MARITIME RESEARCH CENTER
FOUNDATION FOR UNDERWATER DOMAIN AWARENESS

Research Note

E-Learning Module – 2

Tropical Waters and Unique Characteristics: Indian Freshwater Systems

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Introduction

India's riverine conditions are shaped by the many rivers and lakes that run through the country's colossal landscape and affect its hydrological dynamics. Himalayan and Peninsular rivers are the two main groups of rivers based on their origin. Himalayan rivers, like the Ganga, Yamuna, and the Indus, are primarily perennial. They get their water from snow and rain in the mountains. The Western Ghats are the main water split in Peninsular India. Mahanadi, Godavari, Krishna, and Kaveri are some rivers that flow eastward and drain into the Bay of Bengal, where they make deltas. The only long rivers that run west and make estuaries are the Narmada and the Tapi.

Most of India's freshwater lakes are in the Himalayas and were formed by glaciers digging out areas filled with snowmelt. On the other hand, Wular Lake in Jammu and Kashmir is different because it was created by tectonic action. It is also the country's largest freshwater lake. Dal Lake, Bhimtal, Nainital, Loktak, and Barapani are other beautiful freshwater lakes.

India's big rivers are essential to the country's ecosystem because they bring resources to farms, factories, and towns. Seasonal changes affect the flow of these rivers. For example, summer rains cause changes in water levels and flow rates. From June to September, the summer monsoon brings heavy rain that raises water levels and can sometimes cause floods. On the other hand, water levels drop in the winter. With their rich biodiversity, perennial rivers help keep marshes and floodplains alive, which are essential homes for many plant and animal species.

Still, things that people do, like polluting factories, cutting down trees, and building dams, pose major threats to the health of India's water systems. We need to focus on long-term water management, conservation, and waste control to protect the strength and balance of these rivers' ecosystems. They are important to India's economy, society, and climate. This study emphasises the unique features of Indian rivers, which are very important for making policies that work in India. Understanding these features is vital for making sediment management rules for systems like this in countries along the Indian Ocean Rim (IOR).

Himalayan System

The Himalayas are a relatively new mountain range made by ongoing tectonic processes about 10 million years ago. They continue to grow at a rate of about 10 mm per year. These mountains are mostly made up of sedimentary rocks, which play a big role in moving and depositing material around the world. Analysis of sediments from several rivers in the area shows that rocks like quartz, illite, and shale are common. Himalayan rivers never dry up because they get water from glaciers and the summer rains that fall from June to September. The mixture comprises loose mud, silt, pebbles, and soft rocks.

Many rivers start in the Himalayas, where low temperatures slow soil formation. As a result, the mountain soil is thin and needs to be better grounded. These rivers begin when ice and glaciers melt and flow through gorges, deep valleys shaped like Vs. Since the rivers move quickly, big pieces of sediment like rocks, stones, and pebbles get pushed together with smaller details like sand, clay, and alluvium. Ninety per cent of the Himalayan silt in India is made up of quartz. River loads are mostly made up of detrital sands and illitic clays. When these rivers reach the Ganges plain, the slope goes down, slows the flow and lets the silt settle.[1]

Some of the flow patterns of rivers in the Himalayas are changed by the melted snow in the Himalayas. These rivers also flow through a very changeable environment, with significant changes in the water and silt they carry. So, Himalayan rivers are unique because their paths change, they scour the bed and banks, and they take large amounts of sediment the size of sand. Many Himalayan rivers have features that are rare in other rivers. This is because of the unique hydro-climatic and morpho-tectonic conditions.[2]

Sedimentation

On a global level, Asian rivers are known to be the primary sources of sediment in the world's seas. Every year, the big rivers in East and Southeast Asia send about 6300 million tonnes of silt to the waters along the coasts[3]. About 2500 million tonnes of suspended sediments are moved by rivers in the Indian subcontinent every year. This is about 15–20% of the total world sediment flux. About 70% of this sum comes from the Ganga–Brahmaputra and Indus rivers. The rest comes from rivers in the peninsula. Recently, Syvitski et al.[4] calculated that Asian rivers (not including Indonesian rivers) move about 4.74 ± 0.8 billion tonnes of sediment every year. They pointed out that human activities have increased the amount of inland sediment transferred by global rivers through soil erosion by 2.3 ± 0.6 billion tonnes yearly.[5]

Rivers send between 2 and 6 × 1015 grammes of sediment yearly into the Bay of Bengal. This is a big chunk of the 18.3 × 1015 grams of sediment flowing into the world's oceans annually. The Brahmaputra and Ganges rivers, which drain the Himalayas, and other Indian rivers that

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[1] Tenzin, Namgay. (2018). Sediment in Himalayas. 10.13140/RG.2.2.19074.58561.
[2] Kale, V. S. (2002). Fluvial geomorphology of Indian rivers: an overview. *Progress in physical geography*, *26*(3), 400-433.
[3] Milliman, J. D., & Meade, R. H. (1983). World-wide delivery of river sediment to the oceans. *The Journal of Geology*, *91*(1), 1-21.
[4] Syvitski, J. P., Vörösmarty, C. J., Kettner, A. J., & Green, P. (2005). Impact of humans on the flux of terrestrial sediment to the global coastal ocean. *science*, *308*(5720), 376-380.
[5] Gupta, H., Kao, S. J., & Dai, M. (2012). The role of mega dams in reducing sediment fluxes: A case study of large Asian rivers. *Journal of Hydrology*, *464*, 447-458.

run into the Bay of Bengal carry at least 1.1 x 1019 kilogrammes of sediment, which builds up at a rate of 665 x 109 kilogrammes per year on average[6]. Different rocks, especially those in the Deccan Traps, which cover a large part of the Indian peninsula, send debris into these rivers[7]. The Indus, Ganga, and Brahmaputra Rivers have a braided channel pattern, even though their beds are fine sand and their sides are gently sloped. The Ganges-Brahmaputra River system has big changes in how silt moves throughout the day, throughout the year, and during different seasons.[8] It is known that the Alaknanda River is the source of the Ganga River. The river has a high rate of physical weathering, five times the average global rate of physical denudation, and a high rate of chemical erosion, six times the global average.[9]

Some rivers carry much material. For example, the Krishna and Godavari rivers in the Indian peninsula carry about 100 parts per million (ppm) of silt. On the other hand, the Ganga often has more than 2,000 p.p.m. of silt, and the Kosi has even more at 3,310 p.p.m. Rivers all over the world have similar amounts of silt. For example, the Mississippi has 1,750 p.p.m. of sediment, the Nile has 1,500 p.p.m., and the Yellow River in China has an astonishing 240,000 p.p.m.[10]

The Himalayas change shape because of shifting plates, creating much morphodynamic energy. This energy leads to high erosion rates and a lot of sediment output. About 95% of the Ganges' silt load is moved during the monsoons, and nearly half of the river's annual water flow happens in just one week. More than 70% of the river's sediment comes to the delta as silt and only 10% as sand[11]. These sediments move a lot of pollutants and nutrients, like nitrogen and phosphorus. People have caused much damage to the Ganga River through spiritual, commercial, and municipal waste[12]. A study found that the silt in the Ganga River is full of Gram-negative, aerobic, chemo-heterotrophs that mainly react with sulphur, hydrogen, nitrogen, alkanes and alkenes.[13]

[6] Klemme, A., Warneke, T., Bovensmann, H., Weigelt, M., Müller, J., Rixen, T., ... & Lämmerzahl, C. (2023). Sediment transport in Indian rivers high enough to impact satellite gravimetry. *Hydrology and Earth System Sciences Discussions*, 1-15.

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[13] Srivastava, A., & Verma, D. (2023). Ganga River sediments of India predominate with aerobic and chemo-heterotrophic bacteria majorly engaged in the degradation of xenobiotic compounds. *Environmental Science and Pollution Research*, *30*(1), 752-772.

About 53% of India's land area is affected by soil runoff[14]. Land badly eroded along the Yamuna, Chambal, Mahi, and other west-flowing rivers in western Indian states is in a high erosion area[15]. The Himalayan and lower Himalayan areas are in much worse shape now because of heavy tree cutting, road building, mining, and farming on steep slopes. Major river areas are often hit by massive floods and carry much sediment[16]. A sizeable alluvial fan made by a sandbed river is the Kosi River. This type of fan is notorious for being very unstable in its location. A study of how suspended sediment moves through Himalayan rivers shows that rivers that flow from the mountains usually carry much more sediment than rivers that flow from the slopes or the plains.[17]

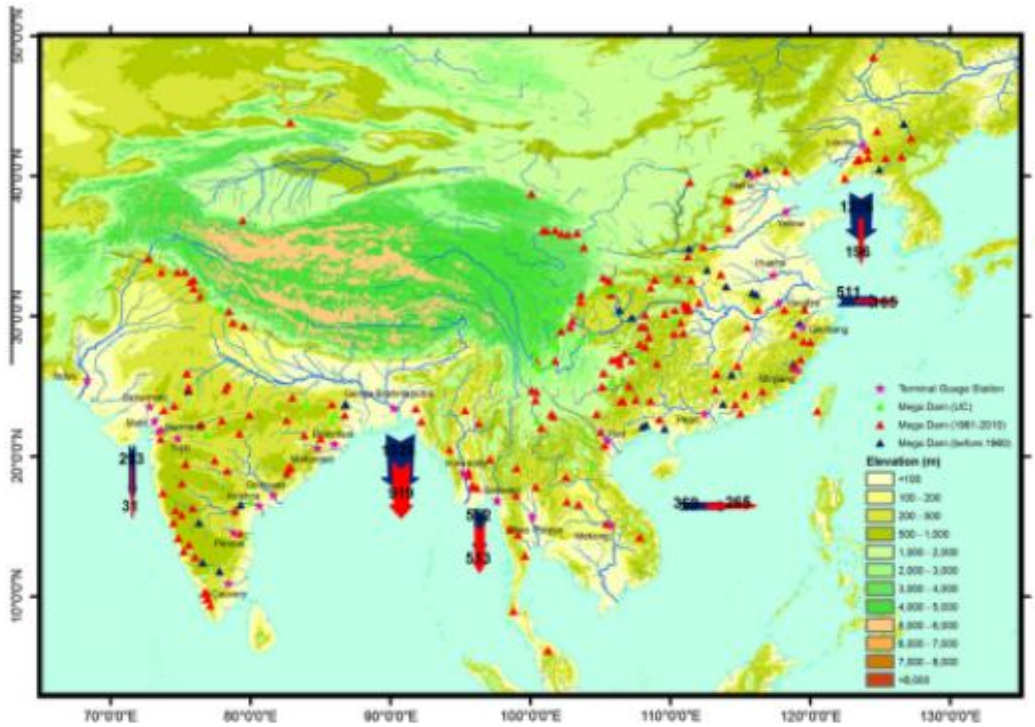

Figure 1: Spatial distribution of mega dams and change in annual sediment flux from large rivers into their respective basins.[18]

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[17] Kale, V. S. (2002). Fluvial geomorphology of Indian rivers: an overview. *Progress in physical geography*, *26*(3), 400-433.

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Monsoonal Floods

In most of India, rivers do most of their work of transporting, eroding, and depositing during the summer rainy season. Large amounts of water are only made in the catchments after it rains for several hours to several days, which causes significant river floods.[19]

The area's weather changes a lot with the seasons, significantly affecting Indian rivers, which behave very differently from one season to the next[20]. It doesn't matter what size or type of river it is; during the four to five months of the monsoon season, most rivers see about 80–95% of their yearly flow and sediment load. When monsoon runoff starts, river activity is massively increased after a long period of stillness. Heavy rains that last several hours to several days are the only thing that causes much flow in the catchments, which causes rivers to flood very severely[21]. During these significant events, when most of the geomorphic work in some rivers happens, the natural force of monsoonal rivers becomes clear.[22]

Indian rivers with big storms are essential for erosion and moving sediment. [23]Because of the different ways it rains in India, the courses of its rivers have changed shape to accommodate a wide range of flows, from low flows during the non-monsoon season to high flows during the monsoon season. Large floods happen every few years to a few decades in these rivers. They are caused by bursts of sediment flow from upstream and tributaries, the channel edge, and the floodplain's sedimentology.[24]

Indian rivers have positive skewness, high variability, and high average flows[25]. Many floods don't change the scenery or channel shape in a way that lasts for a long time, but big floods can make significant changes. This kind of high-magnitude flooding can have effects that last for a long time. Putting together different case studies on Indian rivers, some of the most common flood effects are channel deepening, the deposit of coarse gravel in the channel and floodplain, the erosion of bars and chutes, the scouring of the floodplain, and the formation of channel-in-channel topography.[26]

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Storage Capacity

The steady buildup of sediment from rivers reduces the amount of water stored in reservoirs. This is mainly because the speed of the water moving between rivers and reservoirs is slowing down, making it harder to move the sediment particles[27]. There are two types of siltation in reservoirs: hydrological, which is caused by sediment output, and hydraulic, which is caused by sediment tapping. Anuj Kanwal's study says that Indian dams cover an area of about 50,000 square kilometres and can hold 257 billion cubic metres of water per year. A survey of nearly 350 reservoirs in India shows that about 1.5 BCM of live water is lost yearly.[28]

Studies of big Indian lakes show that at least six big and three medium-sized reservoirs have lost more than 25% of their water storage capacity. The writers give more information about problems with erosion and sedimentation in India.[29]

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CWC BASIN CODE	Name of Basin	Built Up Storages BCM	Sedimentation Data Available for Reservoirs(No.) in CWC	Storage Capacity of Observed Reservoirs in MCM	Average Years of Service as on 2019	Average % loss of Gross storage in the Reservoirs
1	Indus	19.43	9	19.41	25	35
2A	Ganga (Upto Border)	56.326	29	34055	56	15
2B	Brahmaputra (Upto Border)	2.5131	10	275	21.4	16
3	Godavari	43.4515	50	17445	35	7.6
4	Krishna	54.807	53	51.198	55	28
5	Cauvery	9.098	38	10231	52.5	11
9	Mahanadi	14.52	11	13687	45.9	11.8
10	Brahmani and Baitarani	6.25	3	5146	36	7.8
11	Subernarekha	2.459	4	395		8.1
12	Sabarmati	1.686	6	2064	52.8	6.3
13	Mahi	5.167	11	7219	50.7	11.55
14	West flowing rivers of Kutch and Kathiawar including Luni	6.87	49	8639	51	37.3
15	Narmada	24.45	6	7352	31.6	10.5
16	Tapi	10.695	8	9143	74	14
17	West flowing rivers from Tapi to Tadri	17.098	12	2794	51	8.98
18	West flowing rivers from Tadri to Kanyakumari	12.439	50	14084	60	6

Table 1: Basin-wise findings from the collected data of reservoirs in India in CWC. [30]

According to Syvitski et al.[31], the total annual sediment flux would be about 16.2 Gt if no reservoirs existed in the modern world. At the moment, about 70% of the world's rivers are blocked by large reservoirs. Building reservoirs is the most important thing affecting sediment export from land to water.

[30] Anuj Kanwal. Sedimentation of Reservoirs in India. Retrieved From: https://www.cbip.org/ISRM-2022/ICOLD2021/Data/Workshop/Sedimentation%20Management%20in%20Reservoirs%20for%20Sustainable%20Development/Anuj_Kanwal_Sedimentation_Reservoirs29-12-2019-12-22-33.pdf

[31] Syvitski, J. P., Vörösmarty, C. J., Kettner, A. J., & Green, P. (2005). Impact of humans on the flux of terrestrial sediment to the global coastal ocean. *science*, *308*(5720), 376-380.

Pollution

About 90% of the plastic trash that ends up in the oceans comes from 10 rivers: the Yangtze, the Indus, the Yellow River, the Hai River, the Nile, the Ganges, the Pearl River, the Amur River, the Niger, and the Mekong[32]. Mahua Saha[33] from the CSIR-National Institute of Oceanography in Goa pointed out that three rivers—the Indus, the Brahmaputra, and the Ganges—start in India.[34]

Microplastics have been found in all of the rivers that scientists have studied. There were 380 to 684 microplastic pieces per million litres of water in the lower Ganga in five places from Uttar Pradesh to West Bengal. These pieces weighed 143 to 340 grammes.[35] According to another study, the Ganga dumps about 1.3 billion tiny pieces of plastic into the Indian Ocean daily[36]. In the Brahmaputra and Indus rivers sediments, there are more microplastics (less than 150 microns) than bigger ones. The Ganga and the Yamuna have about the same amount of microplastics in their sediments when they meet in Prayagraj, Uttar Pradesh. Also, the Kaveri River in South India had up to 700 microplastic pieces per kilogram of sediment.[37]

According to Lebreton et al.[38], the Ganges is the second most dirty river in the world because it releases about 1.05 x 105 tonnes of plastic into the IOR every year[39]. Along with plastic trash from cities, the Ganges also get plastic debris from fishing. In a recent study by the Wildlife Institute of India and experts from the UK and Bangladesh, fishing gear like nets, ropes, strings, and lines were found in different parts of the river. Nylon was the most common plastic, followed by polyethene, polypropylene, and polystyrene. Gangetic river dolphins, different kinds of turtles, frogs, and birds are all in danger from the trashed fishing gear. By 2050, 33 billion tonnes more plastic will be made than today.[40]

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A study found that the average amount of trash on national beaches dropped from 0.475 to 0.3 items/m2 in 2019 to 0.4 items/m2 in 2021[41]. In 2019 and 2021, 65% and 74% of litter were plastic, with single-use plastics (SUPs) being the most common type. Marine litter is spread out across the whole water column and sediment. During the monsoon, more litter is seen because it is easier to get into coastal waters through creeks, rivers, and bays when there is a lot of freshwater flow.

Way Ahead

- Gauge the sediment erosion rate within the basin effectively.
- Efficiently measure the sediment load within the reservoir.
- Choose the most appropriate sediment treatment method, considering factors such as topography, river flows, effectiveness, economic viability, environmental impact, and other relevant conditions, through comprehensive assessment.
- Implement sediment management measures in coordination with multiple reservoirs within the basin.

[41] Robin, R. S., Karthik, R., Nithin, A., & Purvaja, R. (2023). Removal of marine litter and its impact along the coast of India. *Records of the Zoological Survey of India*, *123*(1S), 67-86.