Bulletin of Pure and Applied Sciences
Geology (Geological Science), Vol.43F, No.1,
January-June 2024: P.57-63
Original Research Article

Print version ISSN 0970 4639
Online version ISSN 2320 3234
DOI: https://doi.org/10.52710/bpas-geo.8
Available online at www.bpasjournals.com

Assessing Sand Replenishment Dynamics in the Girna River Sub Catchment Area of Jalgaon District, Maharashtra, India

[1]S.B. Bhavsar, [2]S.N. Patil*, [3]D.L. Chavhan, and [4]N.S. Patil

Author's Affiliations:
[1,2,3,4]School of Environmental and Earth Sciences, Kavayitri Bahinabai Chaudhari North Maharashtra University, Jalgaon, Maharashtra 425001, India

***Corresponding Author: S.N. Patil**, School of Environmental and Earth Sciences, Kavayitri Bahinabai Chaudhari North Maharashtra University, Jalgaon, Maharashtra 425001, India
E-mail: drsnpatil9@gmail.com
Received on 20.01.2024, Revised on 15.05.2024, Accepted on 26.05.2024

How to cite this article: Bhavsar S.B., Patil S.N., Chavhan D.L, and Patil N.S. (2024). Assessing Sand Replenishment Dynamics in the Girna River Sub Catchment Area of Jalgaon District, Maharashtra, India**.** *Bulletin of Pure and Applied Sciences- Geology,* 43F (1), 57-63.

Abstract:
The study focuses on quantifying the replenishment of sand within the Girna River channel, sourced from the catchment area located in Jalgaon District, for the years 2021 and 2022. The study provides probable figures for sand replenishment in the Girna River channel but also underscores the methodologies employed—specifically, the Dendy Bolton formula for sand replenishment estimation and Khosla's formula for mean annual runoff calculation. The research reveals 386247.2 tons of sand replenished in 2021 and 616619.7 tons in 2022 to the Girna River through its catchment area in Jalgaon District. The implications of this investigation for the local area, especially considering its vulnerability to sand mining, highlight the critical need to comprehend and regulate sediment dynamics in the region's river systems. By offering valuable insights into sediment dynamics, these findings pave the way for the development of robust management strategies. These strategies can help counteract the negative effects of sand mining and uphold the long-term health and sustainability of the river ecosystem in Jalgaon District. It's crucial for stakeholders to heed these insights and collaborate on implementing effective measures to safeguard the ecological integrity of the region's rivers.

Keywords: *Sand Replenishment, Dendy Bolton formula, Khosla's formula, runoff*

INTRODUCTION

Sand is a substance characterized by loose, gritty particles derived from the disintegration of rock, commonly found along water bodies' shores, in riverbeds, or desert dunes (Shaffer, 2006; Atejioye and Odeyemi 2018). Simplified this definition, perceiving sand as a geological resource formed from eroded mountain rocks transported by streams and rivers. In essence, sand is a natural resource with a loose appearance, originating from loose rocks and often observed along or within shorelines and water channels. On a global scale, aggregate mining, constituting approximately 68% to 85% of the total annual material extraction of 59 billion tons (Steinberger, Krausman & Eisenmenger, 2010), stands out as the most rapidly growing sector (Krausmann, Gingrich, Eisenmenger, Haber & Fischer-kowalski, 2009).

The formation of sand layers in river courses is a continually evolving process, crucial for the sustenance of river ecosystems. Riverbeds, streams, channels, and beaches stand out as primary reservoirs of sand. Aggregate mining, comprising both sand mining and gravel extraction, is a routine practice observed worldwide in nations at various stages of development (Draggan, 2008). Sand holds significant importance as a natural resource, highlighted by its status as the second most utilized natural resource on Earth following freshwater (Villioth, 2014). The escalating demand for sand stems from its indispensable role in construction, despite the ensuing environmental repercussions associated with its extraction from rivers, streams, flood plains, and channels (Kori and Mthanda, 2012). Sand mining, the process entailing the removal of sand and gravel, is increasingly becoming an environmental concern as the demand surges in industry and construction sectors. Environmental apprehensions arise when sand extraction outpaces its natural replenishment processes (Mattamana, Varghese & Kichu, 2013). Traditional sand mining sites predominantly comprise rivers and beaches, mining activities now extend to river mouths, banks, and even inland sand deposits. Various effects of sand mining on river mechanisms have undergone evaluation through different fields, experimental, and numerical studies. Previous field studies have delineated phenomena such as the head cutting process, wherein an erodible region moves upstream at the nickpoint, leading to a sudden increase in bed slope (Collins and Dunne, 1989; Surian and Rinaldi,; Marston et al., 2003). Further downstream, sediment deposition within pits and their edges fosters "hungry water," consequently increasing sediment transport capacity (Rinaldi and Simon, 1998; Kondolf, 1997). The consequential increase in downstream river bank heights poses a threat to rivers through bank collapse (Sreebha and Padmalal, 2011; Padmalal et al., 2008; Rinaldi, 2003). Additionally, riverbed material mining decreases the thickness of the large-sized sediment bed layer, subsequently amplifying bed erosion. Proximity and merging of pits due to upstream and downstream erosion lead to reduced sediment bed elevation, altering bed and suspended loads (Calle et al., 2017; Padmalal et al., 2008; Ferguson et al., 2015; Bayram and Önsoy, 2015; Ashraf et al., 2011). Sediment along with sand and gravel material plays a crucial role in fostering the growth of aquatic ecosystems by replenishing nutrients and creating habitat and spawning areas in the bottom of water bodies. These benefits arise from sediment settling, which happens when suspended particles gradually descend to the waterbed. This settling occurs primarily when water flow diminishes, and heavier particles can no longer be sustained by turbulence. Sediment deposition occurs across various parts of water systems, including high mountain streams, rivers, lakes, deltas, and floodplains. However, it's important to recognize that while sediment is essential for the development of aquatic habitats, excessive or insufficient deposition rates can lead to environmental concerns. The transportation and deposition of sediment rely on multiple factors, including the slope of the terrain, annual precipitation, geological composition, river flow intensity, geomorphological characteristics, soil type, geological formations, and land use patterns. The Replenishment Rate denotes the velocity at which sand is conveyed into a river channel, typically the focus of examination or subject to sand extraction. This quantity is often perceived as the sustainable yield of the river. Estimating the discharge of sand through the streambed and its temporary deposition duration poses significant challenges in sediment budgeting, necessitating sophisticated instrumentation and the establishment of numerous gauging stations. Several sediment transport equations are available for predicting the replenishment rate of a river, with notable examples including the Modified Universal Soil Loss Equation (MUSLE) by Williams and Berndt (1977) and the Dendy-Bolton Equation. The equation utilizes the catchment area and average annual runoff as its primary variables. Estimating runoff resulting from precipitation is crucial for water resources planning and design. Numerous researchers have investigated different empirical equations to assess surface runoff. Surface runoff determination is pivotal in analyzing hydrologic issues and managing water resources. Since not all watersheds in India can be directly measured, indirect methods for quantifying runoff are necessary.

The study focuses on the Girna sub-basin, which serves as a significant tributary within the Tapi River basin. Encompassing a total area of 10,195 square kilometers, this sub-basin spans across portions of Nashik, Jalgaon, and Aurangabad districts. Key tributaries within the Girna sub-basin include Manyad, Titur, Anjani, Hivra, and Bahula. The trajectory of the Girna River is evenly distributed between Nashik and Jalgaon districts. As it flows eastward through Nashik district, its path remains predominantly straight. Near Jalgaon town, the river gradually shifts to a northeast direction. Further along, it adopts an almost northward course before eventually reversing its direction to the west. During this westward stretch, the river flows parallel to the Tapi River, traversing a flat landscape marked by a series of meanders. The Girna River's final stretch concludes near Palsod village, where it merges with the Tapi River. Of the total length of the river spanning 265 kilometers, 162 kilometers traverse through Jalgaon district. The sub-basin encompasses 28 watersheds located within Jalgaon district, designated by the Groundwater Surveys and Development Agency (GSDA), Government of Maharashtra. These watersheds cover a combined area of 3,903 square kilometers. The Girna River sub-basin is predominantly characterized by Deccan basaltic lava flows, which were intermittently emitted from the upper Cretaceous to the Eocene period. These lava flows constitute a major geological formation, covering approximately 85% of the sub-basin area. They play a significant role in groundwater occurrence. The remaining 15% of the area is occupied by Girna alluvial deposits, found in the form of pockets and lenses. The sub-basin under investigation is delineated on Survey of India topographic maps 46 O/11, 46 O/12, 46 O/15, and 46 O/16. Its geographic coordinates range from 20°17'25" to 21°07'00" North latitude and 74°45'30" to 75°35'04" East longitude. The typical annual rainfall within the sub-basin varies between 700 mm and 800 mm, with the lowest precipitation occurring in the western region. Rainfall gradually intensifies in the southeast direction. Location map of study area is shown in figure 1. The study aims to determine the sand replenishment rate from the catchment area of the Girna River in Jalgaon District.

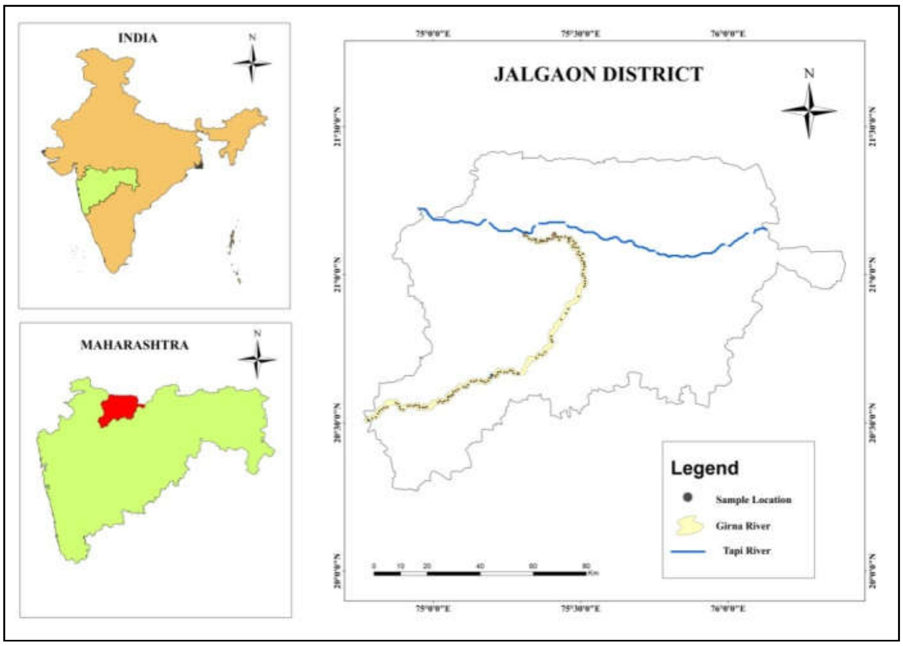

Figure 1: Location map of study Area

MATERIALS AND METHODS

Various sediment transport equations are available for predicting river replenishment rates, some of which are well-known in the field:

a) Modified Universal Soil Loss Equation (MUSLE)
b) Universal Soil Loss Equation (USLE)
c) Revised Universal Soil Loss Equation (RUSLE)

d) Dendy-Bolton Equation

In this study, the Dendy-Bolton Equation was utilized to estimate sediment yield to the Girna river sub basin from Jalgaon district. The runoff factor serves as a critical input for the Dendy-Bolton Equation. Methods like Dendy-Bolton Equation are favored for their ease of application.

Estimation of runoff yield using different empirical methods:

The study utilized empirical equation, i.e. Khosla's Formula to estimate runoff from the Girna river sub-basin catchment in Jalgaon district.

Khosla (1949), formulated a runoff estimation equation by addressing the loss factor. He used annual rainfall data, and temperature data to formulate the equation and found it to yield good estimates of annual runoff. In this method, the amount of monthly runoff is calculated by following formula (Geol & Chander, 2002; Ramasastri & Seth, 1985; Subramanya, 2013; Dalavi et al., 2018:1515)

$R_m = P_m - L_m$

Where, $L_m = 0.48\, T_m, for\ T_m > 4.5^o$

For annual Period

$R = P - \frac{T}{3.74}$

where, R and Rm = Annual and monthly runoff (cm) and Rm ≥ 0, P and Pm = Annual and monthly precipitation (cm), Lm = Monthly losses (cm), T and Tm =Annual and monthly mean temperature of the catchment (°C).

Estimation of sand replenished using Dendy Bolton formula:

The Dendy Bolton formula is commonly employed to estimate sedimentation yield (Dendy & Bolton Citation, 1976). While these equations offer a quick and rough approximation of average sediment yields regionally, they are particularly useful in initial watershed planning. Typically, computed sediment yields are lower in highly erosive regions and higher in well-stabilized drainage basins with dense vegetation, given that the equations are based on average values. These equations elucidate the general relationships among sediment yield, runoff, and drainage area. Research indicates that sediment yield per unit area generally declines as drainage area increases. As drainage area expands, average land slopes typically decrease, reducing the likelihood of intense rainstorms across the entire basin, thereby lowering sediment yield per unit area. In arid regions, sparse precipitation and low runoff act as limiting factors. However, as precipitation increases, vegetation density also rises, leading to reduced erosion. In areas with adequate and evenly distributed precipitation, vegetation becomes the primary limiting factor. Concerning sediment yield versus drainage area, studies show an inverse relationship, with sediment yield being inversely proportional to the 0.16 power of drainage area within the range of 1 to 30,000 square miles. In terms of sediment yield versus runoff, there's a sharp increase in sediment yield up to approximately 1,860 tons per square mile per year as runoff increases from 0 to about 2 inches. However, as runoff continues to increase from 2 to about 50 inches, sediment yield declines exponentially. Since sediment yield must approach zero as runoff approaches zero, a curve fitted through plotted points starts at the origin. The sharp change in slope of the curve at a runoff of 2 inches makes it difficult to create a continuous function defining this relationship. Consequently, two separate equations are derived: one for runoff less than 2 inches and another for runoff greater than 2 inches.

Study area has runoff greater than 2 inches therefore following equation has been used to calculate the amount of sand replenished to the Girna River sub-basin from the Jalgaon district.

$S=1958*(e^{-0.055*Q}) *(1.43-0.26\log (A))$

Where, S= sediment yield of stream (tons/mile^2/yr), Q= mean annual runoff (inch), A= net drainage area (mile^2).

The Girna river sub-basin in Jalgaon district consists of 28 watersheds named by the Groundwater Surveys and Development Agency (GSDA) of the Maharashtra government, encompassing an area of 3903 square kilometers.

RESULTS AND DISCUSSION

The main objective of the study is to find out the amount of probable amount of sand replenished to the Girna River from catchment area in Jalgaon district during the year 2021 and 2022. Khosla's formula was used estimate runoff from the Girna river sub-basin catchment in Jalgaon district. The results for the estimated runoff for year 2021 and 2022 are given in Table 1. Results for the probable sand replenishment to Girna River from Jalgaon district using Dendy Bolton formula are given in Table 2.

Table 1: Results of runoff estimation in Girna river catchment in Jalgaon district using Khosla's Formula.

Year	Annual Rainfall (cm)	Mean Annual Runoff (cm)	Mean Annual Runoff (inch)
2021	723.61	70.76	27.86
2022	591.76	49.15	19.35

Table 2: Results of probable sand replenished in Girna River from Jalgaon district using Dendy Bolton method.

Year	Catchment Area ($Mile^2$)	Probable Sand Replenished $Tons/Mile^2/Yr$	Probable Sand Replenished Tons/Yr
2021	1506.8	256.3	386247.2
2022		409.2	616619.7

The variation between annual rainfall, estimated mean annual runoff by using Khosla's formula and probable sand replenished per sq. mile per year using dendy Bolton method is presented graphically in Figure 2.

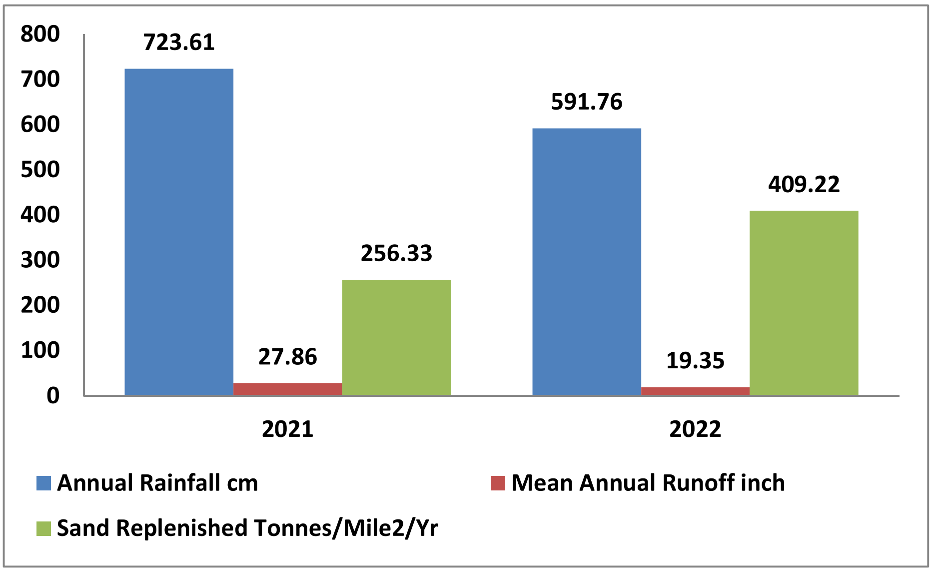

Figure 2: Variation between rainfalls, estimated runoff and probable sand replenished

It has been found that for year 2021 the amount of sand replenished was 386247.2 tons i.e. 256.3 tons/mile^2 and for year 2022 the amount of sand replenished was 616619.7 tons i.e. 409.2 tons/mile^2 from 1506.8 sq. miles of catchment area of Girna river in Jalgaon district. However, calculating the exact amount of sand replenished to a river can be challenging due to various factors such as erosion, deposition, sediment transport, and the complex dynamics of river system that changes over time and space. These estimates provide valuable insights into river dynamics and help in management and conservation efforts.

CONCLUSION

Determining the exact amount of sand replenished to a river is a challenging task due to various environmental factors such as erosion, deposition, and sediment transport, compounded by the dynamic nature of river systems. Despite these challenges, the estimates provided in this study offer valuable insights into the changing dynamics of the Girna River and its catchment area. Moreover, the research highlights the significant influence of rainfall and runoff on sand replenishment, with higher levels of rainfall leading to a reduction in sediment yield, as outlined by Dendy Bolton, who observed that as runoff levels increased from 2 to approximately 50 inches, sediment yield declined exponentially. This underscores the importance of understanding climatic factors and their impacts on river systems for effective management and conservation efforts. By utilizing such insights, stakeholders can make informed decisions to sustainably manage sand resources, mitigate environmental degradation, and promote the long-term health and resilience of rivers like the Girna in Maharashtra.

REFERENCES

1. Ashraf MA, Jamil MM, Yusoff I, Wajid A, Mahmood K (2011) Sand mining effects, causes and concerns: a case study from Bestari Jaya, Selangor, Peninsular Malaysia. Sci Res Essays 6(6), 1216–1231.
2. Atejioye, A.A. & Odeyemi, C.A. (2018). Analysing Impact of Sand Mining in Ekiti State, Nigeria Using GIS for Sustainable Development. World Journal of Research and Review (WJRR) 6(2), 26- 31.
3. Bayram A, Önsoy H (2015) Sand and gravel mining impact on the surface water quality: a case study from the city of Tirebolu (Giresun Province, NE Turkey). Environ Earth Sci 73(5), 1997–2011.
4. Calle M, Alho P, Benito G (2017) Channel dynamics and geomorphic resilience in an ephemeral Mediterranean river afected by gravel mining. Geomorphology 285, 333–346
5. Collins BD, Dunne T (1989) Gravel transport, gravel harvesting, and channel-bed degradation in rivers draining the southern Olympic Mountains, Washington, USA. Environ Geol Water Sci 13(3), 213–224.
6. Dalavi, P., Bhakar, S.R., Bhange, H.N., Gavit, B.K., (2018). Assessment of Empirical Methods for Runoff Estimation in Chaskaman Catchment of Western Maharashtra, India, Int. J. Curr. Microbiol. App. Sci, 7 (5), 1511-1515.
7. Dendy, F.E. and Bolton, G.C., 1976. Sediment yield-runoff drainage area relationships in the United States. Journal of Soil and Water Conservation, 31, 264−266.
8. Draggan S. (2008). Encyclopedia of Earth. Sand and gravel. Washington DC Dyer, H. (2018). Introducing Green Theory in International Relations. https://www.eir.info/2018/01/07/green-theory-in-international-relations/
9. Ferguson RI, Church M, Rennie CD, Venditti JG (2015) Reconstructing a sediment pulse: modeling the effect of placer mining on Fraser River, Canada. J Geophys Res Earth Surf 120(7), 1436–1454.
10. Geol, N. K., & Chander, S. (2002). Regionalization of Hydrological Parameters. National Institute of Hydrology. Roorkee.
11. Kori, E., & Mthanda, H., (2012). An Assessment of Environmental Impacts of Sand and Gravel Mining in Nzhelele valley, Limpopo Province, South Africa.3rd International Conference on Biological, Environmental and Chemistry. IPCBEE. V. 46.

12. Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K-H., Haber, H., Fischer-Kowalski, M., 2009. Growth in global materials use, GDP and population during the 20th century. Ecological Economics 68, 2696-2705.

13. Marston RA, Bravard JP, Green T (2003) Impacts of reforestation and gravel mining on the Malnant River, Haute-Savoie, French Alps. Geomorphology 55, 65–74.

14. Mattamana, B. A., Varghese, S., & Kichu, P. (2013). River Sand Inflow Assessment and Optimal Sand mining policy Development. International Journal of Emergency Technology and Advanced Engineering. V 3.

15. Padmalal D, Maya K, Sreebha S, Sreeja R (2008) Environmental efects of river sand mining: a case from the river catchments of Vembanad Lake, Southwest coast of India. Environ Geol 54, 879–889.

16. Ramasastri, K. S., & Seth, S. M. (1985). Rainfall-Runoff Relationships. National Institute of Hydrology, Roorkee, India.

17. Rinaldi M (2003) recent channel adjustments in alluvial rivers of Tuscany, Central Italy. Earth Surface Processes and Landforms. J Br Geomorphol Res Group 28(6), 587–608.

18. Rinaldi M, Simon A (1998) Bed-level adjustments in the Arno River, central Italy. Geomorphology 22(1):57–71); Kondolf, 1997 (Kondolf GM (1997) PROFILE: hungry water: efects of dams and gravel mining on river channels. Environ Manag 21(4), 533–551.

19. Shaffer, N. R. (2006). The Time of Sands: Quartz-rich Sand Deposits as a Renewable Resource. Electronic Green Journal, 1(24).

20. Sreebha S, Padmalal D (2011) Environmental impact assessment of sand mining from the small catchment rivers in the southwestern coast of India: a case study. Environ Manag 47(1), 130–140.

21. Steinberger, J.K., Krausmann, F., Eisenmenger, N. (2010). Global patterns of materials use: a socioeconomic and geophysical analysis, Ecological Economics, 69, 1148-1158.

22. Subramanya, K. (2013). Engineering Hydrology Fourth Edition (4th ed.). McGraw Hill Education (India) Private Limited. New Delhi. India.

23. Surian N, Rinaldi M (2003) Morphological response to river engineering and management in alluvial channels in Italy. Geomorphology 50(4), 307–326.

24. Villioth, J. (2014). Building an Economy on Quicksand. Available online: http://www.ejolt.org/2014/08/building-an-economy-on-quicksand/

25. Williams, J. R., & Berndt, H. D. (1977). Sediment Yield Prediction Based on Watershed Hydrology. Transactions of the ASAE, 20, 1100-1104. https://doi.org/10.13031/2013.35710

****