Journal of Geoscience and Environment Protection, 2023, 11, 33-48
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

The Influence of Alluvial Mining on the Morphology and Ecological Health of the Jhimruk River in Pyuthan, Nepal

Ankit Kandel[1], Kismat Pokhrel[1], Lenin Adhikari[1], Deep Narayan Shah[1,2]

[1]Goldengate International College, Tribhuvan University, Battisputali, Kathmandu, Nepal
[2]Central Department of Environment Science, Tribhuvan University, Kirtipur, Kathmandu, Nepal
Email: savedaenv@gmail.com

How to cite this paper: Kandel, A., Pokhrel, K., Adhikari, L., & Shah, D. N. (2023). The Influence of Alluvial Mining on the Morphology and Ecological Health of the Jhimruk River in Pyuthan, Nepal. *Journal of Geoscience and Environment Protection, 11,* 33-48.
https://doi.org/10.4236/gep.2023.118003

Received: June 26, 2023
Accepted: August 6, 2023
Published: August 9, 2023

Abstract

Historically, alluvial rivers have been a desirable source of sediment for various industrial purposes. However, the demand for sand is rapidly increasing, leading to environmental concerns associated with its extraction. The extraction of sediment from riverbeds has both visible and invisible effects. This research aims to investigate the dynamics of the Jhimruk River's morphology and its impacts by evaluating the river's quality and studying its changing morphology. To assess morphological changes, satellite images from different years were compared using Geographic Information System (GIS). Physical assessments were conducted by calculating a Habitat score based on various parameters. Water quality assessments involved measuring factors such as pH, temperature, nitrate levels, and alkalinity. A water quality map of the river was generated using color coding to indicate different conditions. The Habitat score demonstrated variations in the data collected from all sites, with factors such as instream cover, bottom substrate stability, riparian vegetation, and aesthetic of the river stretch playing crucial roles in influencing the total score. The Water Quality Index value for the disturbed site indicated moderate pollution, falling under class II. Aquatic macroinvertebrates displayed natural responses to increasing levels of stressors across their life stages, as observed through the analysis of the GRS-BIOS/ASPT index. With the exception of the disturbed site, all other sites were classified under water quality class II, while the disturbed site belonged to class III, indicating a moderate to critically polluted state for most of the Jhimruk River. Furthermore, an increase of 180.87 meters in the river width at the disturbed site provided evidence of morphological changes occurring over the specified period. Mining activities were identified as a significant contributor to the alteration in river morphology.

Keywords

Alluvial Mining, Physical Assessment, Biological Assessment, Water Quality Assessment, Jhimruk River, Sand Mining

1. Introduction

The technique of taking sand or gravel out of its natural habitat is known as "sand and gravel mining" (Langer, 2003). The construction industries all around the world frequently use these materials, which may be found in many different natural locations. Sand and gravel can be found on land, in oceans, rivers, streams, flood plains, or hills (Kondolf et al., 2008). Historically, several industrial users have found alluvial rivers to be a desirable source of silt. Sand is employed in a variety of tasks, including coastline stabilization, the creation of artificial islands, and land reclamation. In Nepal, significant riverbed mining for the use of raw resources including sand and gravel began in 1963-1964 (Baidya, 2003). Riverbed extraction has a number of implications. Some consequences are apparent, while others are not. The primary immediate impacts of gravel extraction include changes to river morphology, effects on hydraulic infrastructure such as dams, spurs, revetment walls, culverts, and bridges, destruction of fish habitat, loss of livelihoods, and externalisation of costs (Kondolf, 1998).

Sand deposits can be classified into two categories: terrestrial and marine (offshore) origins (Gelabert, 2016). Terrestrial sources encompass residual soil deposits, river channel deposits, and floodplain alluvial deposits, while the most common marine sources consist of shore and offshore deposits (Kowalska & Sobczyk, 2014). Sand deposits are often found in environmentally significant areas, primarily in mountainous and river valleys. Offshore dredging, which is more costly than terrestrial exploitation, is predominantly practiced in developed economies due to the specialized equipment and environmental permits required, as highlighted by (Pereira, 2012).

Mining has become an integral part of human development, and river mining is widely utilized in this evolving world due to its ease of extraction, processing, and transportation. In mountainous regions, extraction activities are expanding alongside the growth of engineering infrastructures, urbanization, and industrialization (Dahal, et al., 2012).

Due to the expansion of infrastructure projects and ongoing building construction, the demand for sand is rising increasingly quickly. In the present era, sand is acknowledged as the second most consumed natural resource on Earth, following fresh water (Villioth, 2014). This has led to indiscriminate sand mining, which has had negative effects on the ecosystem such as habitat loss, deterioration of the area's scenic appeal, deforestation of floodplains, and altered stream structure and functionality (Hayer & Irwin, 2008; Kondolf, 1998). Aquatic life is strongly influenced by the stability of physio-chemical characteristics. The various alterations that aquatic species make are necessary for their continued existence. Dissolved oxygen, total hardness, alkalinity, temperature, and other factors all affect how well fish grow in a body of water. Unwanted changes in the physical, chemical, and biological features of air, water, and soil pose a serious hazard to people all over the world.

Shrestha, P., & Tamrakar, N. K. (2012) have observed that rivers in the Lesser Himalaya possess a higher capacity to flush out sediment compared to those in the Siwaliks, primarily due to the unstable slope conditions. Several studies have indicated that rivers in the northern Kathmandu Valley are far from being in equilibrium and face various issues related to bank erosion (Shrestha & Tamrakar, 2007a; 2007b). Guzman et al. (2017) have demonstrated the relationship between suspended sediment concentration and discharge, highlighting that concentrations are higher during low flow and lower during high flow.

The extraction of sand from unauthorized locations has resulted in detrimental effects such as riverbank degradation, the formation of localized deep holes, diversion of river flow due to unbalanced extraction from different river banks, and extraction exceeding the limits set by the DDC contract and related regulations. In light of these issues, the Natural Resources Committee of the Constituent Assembly (CA) has recommended that extraction should only occur after the preparation of an IEE/EIA report, accompanied by a comprehensive environmental management plan (UNDP, 2011). In mountainous rivers like Jhimruk, extraction activities are increasing in tandem with the development of engineering infrastructures, urbanization, and industrialization, ultimately leading to the degradation of river health. Gravel mining from river channels and floodplains is widespread globally due to its cost-effectiveness compared to other sources. This study aims to determine whether river mining is causing changes in the natural state of the river, identify the current and historical river channel patterns, and assess the problems faced by the local community resulting from mining-induced alterations in the river channel.

2. Materials and Methods

Study Area

Study was carried out in Jhimruk River of Pyuthan district which is in 28˚06'38"N and 82˚55'60"E. of the two upper tributaries of the West Rapti River, Pyuthan contains all of Jhimruk River (**Figure 1**). Jhimruk River has the capacity to produce 12 MW of electricity. The valleys have a subtropical climate with temperatures reaching 40˚ Celsius in May and falling to single digits in winter. The Jhimruk River is located in the Pyuthan district of Nepal, specifically within the Pyuthan Municipality area after the confluence of Lung River and Jhimruk River (Pokhrel & Bhandari, 2019). It flows through the municipality, adding to the natural beauty and resources of the region. The river originates from the Dhaulagiri Mountain range, which is part of the Himalayas. As it meanders

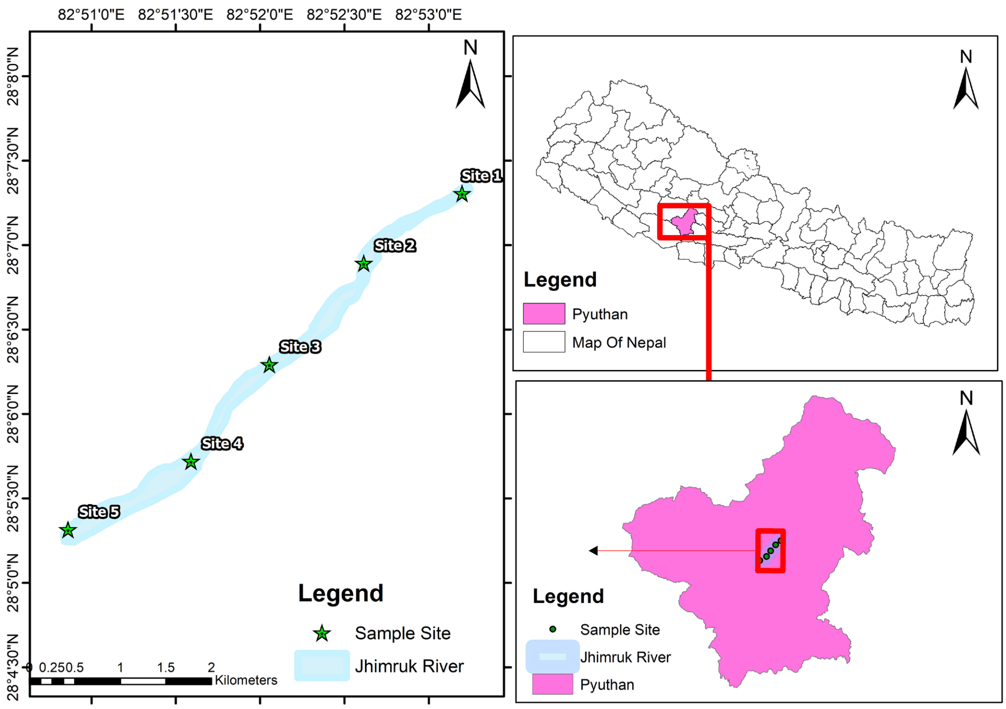


Figure 1. Detail location map of sampling sites for the study.

through the Pyuthan Municipality, it creates a scenic landscape characterized by lush greenery, rolling hills, and valleys.

The Jhimruk River is known for its clear, flowing water and is an important water source for irrigation and agricultural activities in the Pyuthan area. The river's presence enriches the fertile land along its banks, supporting the growth of crops and sustaining local livelihoods. In addition to its significance for agriculture, the Jhimruk River (Figure 2) is also utilized for hydropower generation. There are hydropower projects along the river, harnessing its flowing water to generate electricity for the region. The Jhimruk River in Pyuthan Municipality offers picturesque views and serves as a vital natural resource for the local communities. Its presence adds to the overall charm and ecological importance of the Pyuthan district, making it a notable landmark within the region.

Reference site (S1): It is located at the elevation of 831.0 m. Reference site S1 is 3 Km upstream of disturbed site S3.

Reference site (S2): Reference site S2 is located at elevation of 813.0 m.

Disturbed site (S3): Disturbed site S3 is located at the elevation of 804.0 m. S3 is a mining site also known as disturbed site.

Recovery site (S4); Recovery site S4 is located at an elevation of 789.0 m.

Recovery Site (S5): Recovery site S5 is located at an elevation of 771.0 m.

3. Methods and Data Analysis

3.1. Biological Assessment

3.1.1. Macroinvertebrate Sampling

Samples obtained from five distinct locations along the river (Table 1), each

Table 1. Physical characteristics measures in each sampling sites.

SN	Physical Characteristics	S1	S2	S3	S4	S5
1	Location	Khaprengkhola	Bagdhula	Tikuri	Bijuwar	Jumri dovan
2	GPS coordinates	28.128344˚ 82.900150˚	28.120634˚ 82.884749˚	28.113175˚ 82.876357˚	28.098615˚ 82.861865˚	28.088453˚ 82.846262˚
3	River Width (m)	32	39	20	18	18
4	River Depth (cm)	25	32	55	75	51
5	River Velocity (m/s)	0.41	0.841	0.75	0.65	0.34

Figure 2. Location overview of sampling sites on Jhimruk River using Google earth.

characterized by different substrate types. A representative 100-meter stretch of the stream was selected for the study. Both qualitative and quantitative methods were employed to collect macroinvertebrates. Qualitative sampling involved the use of a Kick net sampler with a net size of 1mm to collect macroinvertebrates from various habitats such as in-stream vegetation, stones, sand, and mud (Dickens & Graham, 2002).

3.1.2. Sample Sorting and Identification

Preserved samples were transported to the laboratory for further analysis and identification. In the lab, the samples were placed in petri dishes and identified up to the family level using the WEBS guideline as a reference (Table 2).

3.2. Physical Habitat Assessment

Water resource agencies conduct assessments that encompass several key aspects. These assessments typically involve providing a general overview of the site, evaluating physical characteristics and water quality, and visually assessing the quality of instream and riparian habitats. In certain states such as Idaho DEQ and Illinois EPA, quantitative measurements of physical parameters are also

Table 2. Transformation of GRS/ASPT value to water quality classes (Sharma & Moog 2005).

NEPBIOS/ASPT	Class	Description	Color Code
7.00 - 10.00	I	Non to very slight pollution	Blue
5.50 - 6.99	II	moderate pollution	Green
4.00 - 5.49	III	Critical pollution	Yellow
2.50 - 3.99	IV	Heavy pollution	Orange
1.00 - 2.49	V	Very heavy to extreme pollution	Red

included in the habitat assessment. Both physical characteristics and water quality parameters are crucial in accurately characterizing the habitat of the stream.

3.3. Water Quality Assessment

Studying physiochemical parameters is of utmost importance in order to obtain a precise understanding of water quality. By comparing the results of various physiochemical parameters with standard values, we can accurately assess the quality of water.

4. Data Analysis

4.1. Physical Habitat Assessment

4.1.1. Habitat Score

Scores are assigned based on the presence of various elements including point, side, and mid-channel bars, eroding cliffs, large woody debris, waterfalls, backwaters, and floodplain wetlands. Additional points are awarded for the diversity of channel substrate, different flow types, in-channel vegetation, distribution of bank-side trees, and the extent of near-natural land-use adjoining the river. These scores are aggregated to determine the Habitat Quality Assessment (HQA) score. Each parameter is assigned a value ranging from 0 to 20, and the scores from each endpoint are combined to calculate the overall Habitat Score.

4.1.2. Water Quality Index

Bach, 1980 developed index (Equation (1)) (A Chemical Index for Monitoring the Water Quality of Running Waters) is specific to monitoring the water quality of flowing or running waters, which is different from other indices. In this index for each parameter the transformed value raised to power of the weight of the parameter assigned and thus obtained eight values for eight parameters are multiplied to get chemical index of that site (Based on Table 3).

$$\mathrm{CI} = \prod_{i=1}^{n} q_i w_i \tag{1}$$

where, CI = Chemical Index;

q_i = Transformed value of each parameter;

w_i = relative weight of nth parameter;

$q_i w_i$ = Value for each parameter is given in the Bach 1980 water quality index.

Table 3. Weight assigned to each parameter (Bach, 1980).

Parameter	Unit	Importance Value (w_i)
Temperature	˚C	0.08
Oxygen saturation	%	0.20
BOD	mg/L	0.20
pH	pH scale	0.10
Nitrate	mg/L	0.10
Phosphorous	mg/L	0.10
Ammonia	mg/L	0.15
Electrical Conductivity	μs/cm	0.07
Total weight		**1.00**

After index calculation for each sampling site, the classification of the index has been done based on (Table 4) in different classes.

4.2. Biological Assessment

Biological Metrics

The following metrices were calculated for the macro-invertebrate's data analysis.

5. Results and Discussion

5.1. Habitat Score (Physical Habitat Assessment)

The results of the study indicate that after considering all the parameters, the obtained scores for the different sites were as follows: 176 for site1, 170 for site2 (reference site), 131 for site3 (disturbed site), 149 for site4 (recovery site), and 158 for site5 (recovery site). The score of the reference site falls within the optimal range, suggesting that the river at this site is in an optimal condition.

As we move from the reference site to the disturbed site (S3), the obtained score decreases, indicating a decline in the state of the river. The score of the disturbed site falls under the suboptimal range, suggesting that the water quality and overall condition of the river at this site are compromised.

Although the condition of the river improves in the recovery sites, both recovery sites still fall under the suboptimal range. This implies that while some progress has been made in restoring the water quality and overall health of the river, further improvements are necessary to bring it back to an optimal state.

The highest score obtained in the stream habitat assessment indicates that the status of the river is more natural in site1 (non-mining site) and less affected by mining and other anthropological effects in the Jhimruk River. The habitat score demonstrates variations among all the sites, with factors such as available in-stream cover, bottom substrate stability, riparian vegetation, and the aesthetic of the reach playing critical roles in influencing the total score.

Table 4. Water quality classification based on chemical index (Bach 1980).

CI	Water Quality Class	Water condition
>83	I	No or very low pollution
73 - 82	I - II	Low pollution
56 - 72	II	Moderate pollution
44 - 55	II - III	Critical pollution
27 - 43	III	Severe pollution
17 - 26	III - IV	Very severe pollution
<17	IV	Excessive pollution

Anthropogenic activities in riparian areas, such as reducing canopy cover and increasing sun's radiation, soil erosion, and siltation in rivers, are known to have a negative impact on stream habitat quality (Mbaka, 2010; Booth & Jackson, 1997). These activities can contribute to the fluctuations observed in the total score across the different sites.

The results suggest that the river's condition deteriorates from the reference site to the disturbed site, indicating the negative impact of anthropogenic activities. Although some improvements are observed in the recovery sites, the river's condition remains suboptimal. The study emphasizes the importance of considering various parameters, including stream habitat assessment, to comprehensively evaluate water quality and the overall health of the river. It also highlights the need for implementing measures to mitigate anthropogenic effects and restore the river's natural state.

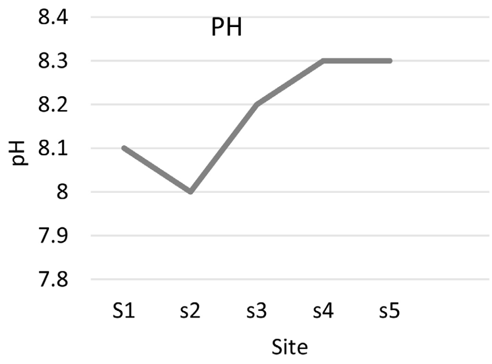
5.2. Water Quality Assessment

The water quality index (WQI) is an effective instrument for assessing and conveying information about water quality. The WQI utilizes physical, chemical, and biological factors to evaluate the quality of water in a specific area or source. The study conducted in the article examines the water quality of different sites, including reference sites, a disturbed site, a recovery site, and a final recovery site.

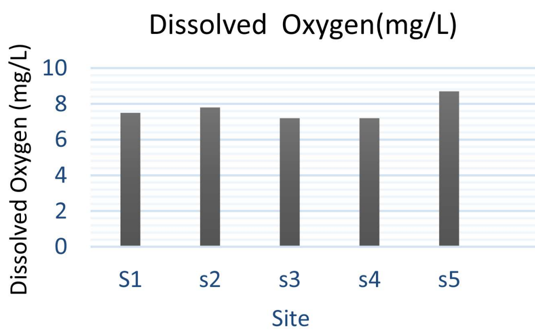
For the reference sites, the water quality class remained in the range of I-II, indicating low pollution levels. This suggests that the water quality in these areas is relatively good and meets the desired standards.

In contrast, the disturbed site exhibited a WQI value (as shown in **Figure 3**) of 62.204, falling under class II, which signifies moderate pollution. This implies that the water quality in the disturbed site is adversely affected by various pollutants, although it is not severely polluted.

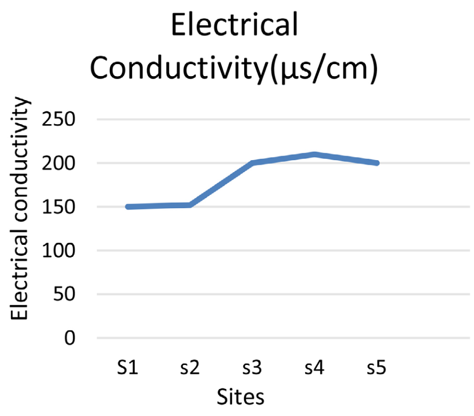
Moving towards the recovery site (S4), the WQI value obtained was 58.093, still falling within class II (moderate pollution). This indicates that although some improvements have been observed, the water quality has not fully recovered to a satisfactory level. It suggests that ongoing efforts may be required to further improve the water quality in this area.


PH
pH
8.4
8.3
8.2
8.1
8
7.9
7.8
S1 s2 s3 s4 s5
Site

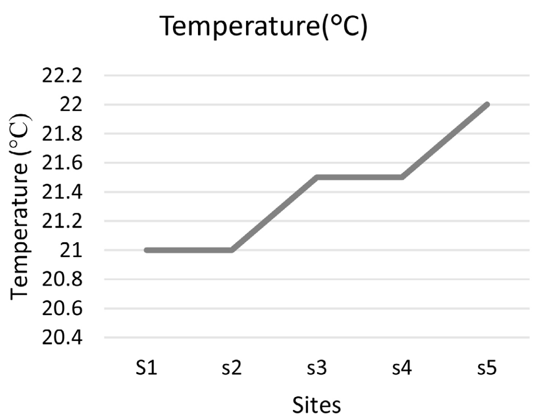
(a)


Dissolved Oxygen(mg/L)
Dissolved Oxygen (mg/L)
10
8
6
4
2
0
S1 s2 s3 s4 s5
Site

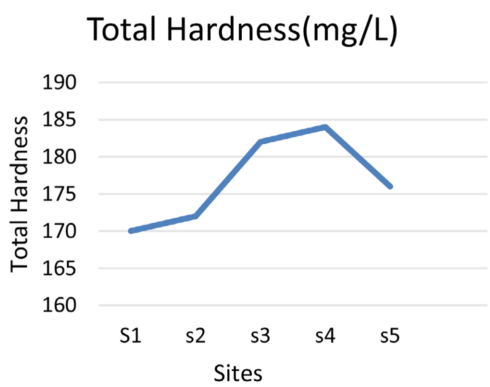
(b)


Electrical Conductivity(µs/cm)
Electrical conductivity
250
200
150
100
50
0
S1 s2 s3 s4 s5
Sites

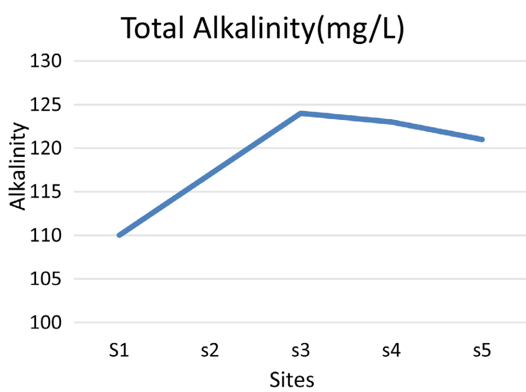
(c)


Temperature(°C)
Temperature (°C)
22.2
22
21.8
21.6
21.4
21.2
21
20.8
20.6
20.4
S1 s2 s3 s4 s5
Sites

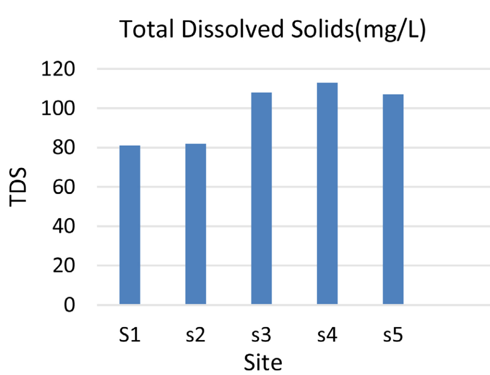
(d)


Total Hardness(mg/L)
Total Hardness
190
185
180
175
170
165
160
S1 s2 s3 s4 s5
Sites

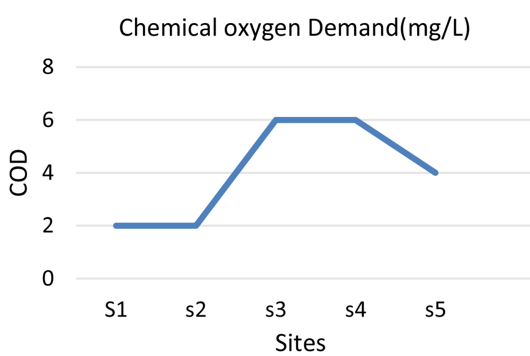
(e)


Total Alkalinity(mg/L)
Alkalinity
130
125
120
115
110
105
100
S1 s2 s3 s4 s5
Sites

(f)


Total Dissolved Solids(mg/L)
TDS
120
100
80
60
40
20
0
S1 s2 s3 s4 s5
Site

(g)


Chemical oxygen Demand(mg/L)
COD
8
6
4
2
0
S1 s2 s3 s4 s5
Sites

(h)

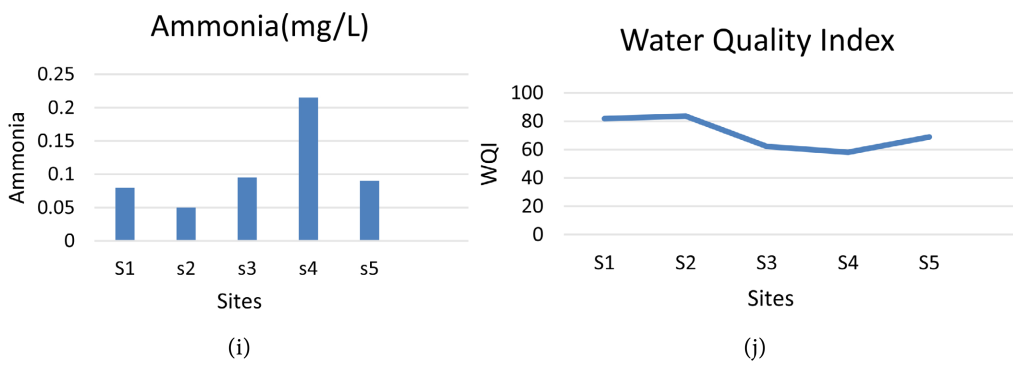


Figure 3. Water quality comparison data of sites (a) pH trend of each sites, (b) Dissolved Oxygen level of each sites, (c) Electrical Conductivity of each site, (d) Water temperature of each site, (e) Total Hardness of each site, (f) Total Alkalinity of each site (g) Total dissolve solids of each site, (h) Chemical oxygen demand in each site, (i) Ammonia Concentration at each site (j) Water Quality Index of Jhimruk River.

Finally, at the final recovery site, the WQI value obtained was 68.94, which falls under class II (moderate pollution). Despite the higher value compared to the previous sites, it still indicates a moderate level of pollution. This suggests that there has been some progress in the water quality improvement at the final recovery site, but further actions may be necessary to achieve a higher water quality class.

Overall, the findings of the study highlight the importance of the water quality index in assessing and monitoring water quality. They also emphasize the need for continued efforts to mitigate pollution and restore water quality to acceptable levels, particularly in the disturbed and recovery sites. The study provides valuable information for policymakers, researchers, and stakeholders involved in water resource management and pollution control.

5.3. Biological Assessment

Wetlands are highly productive ecosystems that hold significant ecological value. Aquatic macroinvertebrates, which are organisms living in water bodies, serve as indicators of environmental stressors. Different stages of their life cycle exhibit varying sensitivities to specific stressors, making them responsive to changes in their environment, particularly during vulnerable phases (Badruzzaman et al., 2007). These macroinvertebrates, acting as bio-indicators, possess diverse pollutant tolerances across species, making them well-suited for assessing site-specific pollution impacts and determining water quality.

Throughout the study period, a total of 273 individuals belonging to 7 different orders were identified in the Jhimruk River. Among the aquatic taxa, the benthic population was dominated by the order Trichoptera, which consisted of three families: Lepidostomatidae, Leptoceride, and Hydrospsychidae. On the other hand, taxa from the order Diptera were found in the least abundance.

Based on Table 5, the Shannon Weiner diversity index, a measure of species diversity, was found to be highest in the reference sites and recovery site 5, indicating

Table 5. Metric calculations.

SN	Metric Type (April)	Metrices	Calculation
1	Richness Measures	Taxa Richness	Total number of present taxa
		Number of EPT Taxa	Number of Ephemeroptera, Plecoptera and Trichoptera
		Number of Diptera	Present number of Diptera Taxa
		Simpson's index of diversity	$1 - D$, $D = \sum n(n-1)/N(N-1)$, where D = Simpson index, n = total number of ith taxa and N = total number of all taxa for a site
		Shannon-Weiner diversity index	$\sum p_i \ln p_i$, where where p_i = relative abundance of i^{th} taxa and S = taxa richness
2	Composition Measures	% of EPT	Percentage of EPT individuals in a site
		% of Diptera	Percentage of Diptera individuals in a site
3	Tolerance Measures	% of Tolerant species	Percentage of present taxa individuals with tolerance score > 6
		% of Facultative species	Percentage of present taxa individuals with tolerance score ≥ 4 to ≤6
		% of Intolerant species	Percentage of present taxa individuals with tolerance score < 4

greater ecological diversity in these areas. Conversely, the disturbed site 3 and recovery site 4 exhibited the lowest diversity index, suggesting a reduced variety of species in these locations.

Analyzing the GRS-BIOS/ASPT index (**Figure 4**), which assesses macroinvertebrate responses to pollution, all sites except the disturbed site fell into water quality class II, indicating a moderate level of pollution. However, the disturbed site 3 fell into class III, indicating a higher degree of pollution. This difference in classification suggests that the Jhimruk River is predominantly experiencing moderate to critically polluted conditions, possibly due to the presence of pollutant-tolerant species thriving under favorable conditions. The critical condition of disturbed site 3 could be attributed to the presence of the Chironomidae family, which is known to indicate deteriorating water quality.

In summary, the study highlights the importance of aquatic macroinvertebrates as indicators of environmental stressors and water quality. The abundance and diversity of macroinvertebrates varied across the different sites in the Jhimruk River, with the disturbed site 3 exhibiting a critical level of pollution, potentially influenced by the presence of pollutant-tolerant species such as the Chironomidae family. These findings emphasize the need for conservation and pollution mitigation efforts to preserve the ecological health of the Jhimruk River and its wetland ecosystem.

5.4. Morphology Analysis

The study utilized satellite images and GIS analysis to investigate the changes in river width at a mining site over a specified period. In 2014, the width of the river at the mining site was measured to be 172.14 meters. By 2017, the width had increased to 314.36 meters, indicating a significant change. Comparing the images from 2014 and 2017, a difference of 180.87 meters in width was observed

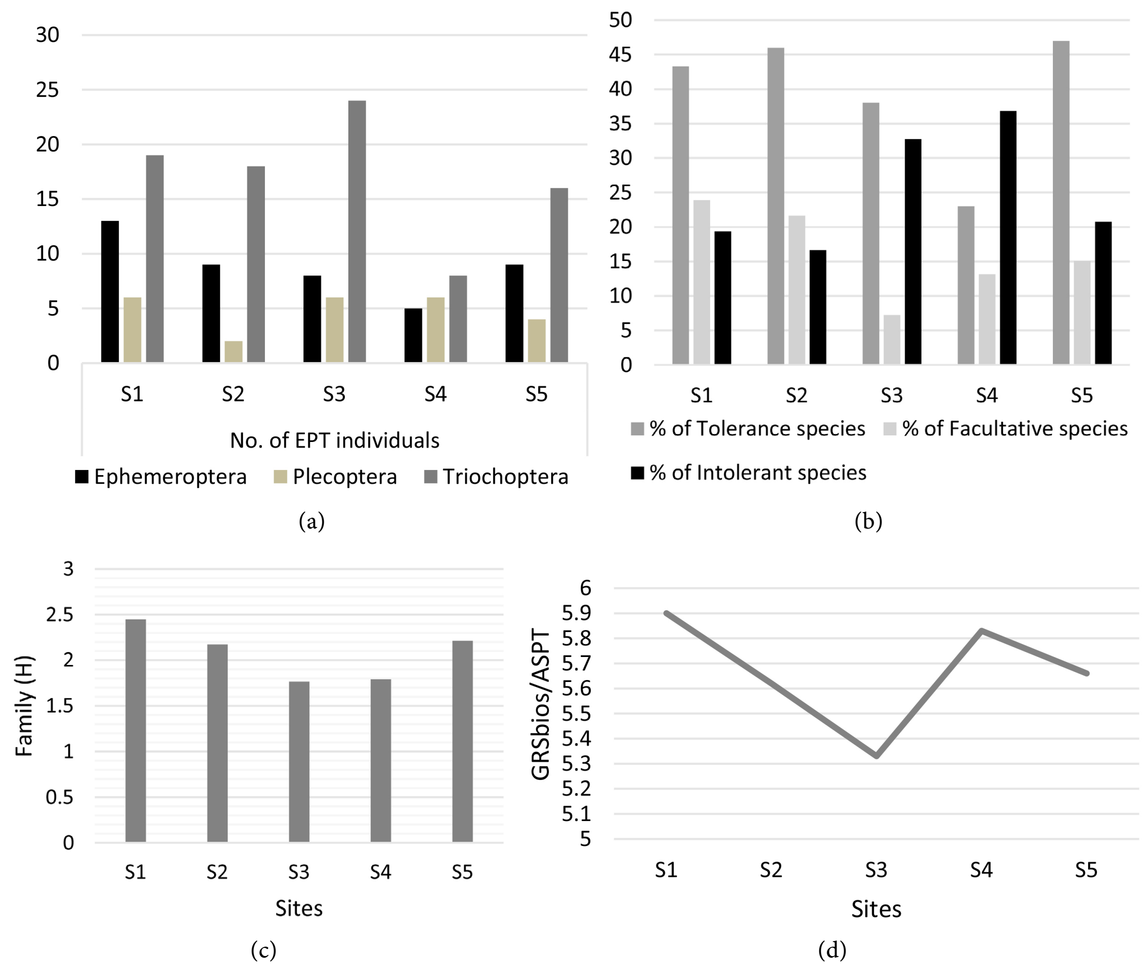


Figure 4. Biological assessment at each sites, (a) Number of EPT individuals in each sampling sites (b) Composition of tolerance, facultative and intolerant species (c) Shannon Weiner diversity index of each sites, (d) The GRSbios ASPT values in each sampling sites.

(as shown in **Figure 5**), providing clear evidence of morphological changes in the mining site over time.

The study further examined two reference sites to compare the morphological changes in the mining site. When comparing the images of the reference sites from 2014 and 2017, it was found that the changes in width were much smaller. Site S1 showed a difference of 92 meters, while site S2 exhibited a difference of 29 meters. Therefore, the mining site experienced a doubling of morphological change compared to the non-mining reference sites.

Although other factors such as floods and anthropogenic activities could potentially contribute to changes in river morphology, the impact of mining was found to be significant. Mining activities were primarily responsible for the observed morphological changes, which affected a considerable area of floodplain, resulting in the loss of agricultural land. This loss had severe consequences for the local population, as it led to the depreciation of high-value properties and negatively impacted their economic status. Additionally, the river channel also shifted from its previous position, resulting in infrastructure losses near the river.

Figure 5. Width of mining site (S3) of year 2014 and 2017.

Overall, the findings highlight the substantial influence of mining activities on river morphology. The study underscores the importance of considering the environmental impacts of mining and the potential socio-economic consequences associated with these changes. Efforts should be made to implement effective mitigation measures and sustainable mining practices to minimize the adverse effects on river systems and the surrounding communities.

6. Conclusion

In conclusion, this study highlights the potential harm that unregulated sand mining can cause to the ecology of rivers. The morphological analysis reveals significant changes in the river's shape and width over time. The disturbed site exhibited a substantial increase of 180 meters from 2014 to 2017, indicating a high degree of alteration.

The Water Quality Index (WQI) indicates a transition from low to moderate pollution as we move from the reference site to the disturbed and recovery sites (**Figure 6**). The GRS-BIOS/ASPT index further confirms this trend, with all sites except disturbed site 3 falling into water quality class II, while disturbed site 3 falls into class III, indicating a moderate to critical pollution level. The presence of the Chironomidae family may contribute to the observed pollution in the river.

Analysis of the physical habitat reveals that the reference sites are within the optimal range, whereas the disturbed sites fall into the sub-optimal range. Shannon Weiner diversity index indicates lower diversity in disturbed site 3 and recovery site 4. The presence of Odonata in some samples suggests varying sensitivities to pollution. The benthic population of aquatic taxa is dominated by the Trichoptera order. Abundant presence of Lebellulidae, which are intolerant of pollution, in the reference site and recovery site (site 5) indicates a moderate water quality.

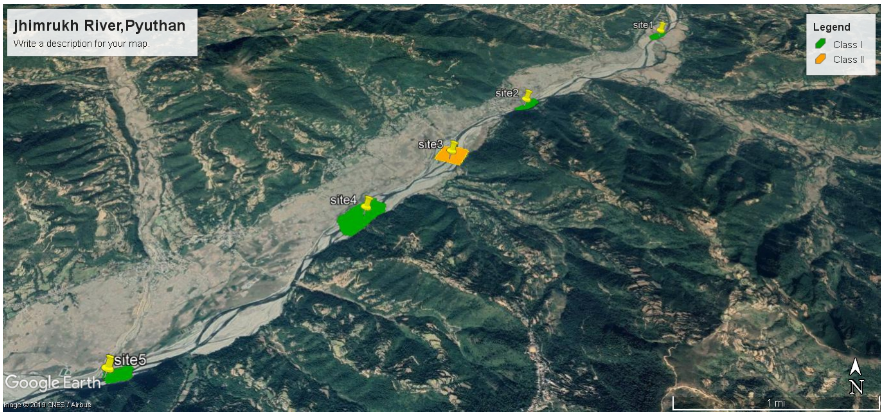


Figure 6. Water Quality Map of Jhimruk River.

Based on the findings, it is recommended that sand extraction from riverbeds should be conducted in an environmentally friendly manner, guided by a technical manual. Regular monitoring of rivers using river gauge stations installed in different locations should be implemented to study the anthropogenic influence on stream characteristics.

Overall, these recommendations and the findings of this study provide valuable insights for better managing sand mining activities and mitigating their detrimental effects on river ecology. It is essential to ensure sustainable practices and monitoring to preserve the health and biodiversity of river ecosystems.

Acknowledgements

We would like to extend our heartfelt appreciation and gratitude to Pyuthan Municipality and Mr. Anil Bhandari for their invaluable support, sincere help, and remarkable coordination during our field work.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Bach, E. (1980). Ein chemischer Index zur uberwachung der Wasserqualitat von FlieOgewassern. *Deutsche Gewasserkundliche Mitteilungen, 24,* 102-106.

Badruzzaman, A. B. M., Bari, M. F., Alam, M. S., Hoque, M. M., Habib, M. E., & Saha, M. (2007). Effects of Thermal Effluent Discharge on the Macroinvertebrate Abundance in the Sitalakhya River in Bangladesh. In *Proceedings of the Scientific Conference; Rivers of the Hindu-Kush Himalaya-Ecology and Environmental Assessment* (Vol. 113).

Baidya, H. (2003). *Twelve Years Struggle for the Conservation of Bagmati River*. Nepal Water Conservation Foundation, Kathmandu.

Booth, D. B., & Jackson, C. R. (1997). Urbanization of Aquatic Systems: Degradation Thresholds, Stormwater Detection, and the Limits of Mitigation. *JAWRA Journal of the American Water Resources Association, 33,* 1077-1090.
https://doi.org/10.1111/j.1752-1688.1997.tb04126.x

Dahal, K. R., Sharma, S., Sharma, C. M., & Bajracharya, R. M. (2012). Effects of Riverbed Extraction on Physicochemical Parameters of Tinau River, Nepal. *International Journal of Development and Sustainability, 1,* 255-267.

Dickens, C. W., & Graham, P. M. (2002). The South African Scoring System (SASS) Version 5 Rapid Bioassessment Method for Rivers. *African Journal of Aquatic Science, 27,* 1-10. https://doi.org/10.2989/16085914.2002.9626569

Gelabert, P. A. (2016). *Environmental Effects of Sand Extraction Practices in Puerto Rico in Managing Beach Resources in the Smaller Caribbean Islands*. http://nsgl.gso.uri.edu/pru/pruw96001/pruw96001_pt-b1.pdf

Guzman, C. D., Tilahun, S. A., Dagnew, D. C., Zegeye, A. D., Tebebu, T. Y., Yitaferu, B., & Steenhuis, T. S. (2017). Modeling Sediment Concentration and Discharge Variations in a Small Ethiopian Watershed with Contributions from an Unpaved Road. *Journal of Hydrology and Hydromechanics, 65,* 1-17. https://doi.org/10.1515/johh-2016-0051

Hayer, C., & Irwin, E. R. (2008). Influence of Gravel Mining and Other Factors on Detection Probabilities of Coastal Plain Fishes in the Mobile River Basin, Alabama. *Transactions of the American Fisheries Society, 137,* 1606-1620. https://doi.org/10.1577/T07-153.1

Kondolf, G. M. (1998). Lessons Learned from River Restoration Projects in California. *Aquatic Conservation: Marine and Freshwater Ecosystems, 8,* 39-52. https://doi.org/10.1002/(SICI)1099-0755(199801/02)8:1<39::AID-AQC250>3.0.CO;2-9

Kondolf, G. M., Williams, J. G., Horner, T. C., & Milan, D. A. V. I. D. (2008). Assessing Physical Quality of Spawning Habitat. In *American Fisheries Society Symposium* (Vol. 65). https://www.researchgate.net/publication/228369597_Assessing_physical_quality_of_spawning_habitat

Kowalska, A., & Sobczyk, W. (2014). Negative and Positive Effects of the Exploitation of Gravel-Sand. *Inżynieria Mineralna, 15,* 105-109.

Langer, W. H. (2003). *A General Overview of the Technology of Instream Mining of Sand and Gravel Resources, Associated Potential Environmental Impacts, and Methods to Control Potential Impacts*. USGS 02-153. https://doi.org/10.3133/ofr02153

Mbaka, J. G. (2010). *Impacts of Canopy Cover Variations and Organic Matter Dynamics on Benthic Invertebrate Community along Njoro River, Kenya* (97 p.). M.Sc. Thesis, Egerton-Kenya.

Pereira, K. (2012). *Sand Mining: The High Volume—Low Value Paradox*. Coastal Care.

Pokhrel, K., & Bhandari, B. P. (2019). Identification of Potential Landslide Susceptible Area in the Lesser Himalayan Terrain of Nepal. *Journal of Geoscience and Environment Protection, 7,* 24-38. https://doi.org/10.4236/gep.2019.711003

Sharma, S., & Moog, O. (2005). A Reference Based Nepalese Biotic Score and Its Application in the Midland Hills and Lowland Plains for River Water Quality Assessment and Management. In *Proceedings of the Conference Plant Response to Environmental Stress* (pp. 105-112). IBD and CO Publisher, Lucknow.

Shrestha, P., & Tamrakar, N. K. (2007a). Streambankerodability and Lateral Instability Hazard in the Manahara River, Kathmandu Basin, Nepal. *Journal of Nepal Geological Society, 35,* 55-66. https://doi.org/10.3126/jngs.v35i0.23640

Shrestha, P., & Tamrakar, N. K. (2007b). Bank Erosion and Bank Material Loss Potential in Manahara River, Kathmandu, Nepal. *Bulletin of Department of Geology, Tribhuvan University, Kathmandu, Nepal, 10,* 33-44. https://doi.org/10.3126/bdg.v10i0.1418

Shrestha, P., & Tamrakar, N. K. (2012). Morphology and Classification of the Main Stem

Bagmati River, Central Nepal. *Bulletin of the Department of Geology, 15,* 23-34. https://doi.org/10.3126/bdg.v15i0.7415

United Nations Development Programme (UNDP) (2011). *A Review of Current Practices of Revenue Generation from Natural Resources for the Local Bodies of Nepal*. Ministry of Local Development, Local Governance and Community Development Project (LGCDP), Nepal.

Villioth, J. (2014). *Building an Economy on Quicksand*. Environmental Justice Organisations, Liabilities and Trade. http://www.ejolt.org/2014/08/building-an-economy-on-quicksand