. Water discharge (Q_d), suspended sediment concentration (Q_s), and cross-sectional data of five hydrological stations are collected from Water Resources Information System in India (India-WRIS). The detailed information regarding the hydrological stations is presented in Table 1.

Initially, to understand the hydro-geomorphic condition of Subarnarekha river basin, daily discharge and sediment concentration data have been used for the calculation of monthly mean discharge and sediment load pattern, annual discharge, annual sediment load, and sediment yield for all the stations. Later, the trends of discharge and sediment load have been calculated by implementing bivariate linear regression, Mann–Kendall non-parametric tests. The homogeneity analysis has been performed to detect the change-points in the time-series data through Pettitt test. A detailed information and procedures are discussed below.

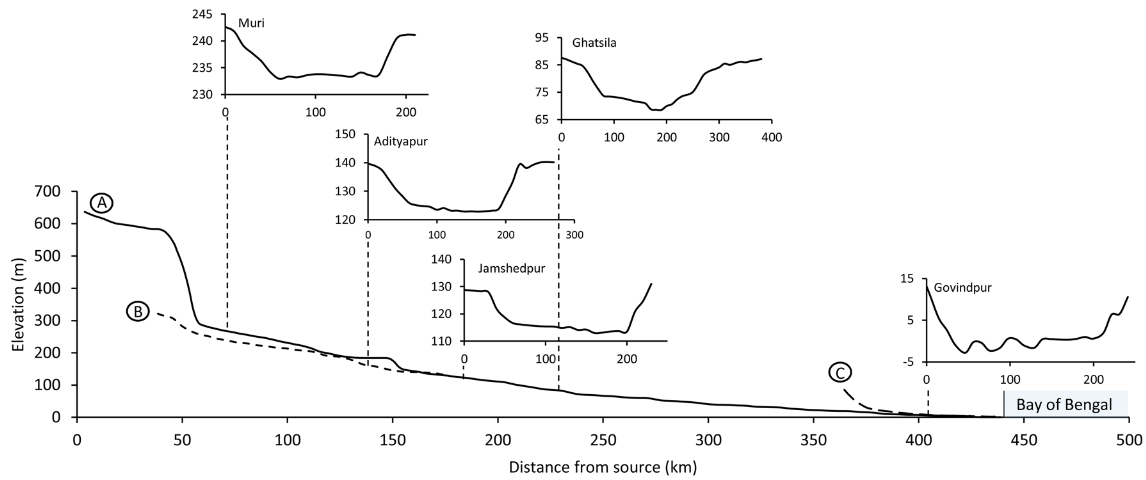

Fig. 3 Longitudinal profile of the Subarnarekha main channel and other tributaries where hydrological stations are located. Transverse profiles represent cross section of each site. Scale of both axes of transverse profiles is in meters. (Channel names: A. Subarnarekha River; B. Kharkai River; C. Burhabalang River.)

Table 1 General information of all hydrological stations in Subarnarekha basin

Station name	Lat (N)	Long (E)	Elevation (m)	Upstream area (km^2)	Q_d data availability	Q_s data availability	Mean discharge (10^9 m^3)[a]	Mean sediment load (10^6 t)[a]	Sediment yield (t km^{-2} year^{-1})[a]
Muri	23°21′46″	85°52′29″	231	1330	1992–2013	Not available	0.65	Not available	Not available
Adityapur	22°47′10″	86°10′28″	123	6309	1974–2013	1976–2013	2.75	1.22	192.69
Jamshedpur	22°48′56″	86°12′58″	111	12,649	1972–2003	1973–2013	6.87	3.01	237.79
Ghatsila	22°35′08″	86°27′42″	72	14,176	1971–2013	1973–2013	6.81	3.67	258.78
Govindpur	21°32′41″	86°55′07″	5	4495	1992–2013	2004–2013	3.37	1.15	254.97

Q_d water discharge, Q_s sediment load

[a]Data calculated in the present study

Mann–Kendall test

To determine the trend of discharge and sediment load, non-parametric test as Mann–Kendall (MK) is performed. Zhang et al. (2008) suggested that non-parametric tests are more ideal than parametric tests because of their ability to handle non-normally distributed data or missing data. The Mann–Kendall equation is as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(X_j - X_i), \tag{1}$$

where X_i and X_j are data values, n represents the length of time-series, and:

$$\operatorname{sgn}(\theta) = \begin{cases} 1 & if \quad \theta > 0 \\ 0 & if \quad \theta = 0 \\ -1 & if \quad \theta < 0 \end{cases}. \tag{2}$$

Mann (1945) and Kendall (1975) explained that when $n \geq 8$, S is almost normally distributed with the subsequent mean and variance:

$$E(S) = 0, \tag{3}$$

$$V(S) = \left\{ n(n-1)(2n+5) - \sum_{i=1}^{p} t_i i(i-1)(2i+5) \right\} / 18, \tag{4}$$

where t_i is the number of ties to the extent i. The statistics S is approximately normal distributed provided that the following Z transformation is employed:

$$Z_{\mathrm{MK}} = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var}(S)}} (S > 0) \\ 0 (S = 0) \\ \frac{S+1}{\sqrt{\mathrm{Var}(S)}} (S < 0) \end{cases}, \tag{5}$$

where Z_{MK} pursues the standard normal distribution with $\mu = 0$ and $\delta = 1$.

The statistics S is closely related to the Kendall's τ is given by:

$$\tau = \frac{S}{D}, \tag{6}$$

where

$$D = \left[\frac{1}{2}n(n-1) - \frac{1}{2}\sum_{i=1}^{p} t_i i(i-1)\right]^{\frac{1}{2}} \left[\frac{1}{2}n(n-1)\right]^{\frac{1}{2}}. \tag{7}$$

The rate of change (regression slope) for the non-parametric test can be assessed by Sen's slope estimator method. The linear slope is calculated as follows:

$$d_k = \frac{X_j - X_i}{j - i}, \tag{8}$$

where d is the slope, X_i and X_j are values at times i and j, $(1 \le i < j \le n)$ n is number of variables.

Pettitt test

The Pettitt test is used to detect a change-point considering sequence of random variables $X_1, X_2, \ldots, X_t$, which have a change-point at τ (X_t for $t = 1, 2, \ldots, \tau$, have a common distribution function $F_1(X)$ and X_t for $t = \tau + 1, \ldots, T$, have a common distribution function $F_2(X)$, and $F_1(X) \neq F_2(X)$) (Pettitt 1979) (cited by Wolfe and Schechtman 1984; Zhang et al. 2008; Memarian et al. 2012). It tests the null hypothesis (H_0) as the T variables follow one or more distributions that have the same location parameter (no change), against the alternative hypothesis (H_a) where a change-point exists. The non-parametric statistics are as follows:

$$K_T = \max\left|U_{t,T}\right|, \tag{9}$$

where

$$U_{t,T} = \sum_{i=1}^{t} \sum_{j=t+1}^{T} \operatorname{sgn}(X_i - X_j). \tag{10}$$

The change-point of the series is located at K_T, provided that the statistics are significant. The significance probability of K_T is approximated for $p \le 0.05$ with

$$p \simeq 2\exp\left(\frac{-6K_T^2}{T^3 + T^2}\right). \tag{11}$$

The statistical trend of the data was based on 95% confidence level. The above procedure was performed using XLSTAT software package.

Results and discussion

Monthly discharge and sediment load pattern

Based on the daily hydrological and suspended sediment data, the calculated graphs indicate that the Subarnarekha River is highly seasonal, and high water discharge can be seen during monsoon months (June–Sept) compared to other seasons (Fig. 4). As the monsoon season ends, the runoff in all the streams within study area decline significantly. Therefore, Subarnarekha is a distinctive seasonal river exhibit monsoonal characteristics.

Sediment load in Subarnarekha is very high during Aug and Sept months, which is attributable to the seasonal discharge pattern. During the dry season, in situ weathering process predominates; whereas erosional process becomes very active and yields a gigantic amount of sediments during monsoon season. A yearly yield of sediment in the Subarnarekha basin is varying between 200 and 260 t km^{-2} year^{-1} for all the stations. Sediment yield is higher in the downstream stations (Ghatsila and Govindpur) as many small tributaries join the trunk stream in between upstream stations, transporting a significant amount of sediments. Abundant sediment supply from the hillslope regions are the major sources of sediments which results remarkably high sediment yield in a river channel (Oguchi et al. 2001). Yoshikawa (1974) indicated that the sediment yield in a steep mountainous tropical river can exceed 1000 t km^{-2} year^{-1}. The Brahmaputra drains more than 500 million t km^{-2} year^{-1} ranks first among the world's river in terms of sediment yield (Tandon and Sinha 2007). However, for small watersheds the sediment yield remains much lower (Ohmori 1983; Millman and Syvitski 1992). In a tectonically active environment, where uplift rate is very high, rivers show very high stream power and produce a large volume of sediment each year (Hovius 1998). In India, the Ganga, Brahmaputra drains exceptionally high volume of sediment due to the tectonically active environment (Tandon and Sinha 2007). However, the only exception is Godavari which shows high sediment yield despite the cratonic configuration (Tandon and Sinha 2007). Compared to these large river systems, Subarnarekha and Burhabalang shows a significant sediment yield due to its mountainous erosional environment in the upper reach and the hill-slope processes, contributing a greater amount of sediment.

Water discharge (Q_d) trend

Table 2 shows the results of trend analysis of discharge using linear bivariate regression and Mann–Kendall

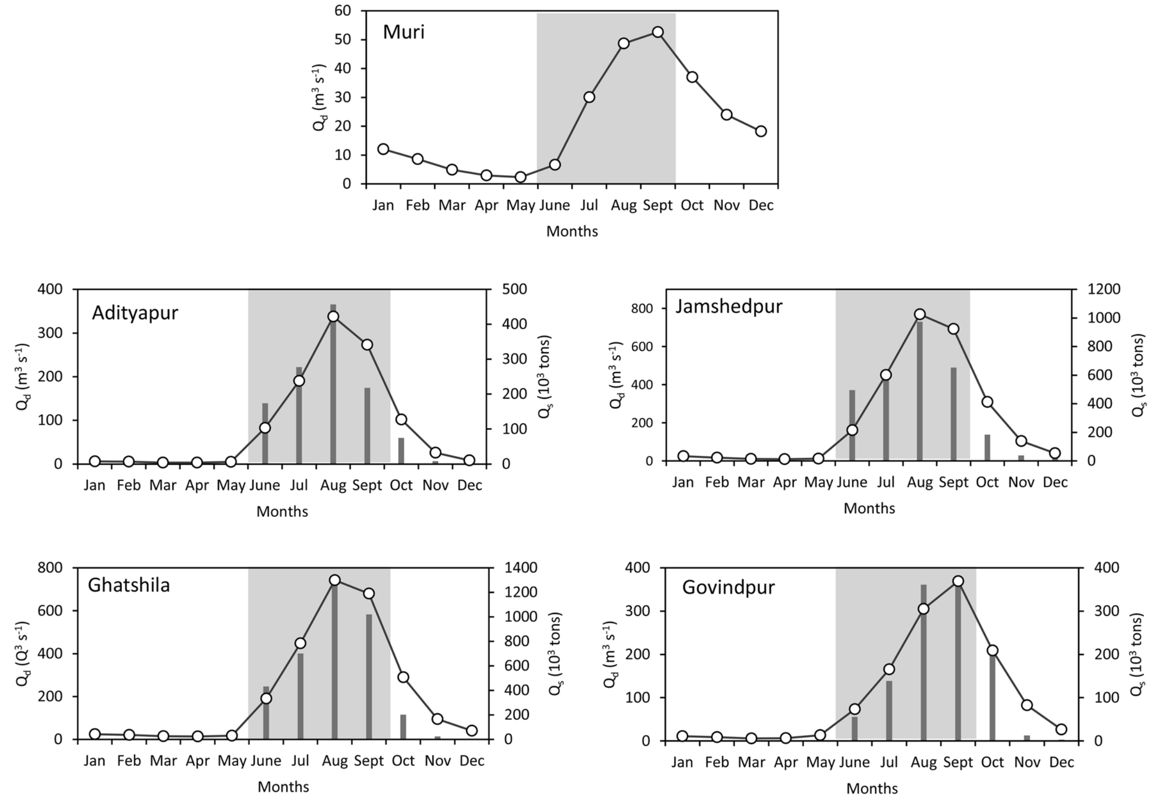

Fig. 4 Monthly mean water discharge and sediment load pattern for all hydrological stations

Table 2 Results of trend analysis of discharge (Qd) for Subarnarekha River

Station name	Mann–Kendall's non-parametric test			Linear regression coefficient	
	Kendall's Tau	Sen's slope	Trend	Exponent (b)	Trend
Muri	− 0.493	− 0.029	(−)[a]	− 0.0283	(−)[a]
Adityapur	0.097	0.013	(+)	0.0133	(+)
Jamshedpur	− 0.024	− 0.014	(−)	− 0.0050	(−)
Ghatshila	0.125	0.048	(+)	0.0434	(+)
Govindpur	0.247	0.080	(+)	0.0678	(+)

[a] indicates statistics which are significant at 95% confidence level

non-parametric tests for five major hydrological stations in the Subarnarekha basin for a time span of about 40 years. Discharge pattern in Subarnarekha is reasonably complicated as few stations show an increase and few others show decrease in the hydrological regime in last four decades. However, a statistically significant decrease of the Q_d is found only in case of Muri station (Fig. 5). Barring this, all the other stations show insignificant trends. Adityapur and Ghatsila show a positive, but an insignificant trend of Q_d, while Jamshedpur, located in the middle of these two stations shows a negative rate. The explanation of this anomaly lies in the locational settings of the Adityapur and Jamshedpur stations. Adityapur hydrological station is located at the outlet of Kharkai River, a major right-hand tributary of Subarnarekha. By contrast, Jamshedpur is situated on the mainstream of Subarnarekha about 8–10 km downstream of the confluence of Kharkai and Subarnarekha. The negligible rate of change of discharge in Adityapur (− 0.005) indicates the mainstream above the confluence of Kharkai and Subarnarekha have a very low flow regime which supports the significant declining Q_d trend in Muri station. This observation clearly indicates that the main channel of Subarnarekha is a contributing lesser amount of water compared to its major upstream tributaries such as Kanchi, Karkari and Kharkai. Govindpur station on Burhabalang River shows an insignificant decreasing trend of Q_d.

Numerous studies have been carried out by many researchers to understand the rainfall pattern of this area since last two decades. Kumar and Jain (2011) reported that an increasing trend of rainfall is found in Subarnarekha basin during the period of 1951–2004. Few other researchers have carried out subdivision and state-wise rainfall trend analysis, where they reported a significant decreasing trend in Jharkhand region from where Subarnarekha originates

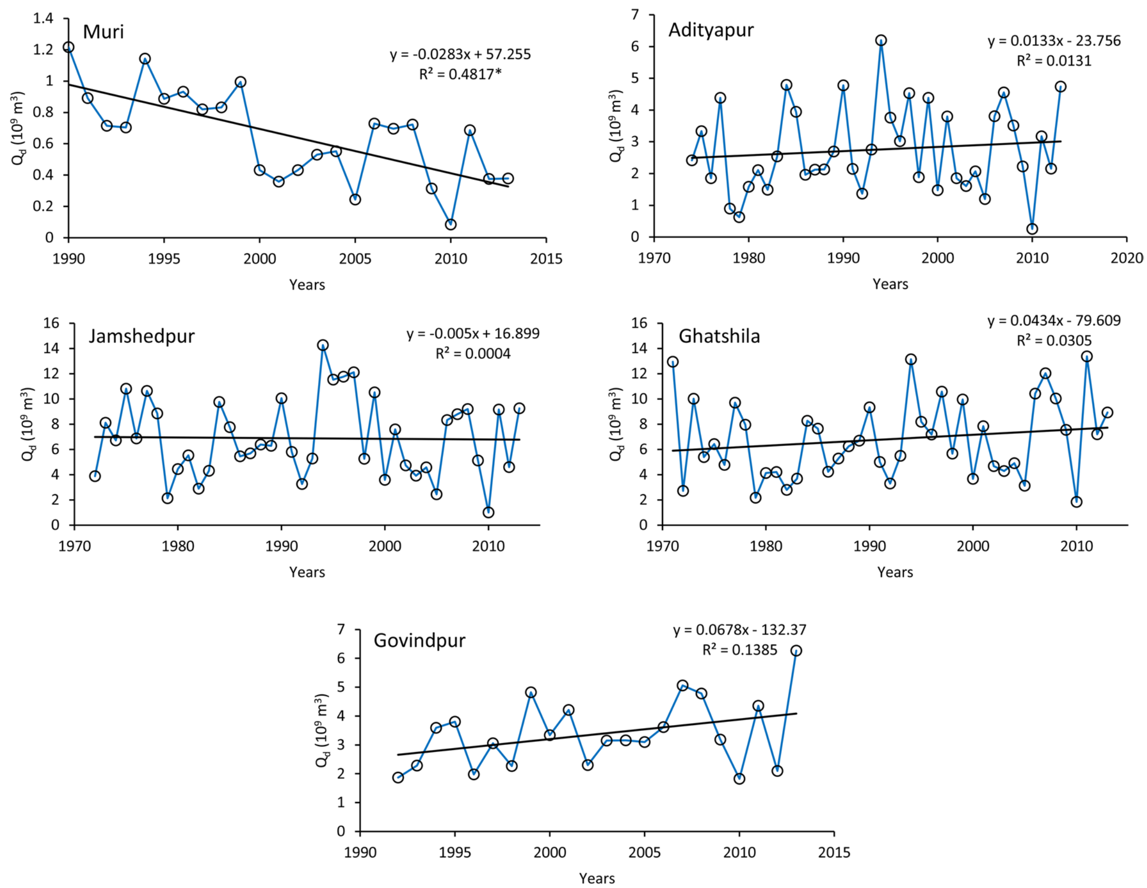

Fig. 5 Temporal variation and linear trends of average yearly discharge (Q_d). *Significant at 95% confidence level

Table 3 Results of trend analysis of sediment load (Qs) for Subarnarekha River

Station name	Mann–Kendall's non-parametric test			Linear regression coefficient	
	Kendall's Tau	Sen's slope	Trend	Exponent (b)	Trend
Adityapur	−0.266	−0.277	(−)[a]	−0.0396	(−)[a]
Jamshedpur	−0.149	−0.030	(−)	−0.0552	(−)
Ghatshila	−0.341	−0.095	(−)[a]	−0.1033	(−)[a]
Govindpur	−0.378	−0.163	(−)	−0.1591	(−)[a]

[a] indicates statistics which are significant at 95% confidence level

(Rajeevan et al. 2006; Guhathakurta and Rajeevan 2008). All these studies suggest that climate change (rainfall variation) may have a strong influence on the discharge regime in Subarnarekha and its adjacent Burhabalang River.

Sediment load (Q_s) trend

Table 3 shows the results of trend analyses of Q_s for all the major hydrological stations except Muri (Muri: data unavailable). The results indicate that in the last few decades, the Q_s of Subarnarekha has been decreased (Fig. 6). In case of Adityapur and Ghatshila, this trend is statistically significant. A report by Panda et al. (2011) indicates that there is a negative change in the sediment load of the tropical rivers in India (i.e., Godavari, Krishna, Mahanadi, Narmada, Tapi, Mahi), indicates the recent climate variability and its interaction with the human activities. The early report shows that almost all the peninsula rivers are experiencing a decrease in sediment load during the last few decades, while in few rivers the change is significant (Panda et al. 2011). The reason behind declining trend in sediment discharge in Subarnarekha may be due to the potential anthropogenic factors and the impact of climate change (variation of precipitation) on sediment load which (the exact reason) is very hard to recognize without additional analysis. Long-term trends of Q_s of a river depends on several factors such as climate attributes, lithology and geological setting of an area, land-use practice, and water conservation projects as a dam or reservoir construction. Panda et al. (2011) advocates that for all the peninsula tropical Indian rivers, the sediment supply is

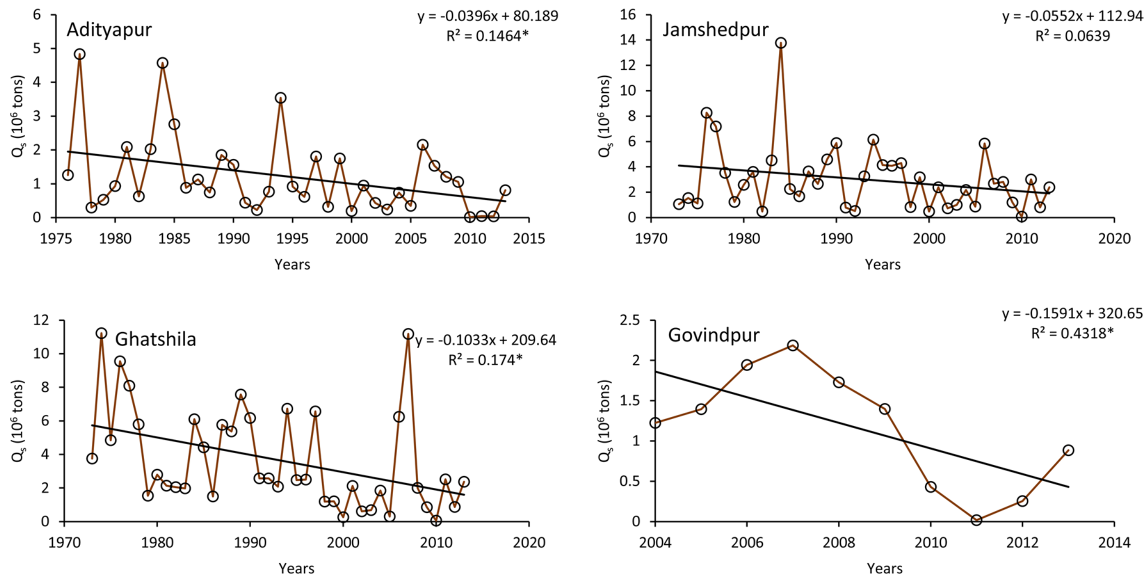

Fig. 6 Temporal variation and linear trends of average yearly sediment load (Q_s). *Significant at 95% confidence level

Table 4 Results of abrupt change-points of discharge (Q_d) and sediment load (Q_s) in Subarnarekha River

Station name	Parameters	Pettitt homogeneity test			
		KT	P	Shift	Change-point (year)
Muri	Q_d	132	0.0001	Downward	2000
	Q_s	–	–	–	–
Adityapur	Q_d	115	0.452	–	–
	Q_s	161	0.071	–	–
Jamshedpur	Q_d	110	0.599	–	–
	Q_s	182	0.072	–	–
Ghatshila	Q_d	144	0.318	–	–
	Q_s	266	0.001	Downward	1998
Govindpur	Q_d	53	0.281	–	–
	Q_s	24	0.006	Downward	2010

The statistics is presented at 95% confidence level

significantly low during drought years. Abrupt reduction of the sediment load can be attributed to the construction of dams which can entrap up to 60–80% of the sediment load (Gupta and Chakrapani 2005; Yang et al. 2006). According to the CWC report, totally 36 dams have been constructed in last four decades in which a large dam has been built in the upstream of Subarnarekha main channel and several small dams and reservoirs are made in other tributaries. Perhaps there is a severe impact of these dams for declining sediment load in the downstream only if a significant proportion of sediment gets deposited in this dam's reservoir.

Change-point detection

Table 4 attributes the results of homogeneity analysis of Q_d and Q_s data by implementing Pettitt test to find out the abrupt changes in the time-series. Muri shows a significant abrupt downward change for Q_d in the year 2000 (Fig. 7). Other hydrological stations do not exhibit any such change for Q_d.

Sediment load at downstream of both Subarnarekha (Ghatshila) and Burhabalang (Govindpur) show statistically significant abrupt change from 1998 and 2010, respectively (Fig. 8). However, Q_s at Adityapur and Jamshedpur does not show any abrupt change during last four decades. Variation of Q_s in Subarnarekha downstream indicates two episodic manners of sediment discharge pattern. Most of the dams in the study area have been built during the period of 1980–1990s. Therefore, it clearly indicates the impact of dam construction on the sediment load pattern, as all the change-points are found post-dam construction period on the Subarnarekha River.

Double mass plot has been instigated to understand the changes in the ratio of Q_s and Q_d in Subarnarekha (Ghatshila) and Burhabalang River (Govindpur). In case of Ghatshila, the Q_d–Q_s ratio shows a steeper regression slope (0.53) after 1997 when the extreme outliers are considered; otherwise the regression slope is declining, while the slope is 0.43 before the change-point (Fig. 9). Govindpur station shows an opposite scenario, where before 2009 the regression slope is steeper (0.33). These results imply

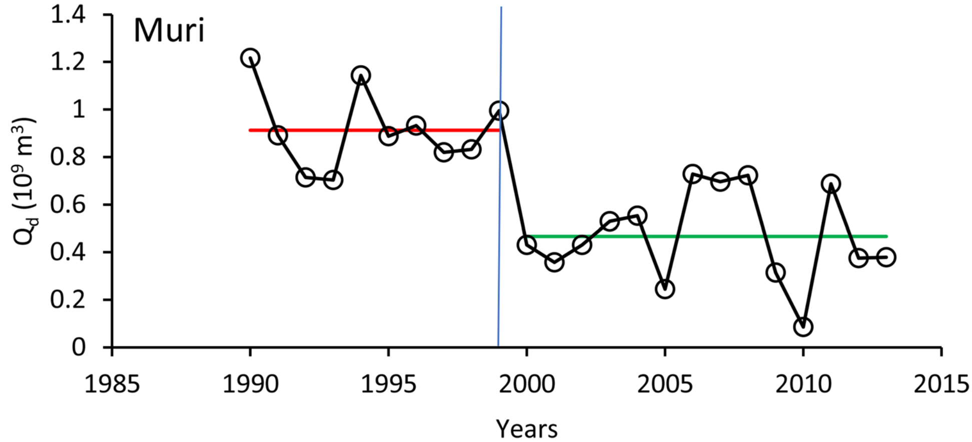

Fig. 7 Abrupt change in water discharge (Q_d). Significance at 95% confidence level

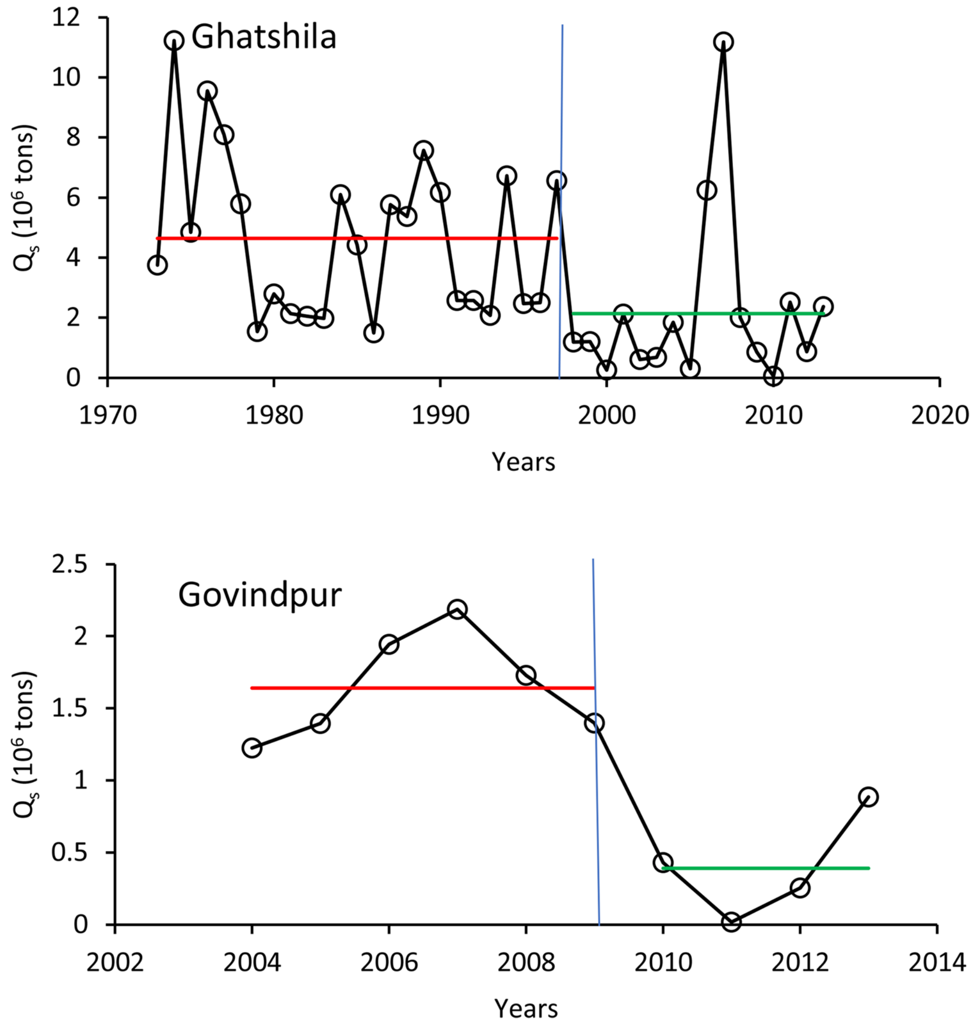

Fig. 8 Abrupt changes in sediment load (Q_s). Significance at 95% confidence level

that in recent times the water discharge and sediment load ratio is increasing in the downstream of Subarnarekha River. By contrast, Burhabalang River is experiencing a decrease in the ratio of water discharge and sediment load.

The fourth assessment of the Intergovernmental Panel on Climate Change (IPCC) prognosticated that sea-level rise with rainfall variability may intensify the coastal ecosystem for the densely populated river basins of Asia (Cruz et al.

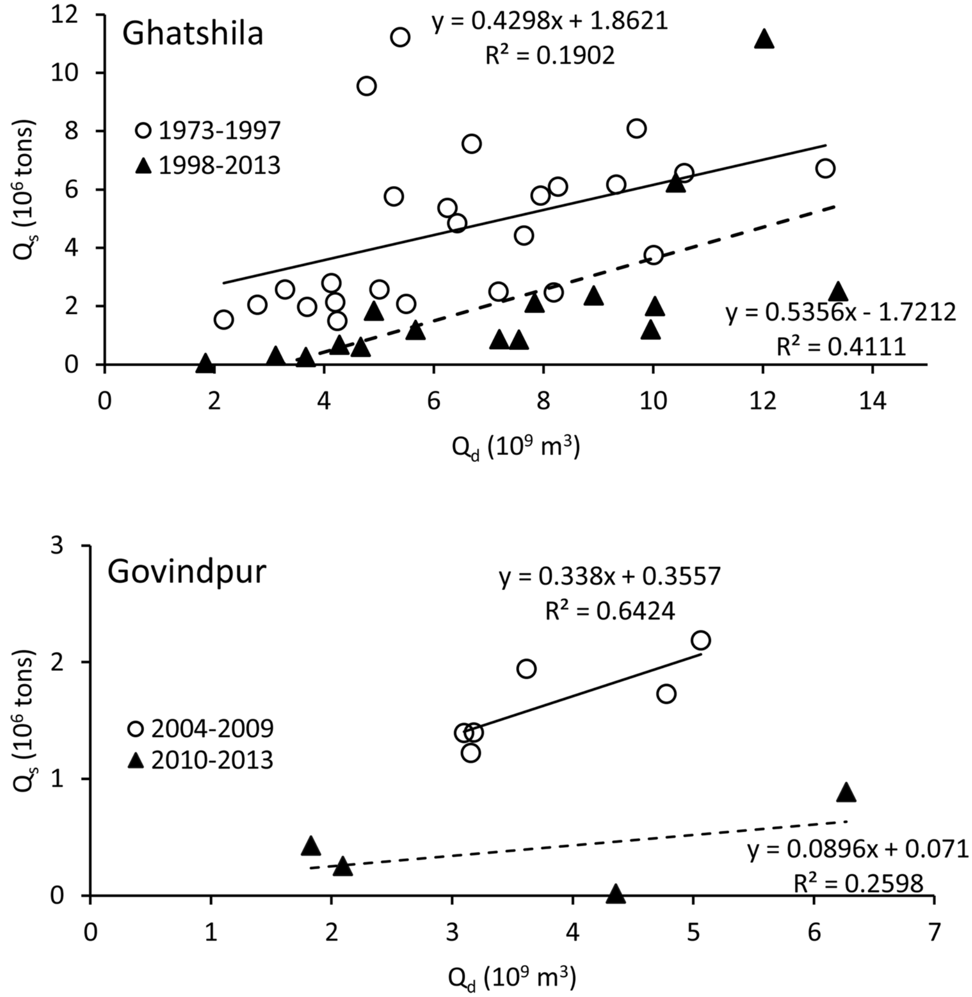

Fig. 9 The relationship between yearly discharge and sediment load for Ghatshila and Govindpur hydrological station, before and after the abrupt change

2007). With the rising sea level in Indian coast (Unnikrishnan and Shankar 2007), the reduction of sediment supplies in the Subarnarekha and Burhabalang rivers appears to have made the coastal regions more vulnerable to coastal erosion. Malini and Rao (2004) indicate that the adjacent second largest river system in India, Godavari River was the 9th largest sediment transporting river on a global scale. However, a change-point is found during the period of 1990–1998 due to the construction of dams and after that the sediment load has been declined significantly. Hence, all the declining rates of sediment and the increasing anthropogenic activities with climatic variability likely to cause coastal erosion due to loss of mangrove vegetation and the displacement of the human habitation in the near future (Malini and Rao 2004; Rao et al. 2008; Gamage and Smakhtin 2009; Panda et al. 2011; Wang et al. 2011).

Conclusion

A very detailed assessment of water and sediment discharge is carried out in this study, which provides a few interesting results regarding the changes of discharge and the sediment flux pattern of the Subarnarekha basin since last few decades. Bivariate linear regression, Mann–Kendall non-parametric test, and Pettitt test have been applied in the data sets of past 40 years to identify the trends and abrupt changes in the discharge and sediment load using the data provided by WRIS-India. A statistically significant decreasing trend of discharge and downward abrupt change is found in the upper reach of the Subarnarekha River (Muri station). The downstream reach of the study area shows an insignificant but increasing trend of discharge which has been impacted by precipitation variation in the past few decades. Sediment load at all the stations show decreasing trend for past few decades. Not all the changes are statistically significant, but stations located at downstream of the Subarnarekha and Burhabalang have shown a significant decreasing trend at 0.05 level of confidence. The results of this study divulge clear signals of the declines in sediment load which may be attributed to the impact of recent climate change and its interaction with anthropogenic activities in the study area. However, additional research is essential to enumerate the relative influences of different factors that regulate the sediment load and variability in Subarnarekha and Burhabalang rivers. Based on the substantial results found in this present study, the regions where sediment load is declining significantly, policy measures are essential to be commenced for the environmental flow requirements to protect the ecology and geomorphology of the densely populated regions and coastal environment.

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