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Research article

Quantification of annual sediment deposits for sustainable sand management in Aghanashini river estuary

T.V. Ramachandra [a, b, c, *], S. Vinay [a], M.D. Subash Chandran [a]

[a] Energy & Wetlands Research Group, Centre for Ecological Sciences (CES), Indian Institute of Science, Bangalore, Karnataka, India[1]
[b] Centre for Sustainable Technologies (astra), Indian Institute of Science, Bangalore, Karnataka, India
[c] Centre for Infrastructure, Sustainable Transportation and Urban Planning (CiSTUP), Indian Institute of Science, Bangalore, Karnataka, India

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ABSTRACT

Sedimentation involving the process of silt transport also carries nutrients from upstream to downstream of a river/stream. Sand being one of the important fraction of these sediments is extracted in order to cater infrastructural/housing needs in the region. This communication is based on field research in the Aghanshini river basin, west coast of India. Silt yield in the river basin and the sedimentation rate assessed using empirical techniques supplemented with field quantifications using soundings (SONAR), show the sediment yield of 1105–1367 kilo cum per year and deposition of sediment of 61 (2016) to 71 (2015) cm. Quantifications of extractions at five locations, reveal of over exploitation of sand to an extent of 30% with damages to the breeding ground of fishes, reduced productivity of bivalves, etc., which has affected dependent people's livelihood. This study provides vital insights towards sustainable sand harvesting through stringent management practices.

1. Introduction

Roots of vegetation bind the soil, which helps in arresting soil erosion. However, indiscriminate removal of tree cover has altered the landscape integrity resulting in the transport of surface soil particles that gets deposited in the river bed and estuaries. Nutrient rich sediment supports numerous aquatic life forms, which is evident from high ecosystem goods from estuaries. Soil erosion and subsequent sedimentation is the result of complex processes (Fig. 1) involving (i) frosting and thawing action of rocks, (ii) removal of vegetation cover and transportation of surface soils ((NIH Roorkee, 2000; Bishop et al., 2002; Chandramohan and Durbude, 2002; Zhang et al. 2008). These processes are influenced by climatic, topographic, geologic, geomorphic, land use characteristics and aggravated by anthropogenic activities such as deforestation, urbanization and agricultural intensification (Bhattarai and Dutta, 2005). These deposits with suspended inorganic matter, suspended organic matter, phytoplankton, dissolved organic matter and detritus (Kondratyev and Filatov, 1999) forms an essential component of fresh water ecosystem (Turley et al., 2016) and play an important role in (i) protecting the environment, (ii) supporting aquatic life forms by providing habitat that acts as feeding, roosting and breeding grounds, (iii) natural barrier against waves, and (iv) anthropogenic activities such as all constructions activities, recreation, etc. (Saviour, 2012). Nevertheless, enhanced anthropogenic activities have led to modification in sediment levels impacting physical, chemical and biological characteristics of an ecosystem (Wood and Armitage, 1997; Turley et al., 2016).

Large volume of sediments from the river catchment during precipitation, gets transported to the downstream river bed, lakes, reservoirs, estuaries, etc., which reduces the storage capacity while affecting the biotic life (Katiyar et al., 2006). This necessities periodic removal of deposited sediments to mitigate the problems such as (i) tendency of increasing flood plains (Kothyari et al., 2002), (ii) decreasing storage capacity due to increasing bed level (iii) displacement of mouth of estuaries. However, removal of deposited sediments needs to be lower than the quantity yielded during the period in the catchment to minimize impacts of over exploitation. This requires the knowledge of the quantity and also the rate of

* Corresponding author. Energy & Wetlands Research Group, CES TE15, Centre for Ecological Sciences, Indian Institute of Science, Bangalore, 560012, India.
E-mail address: cestvr@ces.iisc.ernet.in (T.V. Ramachandra).
URL: http://ces.iisc.ernet.in/foss
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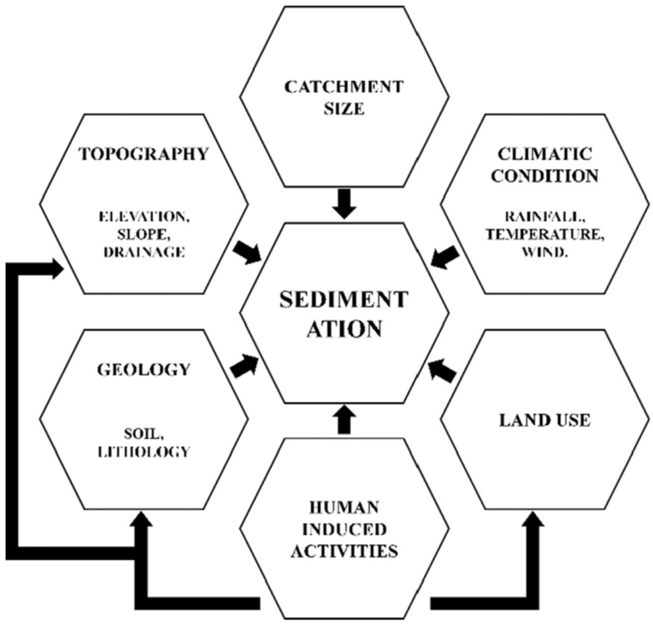

Fig. 1. Factors of the sedimentation process.

sedimentation in the rivers. Land use analyses carried out using the temporal spatial data acquired through space borne sensors shows about 500 m shift in Sharavathi river mouth in Uttara Kannada between 1973 and 2016 (Ramachandra et al., 2016). Fig. 2 outlines the environmental impacts associated with the over exploitation of sediments that can be classified under two categories *viz*. offsite and onsite impacts (Kitetu and Rowan, 1997). Onsite impacts can be further classified as excavation impacts and water supply impacts (Sunil Kumar 2002, UNEP, 1990; Padmalal et al., 2003, MoEFCC). The devastating effects on ecosystems including the alterations in the very integrity of water bodies due to the indiscriminate sand mining in the past have led to the formulation of norms to ensure sustainable management of resources through policy interventions. This includes constitution of vigilance committee, identification of locations for extraction, time restriction with ban on extraction during late evening and during monsoon period, automation towards monitoring sand extraction, transportation, storage and disposal. GPS enabled trucks and other carriers helped in monitoring sand extracted at each site. Table 1 provides the summary of the norms as per various agencies such as Department of Mining and Geology, Government of Kerala, Directorate of Geology and Mining, Government of Maharashtra, MoEFCC (The Ministry of Environment, Forests and Climate Change), Geological Survey of India, District Sand Mining Commission-CRZ Uttara Kannada district.

There are hardly any scientific investigations in the west flowing rivers of Karnataka on the impact of sand mining on environment. This study profiles sand mining in the upstream portion of Aghanashini estuary, which experiences relatively lower salinities during the post and pre-monsoon times. Sand extraction has been taking place here in unprecedented scales, and the current study attempts quantification of the extracted sand. This

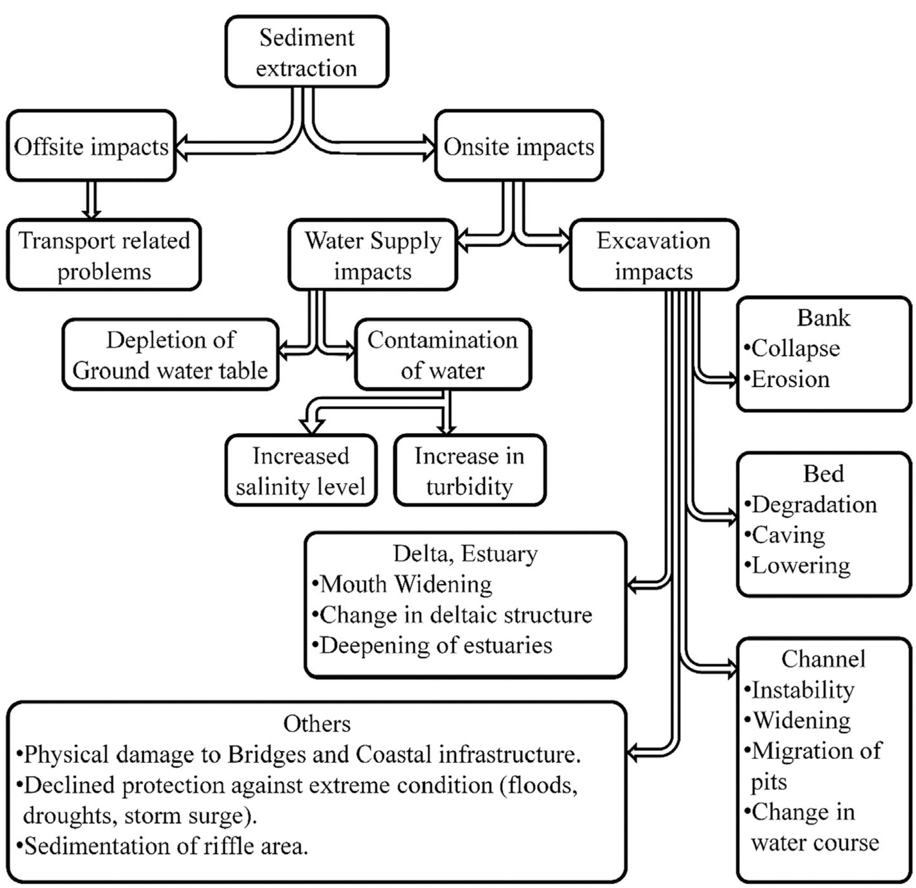

Fig. 2. Impact of over exploitation of sediments.

Table 1
Norm/Policies as per various agencies.

Sl. no	Description	Govt. of Kerala	Govt. of Maharashtra	MoEFCC	GSI	District Mining Commission-CRZ, Uttara Kannada
1	Creation of No Development Zones (NDZ)		Y	Y		
2	Fixing of time for silt removal	Y				Y
3	Fixing of sand removal location	Y	Y	Y	Y	Y
4	Fixing vehicle loading points	Y				Y
5	Restriction on mechanized removal	Y				Y
6	Restriction or ban on sand removal	Y			Y	Y
7	Different stretch of rivers different regulations and extractions based on yield		Y		Y	Y
8	Flood Plain protection				Y	
9	Creating awareness among the stake holders					
10	Afforestation/Maintain the vegetation cover	Y	Y	Y		
11	Continuous Monitoring	Y	Y	Y		
12	Minimum depth of sand bed to be maintained					Y

Note: Govt.: Government; MOEFCC: The Ministry of Environment, Forests and Climate Change; GSI: Geological Survey of India; CRZ: Coastal Regulatory Zone.

helps to develop sand inflow model for Aghanashini River and arrive at sand extraction in optimal quantities. Estimation of sediment yield has been carried out using various empirical methods involving GIS, Remote sensing (Basavarajappa et al., 2014; Rahul et al., 2012, Myint and Walker, 2002; Mishra et al., 2006; Katiyar et al., 2006; Turley et al., 2016). Empirical methods also referred as mathematical models (Sander et al., 2009) are derived from field observations and also laboratory based experiments (Field measurement of soil erosion and runoff, 1993). They are both simple and complex (Eisazadeh et al., 2012) which takes into account various layers such as land use, topography, lithology, geomorphology, climatic factors, discharge in rivers *etc.* that are mathematically analysed to estimate sediment yield. Most common empirical models are USLE, RULSE, CORINE, ICONA, LEAM, MOSES, Garde & Kothyaris methods, Khoslas methods, Lacey – Inglis methods, and so on. ULSE, RULSE (Wischmeier and Smith, 1965; 1978) has been extensively used in quantification of Sediment across the globe such as Nile basin (Gelagay, 2016). Similar to ULSE/RULSE and other empirical methods GIS based methods such as SWAT tool is also being used in the recent studies at Moracco, Amazon, Oka river basin (Briak et al.. 2016; Castro et al., 2013) indicating the role of GIS in quantification of sediments. Both the methods i.e., ULSE/SWAT are data intensive and uses multiple layers which are sometimes not available for specific locations. In order to quantify sediment yield at data deficient (non-availability) locations, simple mathematical models such as Garde & Kothyaris methods, Khoslas methods, Lacey–Inglis methods were adopted. Objectives of the current communication are (i) quantification of sediment yield in Aghanshini river basin using empirical methods; (ii) validation of quantifications with field measurements though soundings; and (iii) assessing the implications of over exploitation of natural resources (sand).

2. Study area

River Aghanashini (Fig. 3), is a west flowing river originating at Manjguni (Gazetteer, 1985)/Gadihalli (Water Resource Information System - WRIS)/Shankara honda (Suttona Banni) of Sirsi taluk, flows for about 117 km before it joins Arabian sea at Belekan, Kumta. Catchment spreading for about 1149 sq km, is distributed across taluks of Kumta, Sirsi, Siddapur, Honavar, Ankola. Rainfall is orographic (south west monsoon) ranging between 2000 mm to over 5000 mm (Vinay et al., 2017; DoS, Govt of Karnataka; Indian Meteorological Department). Soils are alluvial at coasts and lateritic in rest of the catchment (National Bureau of Soil Survey and Land Use Planning - NBSSLUP). Changing land uses (Ramachandra et al., 2016; Vinay et al., 2017) coupled with the loose texture of soils has accentuated silt yield in the river. River Aghanashini has free flow of water across the catchment with unhindered passage of sediments to the downstream and to the estuary. Aghanashini estuary supports large biodiversity of aquatic and terrestrial life forms i.e., over 50 fish species which has an economic value of 435 Million rupees per year supporting about 6100 families (Mahima et al., 2012), 8 Bivalves species and shells which has an economic value of 57.8 Million rupees per year supporting livelihood of over 2400 families (Boominathan et al. 2008), about 30 crab species (Ganesh et al., 2016) over 100 bird species (Chandran et al., 2012). The aquatic species depend upon the nutrient rich sediment deposits for their survival.

The District Sand Mining Commission, regulated extraction of 60 cm to 100 cm of sand at specified location to protect the habitats in the river and to maintain the bed (Fig. 4 with identified sand bars), depending on the rainfall in the catchment. Due to unregulated exploitation of sand in Aghanashini, there has been (i) threat/loss to the aquatic biodiversity (ii) deeper river bed leading to Sea water intrusions to ground water resources. In order to understand the quantity of silt depositions, also extractions, about 6 sites namely Mirjan, Hegde, Kaiyari, Dundukilu, Tandrikuli and Divgi in Aghanashini estuary were continuously monitored for 18 months i.e., between August 2015 to January 2017. Mirjan, Hegde and Dundukuli were straight stretches where as Kaiyari, Tandrikuli and Divgi were along the meandering portion in the upper reaches of Aghanashini estuary. The selection of transects were either closer to/along the extraction sites, specified by the Sand Mining Commission of Uttara Kannada. This region supports livelihood of local people through small and large scale fishing activities, extraction of bivalves, shell mining, etc.

3. Materials and method

Sedimentation analysis was carried out in two modes i.e., (i) Empirical methods, (ii) Field measurements -bathymetric method.

3.1. Empirical methods

Empirical methods involve quantification of sediment yield using empirical methods using GIS platform and spatial data. Empirical methods consider various catchment characteristics such as land use, topography, soil, rainfall, size of catchment, discharge etc., land use of the year 2016 (Ramachandra et al., 2016), topographic characteristics were obtained from Digital Elevation Model

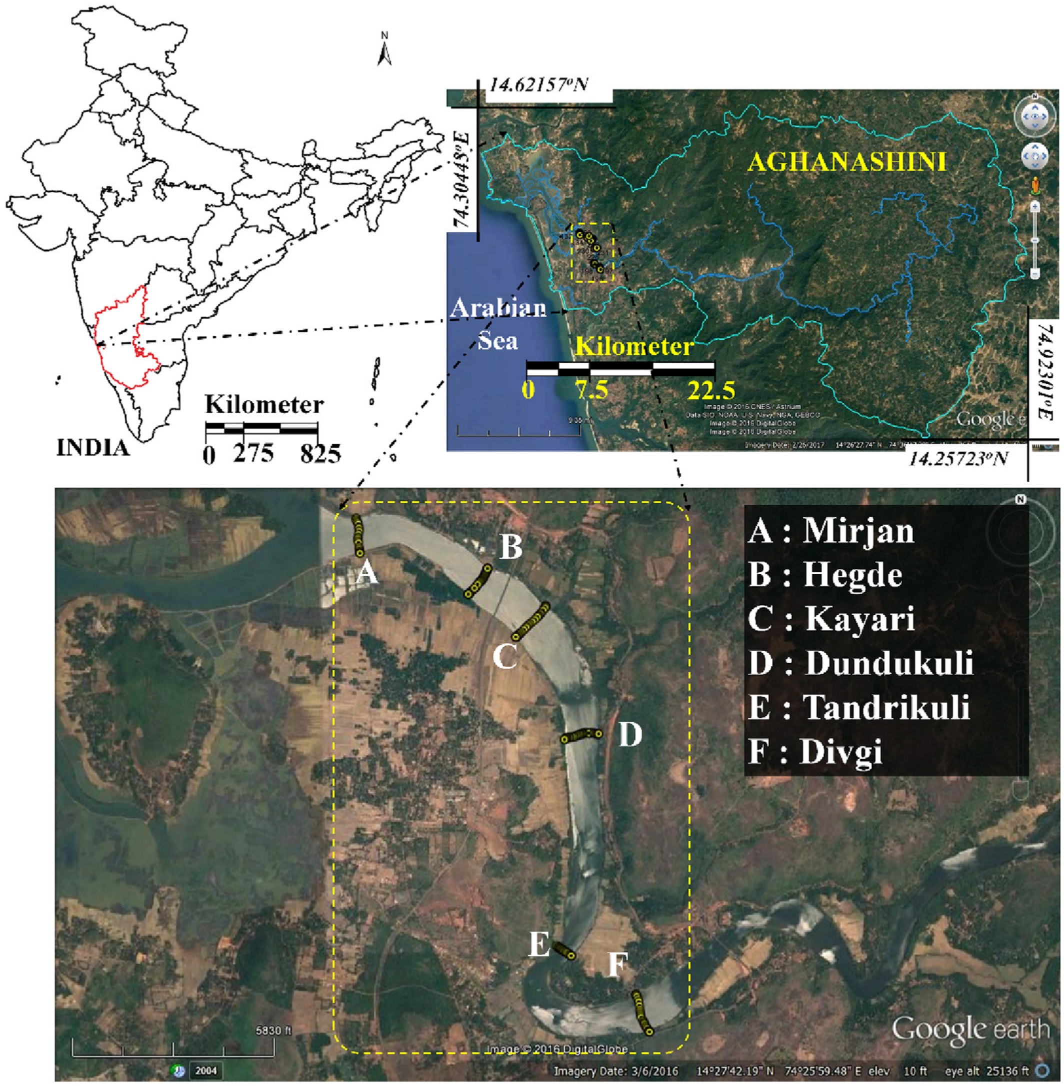

Fig. 3. Study Site.

of SRTM (Earthexplorer, USGS), Rainfall data from Directorate of Economics and Statistics, Govt of Karnataka. Discharge data were based on the field measurements carried out between 2014 June to 2016 April. In the current study empirical methods such as Khosla, Garde- Kothyaris, Lacey-Inglis methods were used.

3.1.1. Khosla's equation

Sediment yield is directly proportional to the Area of Catchment. Sediment yield using Khosla's method is given as in eq. (1) (Khosla, 1953; Rahul et al., 2012; Mutreja, 1986), where *A* is the catchment area in sq km and 0.00323 is erosion factor.

$$\text{Sediment Yield}\left(\frac{\text{Million.cum}}{\text{year}}\right) = 0.00323\ A^{0.72} \tag{1}$$

3.1.2. Garde and Kothyari method

Sedimentation yield is determined based on the data from 50 small and large catchments of Indian rivers along with the hydro-meteorological, geological, physiographical, topographical characteristics (Garde and Kothyari, 1987; Kothyari et al., 2002). The factors such rainfall (*P*), slope(*S*), drainage density (D_d), erosion factor (K_e) that is dependent upon the land use characteristics play an important role in determining the sedimentation (eq. (2) and (3))

$$\text{Sediment Yield} = 0.02\ P^{0.6}\ K_e^{1.7}\ S^{-0.25}\ D_d^{0.1}\left(\frac{P_{max}}{P}\right)^{0.19} \tag{2}$$

$$K_e = \frac{1}{A}\left(0.8A_a + 0.3A_f + 0.6A_g + 0.1A_w\right) \tag{3}$$

where P_{max} is the average maximum monthly rainfall, A is the total Catchment area, A_a is Irrigable area, A_f is Forest area, A_g is area under grass land and A_w is are under Waste lands.

3.1.3. Lacey-Inglis formulae

Developed in the early 20th Century, this considers runoff (discharge as cum/s), average particle size (mm) to quantify the sediment deposition (Garde and Kothyari, 1998; Kothyari, 2007). Particle size defines the silting factor. The scour depth is quantified as

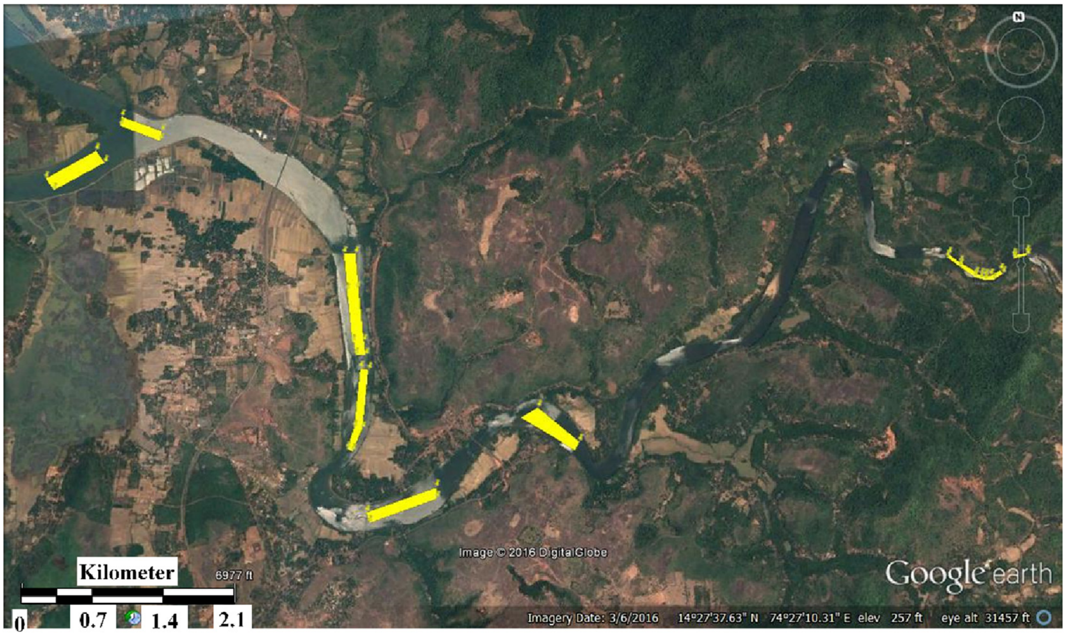

Fig. 4. Sand bars of Aghanashini river.

$$D_{LQ} = 0.47\ K\left(\frac{Q}{f}\right)^{\frac{1}{3}} \quad (4)$$

$$f = 1.76\sqrt{d} \quad (5)$$

where D_{LQ} is the scouring depth in meters, Q is discharge in cum/s, f is the scouring factor, d is particle size in mm which varies between 0.15 and 0.43 mm, K varies between 1.76 and 2.59.

3.2. Field measurements

Discharges were measured in Aghanashini catchment at various locations since March 2014 to April 2016, such as Yaana, Mastihalla, Bialgadde, Beilangi, Alkod, Aanegundi, Hebbail, *etc*. of which Bialgadde being the largest catchment consisting all said measuring stations within. In order to quantify the deposit at Aghanashini, assuming similar characteristics such as rainfall, topography, land use, soil *etc.* prevail in both catchments of Aghanashini and Bialgadde, discharges across months in Bialgadde were considered, scaled up to quantify the relative discharge in Aghanashini. Relative discharge at Aghanashini (eq. (6)) was computed as the product of discharge and ratio areas

$$Q_{Ag} = Q_{Bg}\frac{A_{Ag}}{A_{Bg}} \quad (6)$$

where Q_{Ag} and Q_{Bg} are discharges as cum/s and A_{Ag} and A_{Bg} are the catchment area in Aghanashini and Bialgadde.

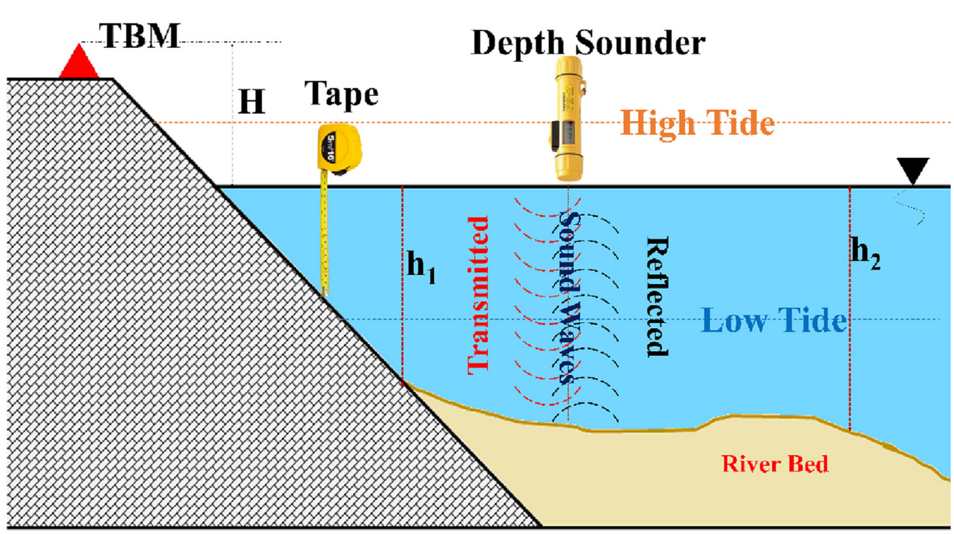

Fig. 5. Soundings in bathymetric method. (TBM: Temporary Bench mark above the high flood level, H: Depth of current water level with respect to TBM, h_1, h_2: depth of river bed across the section with respect to current water level).

3.2.1. Bathymetric method

This involved collection of soundings at regular intervals every month during August 2015 to January 2017 along the cross section of the channel (Fig. 5). Soundings (depth measurements) were carried out along 6 transects (3 transects - along the curves and remaining along the straight stretches) of Aghanashini Estuary. Cross sections along the transects were made considering temporary benchmarks on the either sides of the river such as bunds, electrical poles, trees, *etc.* Soundings were carried out each month with help of depth sounders (SONAR), tape and GPS to determine the sounding locations. Based on the difference in depth measurements during monsoon and pre-monsoons, sediment deposition and extraction were quantified. Both empirical/desktop method and field measurements -bathymetric methods were compared to determine the best suitable empirical for the analysis of sediment yield. District sand mining commission —CRZ of Uttara Kannada district was used as reference and the bathymetric measurements were compared to understand exploitation of resource.

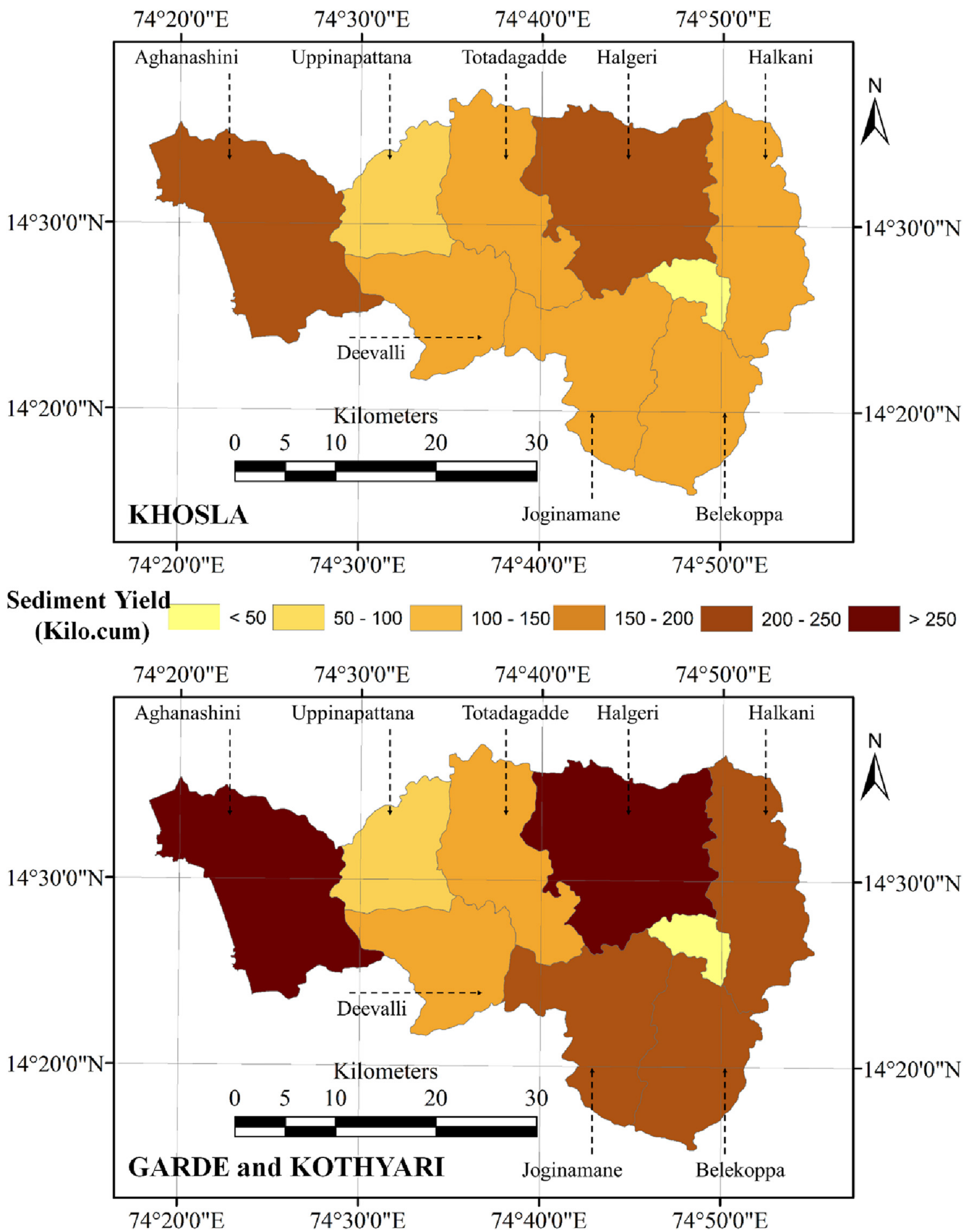

Fig. 6. Sediment yield quantification (Kilo.cum) using empirical methods.

4. Results and discussions

4.1. Quantification of sediment yield based on empirical methods

Khosla's, Garde and Kothyari's and Lacey-Inglis techniques were attempted to quantify sediment yield in the estuary

i. Khosla's method: Khosla's method quantifies sediment yield in the catchment based on catchment size. Assessment of sediment yield at sub catchment level (Fig. 6a) at estuary of Aghanashini, show an annual yield of 1105 Kilo cum per year. The disadvantage of this method is yield can be either over estimated or under estimated as the method doesn't account any other factors other than the catchment size.
ii. Garde and Kothyari's: This method, compared to Khosla's method, considers variations in the landscape, topography, rainfall conditions in the catchment. Sediment yield assessment through this method shows an annual yield of 1367 Kilo cum. sub catchment wise silt is as depicted in Fig. 6b. Presence of thick evergreen forest patches in the Ghats keeps the soil stabilized, while large scale erosions were observed in the catchments with degraded landscape.
iii. Lacey-Inglis Method: This method uses the discharge observations for sediment yield quantification compared to earlier techniques. Based on the discharge measurements carried out between May 2014 and April 2016 at Bialgadde, relative discharge in Aghanashini was computed during the monsoon seasons of 2014 and 2015. The sediment transport occurs mainly during monsoons, with respect to which sediment depositions were quantified and are listed in Table 2. About 71.5 cm of sediment deposit was estimated between June to October 2014, where as in the year 2015 reduction in rainfall has led to lower deposition of sediments (about 61.5 cm).

4.2. Quantification of sediment yield based on field measurements-bathymetric method

Soundings were carried out as discussed earlier at Mirjan, Hegde, Kaiyari, Dundukuli, Tandrikuli and Divgi during August 2015 to January 2017. Five stations other than Tandrikuli (due to variations in the benchmarks) are presented in the result section. It was observed, sediment deposit was maximum between June and September. During monsoon (June to September) period, sand mining activities are minimal and peak during October to May. The difference in the minimum depths of monsoon and maximum depths in post monsoons would account the amount of deposit or transport of sediments. For example: depth between August 2015 to September 2015 was taken as initial reference and depth observed between October 2015 to May 2016 was considered as the second reference. The difference of these two reference sections gives the amount of sediments transported in 2015–2016, similarly the difference between observed (during October 2015 to May 2016) and depth during June 2016 to September 2016 gives the amount of sediment deposited in 2016. Based on these criteria's, bathymetric results are as presented in Fig. 7 and Table 3. Among the sampled locations, Divgi had lowest extraction as well as deposition. Lower extraction at Divgi is due to harvesting of bivalves. Maximum deposits and extraction were observed at Dundukuli and Kayari stretches of Aghanashini. An average depth of deposition about 62 cm was observed in Aghanashini, along the valley about 1301 kilo cum of sediment deposits was estimated in the year 2016.

4.3. Sediment extractions and norms

District Sand mining commission – CRZ of Uttara Kannada identified locations of sand bars and quantity that can be extracted. Depth of Sand bars varies between 1.1 m at Uppinpattana to 0.6 m at Aigalkurve. For the year 2017, as per the commission, average sand bar extraction depth is 0.6 m across select stations (Fig. 8- red shade), according to this, about 237 kilo cum (404303 Tons) of sand can be extracted, Table 4 provides the quantum of sand yield at different stations. However, during the earlier year's maximum depth of sand mining was limited to 1.1 m (2015), and 0.8 m (2016).

Fig. 9 gives the cross sections at various locations in Aghanashini estuary with sand bars. Field observations of sediment deposit in the sand bars ranges between 0.38 m near Divgi to 0.9 m at Mirjan and on an average sediment deposition across the stations is 0.65 m (given in Table 5). Sand is also mined at places like Kaiyari, i.e., location between the railway bridge and Dundukuli (SB AG 02), around 1.3 m of sediment is mined/scoured, while sediment deposition is 0.9 m. Over exploitation was observed during earlier years (i.e., 2015–2016) as sediment extracted within the sand bed area is higher than the yield. At sites SB-AG-01 (Mirjan), SB-AG -02 (Dundukuli), average depth of sand bars were 0.6 m and 0.7 m, whereas the mined depth was about 0.97 m and 0.9 m respectively.

Comparative assessment of empirical methods and field based bathymetric measurements show that Khosla's methods of sediment quantification underestimate the sediment yield (i.e., 1105 kilo cum), whereas estimate as per Garde-Kothyari's (1367 kilo

Table 2
Sediment deposit in Aghanashini using Lacey-Inglis.

Year	Area (hectares)	10270.44	160974.60	Depth of Sediment - cm
	Month	Bialgadde discharge – cum/s	Aghnashini discharge – cum/s	
2014	June	12	298	8.48
	July	279	7000	24.03
	August	226	5656	22.40
	September	22	544	10.34
	October	5	117	6.22
	Total			**71.5**
2015	June	1	25	3.75
	July	30	757	11.54
	August	111	2777	17.71
	September	259	6486	23.43
	October	2	62	5.05
	Total			**61.5**

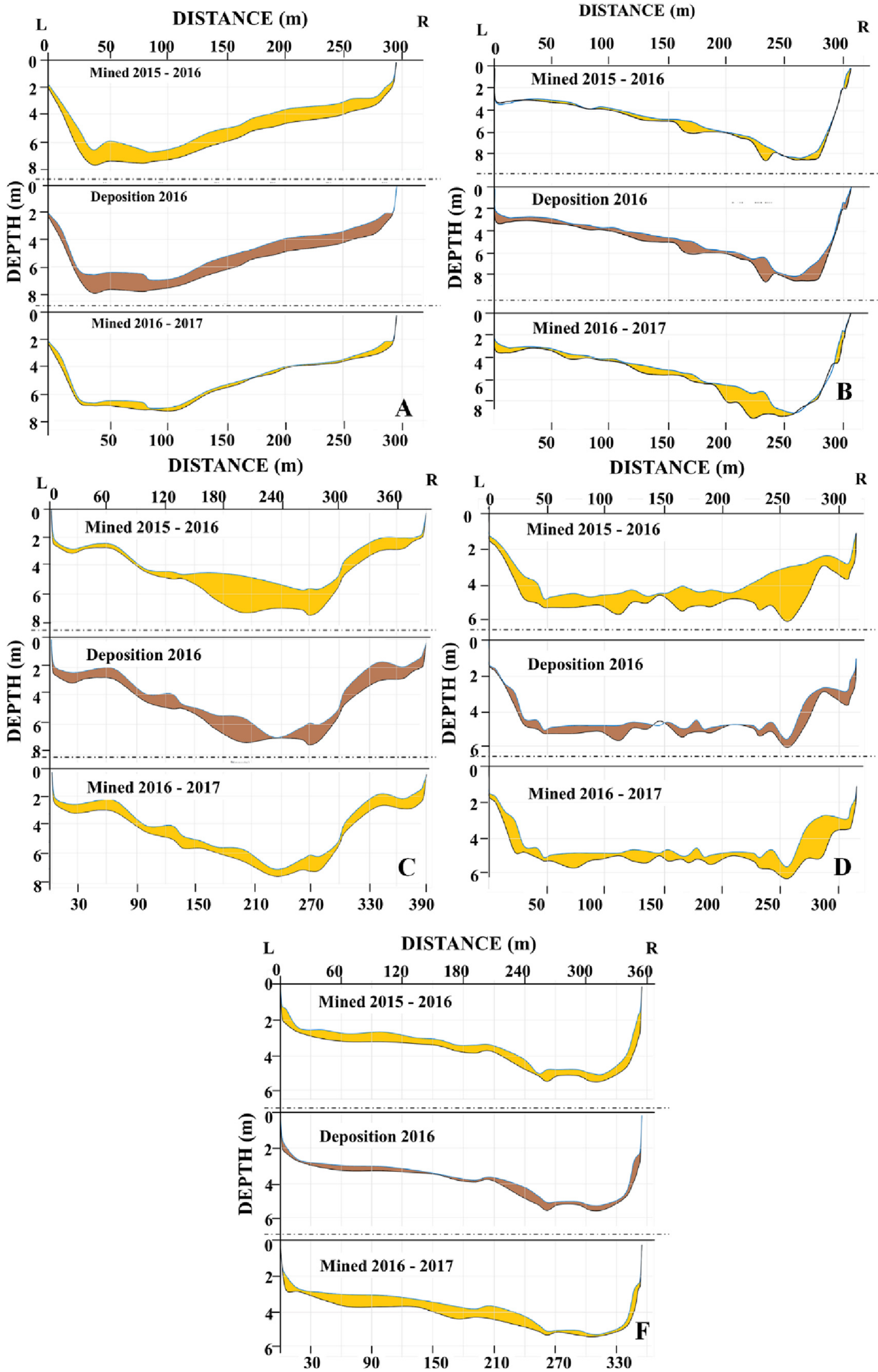

Fig. 7. Sediment Yield and Deposition between (L and R: Left and Right banks of river; A: Mirjan, B: Hedge, C: Kaiyari, D: Dundukuli, F: Divgi).

Table 3
Average Sediment Deposited and Mined/Scoured across the study sites.

Sl. no	Site id	Site Name	Mined/Scoured in 2015–2016 (m)	Deposited in 2016 Monsoon (m)	Mined/Scoured in 2016–2017 (m)
1	A	Mirjan	0.89	0.97	0.43
2	B	Hegde	0.37	0.55	0.57
3	C	Kayari	0.85	0.82	0.72
4	D	Dundukuli	0.93	0.43	0.65
5	F	Divgi	0.52	0.32	0.41
Average Depth			0.71	0.62	0.56

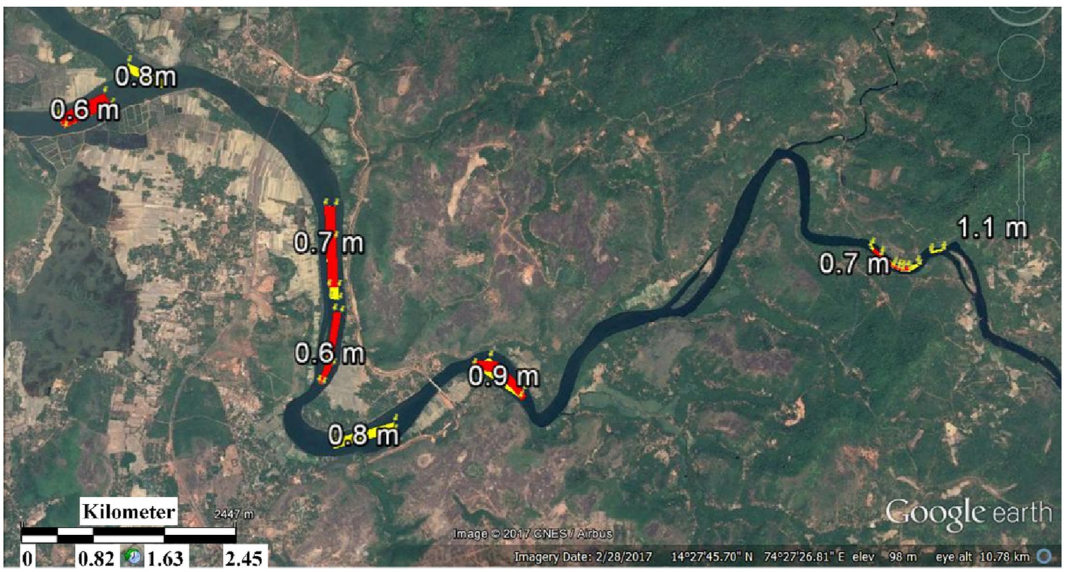

Fig. 8. Sand and Sand column depth in Aghanashini (Yellow represents 2015–2016, red represents 2016–2017 sand bars). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 4
Sand Yield at Aghanashini 2017.

Station	Length (m)	Width (m)	Area (Ha)	Average Sand bar depth (m)	Volume (cum)	Removable Sand (Tons)
SB AG 01	610	164.9	10.06	0.6	60353	103216
SB AG 02	950	120	11.4	0.6	68400	116964
SB AG 03	850	84.9	7.22	0.6	43299	74007
SB AG 04	770	106.9	8.23	0.6	49388	84440
SB AG 05	660	39.4	2.6	0.6	15602	26676

Table 5
Comparison of yield of observed field data w.r.t sand bars.

Station as per 2017	Sand Mining Commission		Field Data within the sand bars		
	Average Sand Bar Depth (m)		Scoured and mined 2015–2016 (m)	Deposit 2016 (m)	Location
	2015, 2016	2016–2017			
SB AG 01	0.6	0.6	0.97	0.9	MIRJAN
			0.65	0.44	HEGDE
			1.36	0.9	KAIYARI
SB AG 02	0.7	0.6	0.90	0.72	DUNDUKULI
	0.8	0.6	0.52	0.38	DIVGI
SB AG 03	0.7	0.6			
SB AG 04	0.6	0.6			
SB AG 05	0.9	0.6			

cum) are comparable to the observed (1301 kilo cum). Lacey – Inglis method also shows closer results i.e., estimated deposit of 61.5 cm against 62 cm observed in the year 2016. This highlights that both Garde-Kothyari's and Lacey-Inglis methods of estimation are appropriate and comparable to field observations.

Over exploitation of sand (30%) beyond the natural replenishment, making it unsustainable is noticed through the field observations based on bathymetric survey violating the District sand mining commission – CRZ norms. Taking into consideration the places of occurrences of the adverse environmental impacts of

Fig. 9. Overlay of Transects and Sand bars (Yellow blocks: Sand bars, red dots: transects). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

river sand mining, the impacts can be broadly categorized as offsite impacts and onsite impacts. The offsite impacts are, primarily, transport related, whereas, the onsite impacts are generally channel related. The onsite impacts are classified into excavation impacts and water supply impacts. The impacts associated with excavation are channel bed lowering, migration of excavated pits and undermining of structures, bank collapse, caving, bank erosion and valley widening and channel instability. The depletion of sand in the streambed of coastal region, which has caused deepening of estuaries, and the enlargement of river mouths and coastal inlets, leading to saline-water intrusion. Thus, sand mining results in the destruction of aquatic and riparian habitat through large changes in the channel morphology. This had adverse impact on aquatic ecosystem mainly due to habitat loss and decreased humus or organic matter, evident from the decline (estimated as 40–50%) of bivalve and fish catch during the last three years, which was quantified through survey of fishing communities using questionnaires. This emphasizes the need to adopt stringent vigilance across the mining areas to ensure sustainable extraction of resources. This entails regulating optimal quantities that could be removed from each stretch based on the pattern of deposition. Locations suitable for sand extraction through the non-mechanized process are to be identified based on the scientific analyses in consultation with the hydrologists. Different zonation's with respect to the characteristics and specifying the time during which the mining is allowed followed by the strict monitoring of sediment extraction.

5. Conclusions

Rising rates of soil erosion due to large scale landscape changes, demand for sand in developing nations across the globe has led to alterations in the river morphology, damaging aquatic biodiversity, habitats, there by affecting the livelihood of the dependent people. Instream sand mining is a common practice in many developing countries namely China, Malaysia, India, either using mechanized or non-mechanized modes of extraction. Along the west coast of Karnataka, India, the costal regulatory agency has banned mechanized mode of sand extraction since it damages the habitat, instream biodiversity, *etc.* Aghanashini River originating in Western Ghats that joins west coast (Arabian sea) is a pristine ecosystem sustaining diverse aquatic (i.e., fresh and marine) life forms, while providing ecosystem services - food, fodder, shells, sand *etc.* Sustainable sand mining would help the community in meeting the essential demand while maintaining the bed level, storage volume, replenishment of ground water, etc. Attempt was made to quantify the sediment deposits and extractions using both empirical methods and field investigations (soundings). The sediment yield assessment based on empirical methods shows the yield of 1367 kilo cum (Garde and Kothyari's method) and about 61–71 cm depth of deposit annually (Lacey-Inglis). Field observations shows that the sediment yield is about 1301 kilo cum (in 2016), with an average sediment deposit of 62 cm, while sand extracted ranges from 71 cm (October 2015 to May 2016) to 96 cm (Oct 2016 to January 2017). Comparative evaluation of estimation methods indicates that empirical methods such as Gadre and Kothyari's; Lacey-Inglis are closer to the observed field data. Assessment of sandbars reveal of 30% overexploitation. The study emphasis that there is a need to regulate and stringent implementation of sand mining norms to ensure sustainable sand extraction in the Aghanashini estuary.

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