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Monitoring of Water Quality to Assess the Impact of Unscientific Sand Mining in the Catchment Areas of Umtyngar River, Meghalaya (North-Eastern India)

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ABSTRACT: Umtyngar River (Meghalaya, India) is the source of raw water for the supply of drinking water in Shillong City. However, Water quality of Umtyngar River is found turbid/ muddy due to impact of uncontrolled/ unscientific sand mining at the catchment area of the river. Citizens have occasionally reported the presence of an oily layer in the treated water from the Umtyngar River, supplied by Greater Shillong Water Supply, which is attributed to the excessive use of Alum to remove high levels of suspended solids in the river water. Thus, a scientific study was undertaken to investigate impacts on the water quality on the Umtyngar River caused by unscientific sand mining and to develop a sustainable management plan for restoration of river quality. Water samples were taken at upstream and downstream stations of Umtyngar River on a monthly basis starting from April, 2021 to November, 2022. Collected water samples have been analyzed for various physico- chemical parameters like pH, DO, BOD, COD, Conductivity, Turbidity, TSS& TDS. The sharp increase in values for the parameters conductivity, turbidity, and TSS in downstream station compared to upstream stations suggests that the majority of sand mining activities are located along the downstream station Umtyngar. Cluster Analysis & Principal Component Analysis also confirms that the downstream station Umtyngar is more affected by the unscientific sand mining at the river catchment area during the summer, monsoon, and post monsoon seasons of the year. Existing Sand mining practices were also deeply evaluated through extensive field visits. Particle size distribution of soil at the catchment areas was also examined to promote scientific sand mining practices and dry separation technology (like rotary sieving drum) to improve water quality in the river as well as considering economic angle of local communities.

Keywords: Cluster Analysis, Particle Size Distribution, Sustainable Management, Turbidity, TSS, Unscientific Sand Mining, Water Quality.

INTRODUCTION

The roots of human civilization germinate on the bank of the river. Rivers have been the foundation of human civilization for thousands of years. They are the veins of the earth that make life possible. However, river's never-ending maternal care, love, and devotion failed to decipher the sinister motive of highly ambitious human beings. In the ambition of growth & development, indiscriminate use of living & non-living sources, overexploitation of rivers as their garbage dumping site, changing of flow directions for their interests to create large compounds & industries and other related un-sustainable activities put forth a threat to river water quality and river dynamics as well as human civilization to a greater extent. Among these, rampant extraction of sands & gravels from the river-bed and river-bank is the most catastrophic activity that poses a huge menace to the river ecosystem. The associated process for removal of sand and gravel from their natural occurrence is referred to as "Sand Mining" (Langer, 2003). Due to its numerous applications, sand has grown to be a crucial component in our culture. In the world, roughly 40 billion metric tonnes of sand are extracted each year for a variety of uses including construction and the production of glass (Edwards *et al.*, 2015). River-borne coarser particles are a viable option for construction raw materials due to their durability and methodical sorting by fluvial action (Kondolf, 2002). Thus, Sand has integrated seamlessly into the growth of society.

Over time, the "culture-bearing" primates have developed unique strategies for extracting priceless sand from the natural environment. As per Wise-GEEK (2003), artisanal mining operations, which use a variety of hand tools and techniques, are a smaller-scale alternative to corporate large-scale mining for sand. This method of sand mining, which is quite common in developing nations and has a negative influence on river basin habitats, calls for prompt action and corrective measures. On the contrary, heavy machinery, high explosives, and chemical treatment are prevalently used in large-scale mining operations. Due to the significance of sand in the natural river ecosystem and the significant impact when sand is mined, the practice has come under more attention and has been outlawed as public awareness of the environmental consequences of sand mining in river catchment area has grown in recent years (Chauhan, 2010). Sand Mining is a low-investment industry that makes quick money (Goneka, 2013). Sand is in unprecedented demand due to the constantly expanding population and urbanization to meet the needs of the building sector (Victor, 2013). By hiring people to work in digging, loading, transporting & supplying, it generates employment prospects and subsequently income provision for the local community (Salifu, 2016). The negative aspect of this activity is that it has an influence on the environment, which further has an effect on other ways to those workers associated with sand mining (Victor, 2013; Chauhan and Kharumnuid 2012). Because of this, the impact of sand mining on livelihoods may be either beneficial, bad, or a mix of the two.

Sand plays a crucial function in protecting the coastal environment. First and foremost, it serves as a barrier against powerful storm surges and tidal waves by lessening their effects as they approach the shoreline. If sand is being mined at a very high rate, it could endanger surrounding bridges by causing the river mouth to widen due to erosion. Damage to infrastructure can result from instream sand mining, which degrades riverbeds (Channel incision), by undermining bridge piers and exposing hidden infrastructure, such as pipelines (Ashraf *et al.*, 2011). The river's water quality will be influenced by instream sand mining operations. The mining site's increased short-term turbidity is caused by sediment suspension, sedimentation from the storage and disposal of residual mining products, and organic particle matter. (Ashraf *et al.*, 2011; Sugden, 2013). In-stream mining may also result in the destruction of aquatic life. "Sand mining on either bank of the river upstream or downstream is one of the major causes of environmental degradation and hence poses a threat to biodiversity", stated the Indian Supreme Court in February 2011.

Meghalaya, one of the eight states that comprise India's North-Eastern Region (NER), is located between latitudes 25°02'E and 26°07'N and longitudes 89°49'E and 92°50'E. The Umtyngar River is the main source of raw water for drinking water supply at Shillong, Capital city of Meghalaya. Raw water from Umtyngar River (Meghalaya) falls into the Mawphlang Dam for water supply to Shillong city, India. Due to uncontrolled entry siltation to the rivers from unscientific sand Mining, water quality is affected. Moreover, the water quality of the Umtyngar River has been observed to be turbid/muddy. Citizens have occasionally reported the presence of an oily layer in the treated water from the Umtyngar River, supplied by Greater Shillong Water Supply, which is attributed to the excessive use of Alum to remove high levels of suspended solids in the river water. Further, previous studies by Shymbin and Nongbri (2022) focused to detect the impact of sand mining on the Umtyngar river's physical health of the Umtyngar river w.r.t the channel of the river along with some of the impact of sand mining on the livelihood of the local community in the catchment areas of the river. However, no scientific study exists till date on determining the impact of water quality due to unscientific sand mining at the catchment areas of Umtyngar river. Therefore, conducting a scientific study is necessary to establish a management plan in the river areas affected by sand mining. In this context, the objective of the study is to assess how unscientific sand mining has impacted the water quality of the Umtyngar River in Meghalaya and what parameters are the main drivers for such water quality change in the river. This essay also attempted to shed light on some of the sustainable sand mining techniques/technology to enhance both the river's water quality and the local community's standard of living.

MATERIALS & METHODS

A. Study Area

One of the main rivers in the East Khasi Hill District of Meghalaya, the Umtyngar River travels from the east to the south-west of the state, joining the Umiew River before falling into the Mawphlang Dam (Fig. 1). Geographically, the research area for the Umtyngar River is at the southern edge of Shillong, the state capital of Meghalaya. The study area altitude ranges between 900 meters to 1900 meters above sea level. The river is best suited to examine how sand mining affects river health since it has long been mined for high-grade sand that is exported to cities for construction purposes.

Different sites across the Umtyngar River have been chosen for this study. Following table (Table 1) depicts the upstream & downstream stations that have been considered for water quality assessment.

Table 1: Upstream & Downstream Locations for the Study.

Locations	Stations	Longitude & Latitude
Upstream	**Umiew**	**Longitude: 91°52'30''E Latitude:25°28'30''N**
Downstream	**Wah Khillon**	**Longitude: 91°49'0''E Latitude:25° 27'0''N**
		Longitude: 91°49'30''E Latitude:25°28'30''N

B. Methodology

Water samples were taken at upstream and downstream stations on a monthly basis starting from April, 2021 to November, 2022. Three locations were used for the sampling activity: one downstream (Umtyngar) and two upstream (Umiew and Wah-Khillon) stations. The sites for sample were chosen after considering the resources available for experimental sampling and checking water quality characteristics. The water samples were collected in 1-liter sample vials, kept chilled at 4° C, and shipped as quickly as possible to the lab for physicochemical parameter estimations.

Collected water samples have been analyzed for the following parameters: pH, Dissolved oxygen (DO, in mg/L), Biological Oxygen demand (BOD, in mg/L), Chemical Oxygen Demand (COD, in mg/L), Conductivity (EC), Turbidity, Total Suspended Solids (TSS) & Total Dissolved Solids (TDS) as per the analysis procedures recommended by the "American Public Health Association (APHA, 2017)". Physicochemical characteristics were analyzed in Central Pollution Control Board, Regional Laboratory-Shillong. The study adopted quantitative method to assess the impact on water quality of Umtyngar River in Meghalaya due to unscientific sand mining in the river-catchment areas. The research work is accomplished by extensive field visits, water sample collection from both upstream & downstream stations of the river, where sand-mining is majorly prevalent. This work has also made an attempt to recommend about the sustainable sand mining technologies to reduce the impact in the water quality of Umtyngar River.

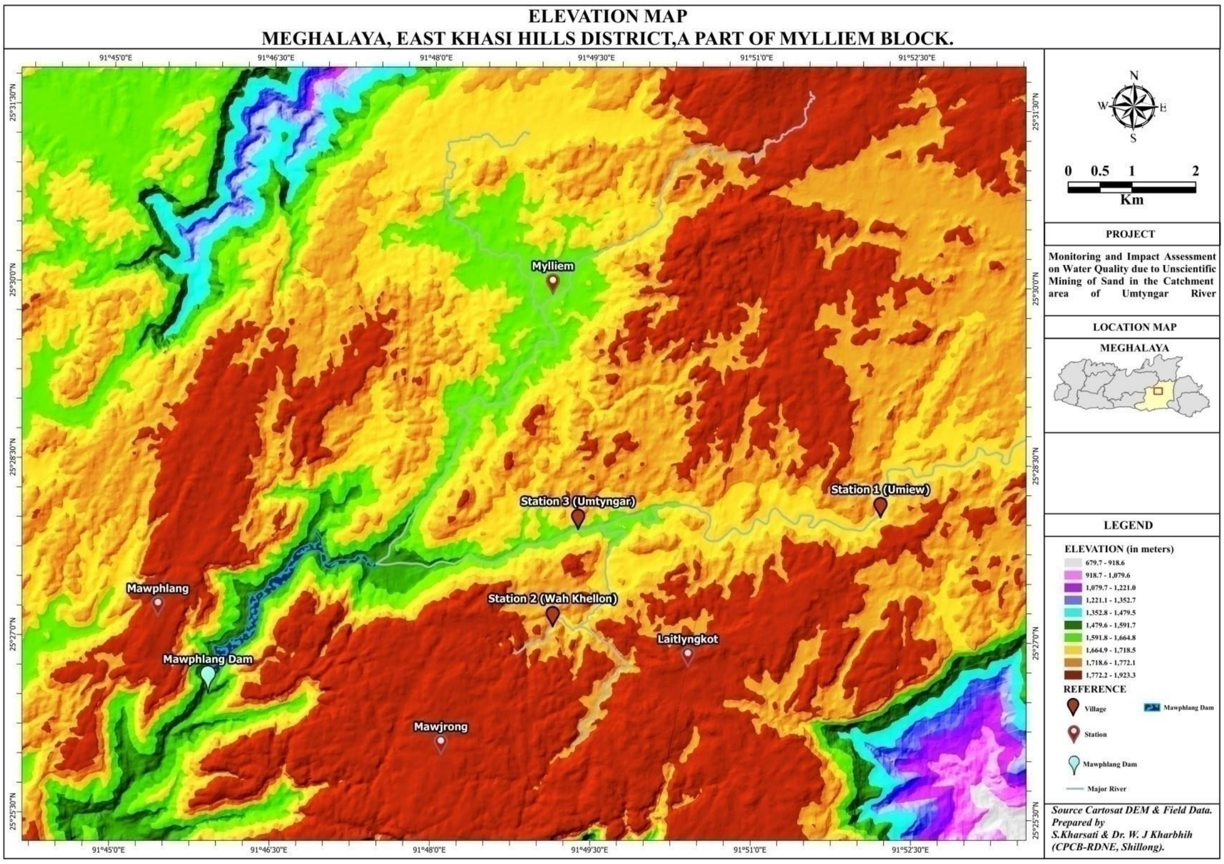

Fig. 1. Elevation Map of the Study Area (Umtyngar River Catchment Area).

C. Water Quality Criteria

Designated best use water quality criteria Matrix as per Central Pollution Control Board, MoEF&CC, India(https://cpcb.nic.in/wqm/Designated_Best_Use_Water_Quality_Criteria.pdf) Guidelines was used to assess the water quality of the collected samples.

D. Statistical Analysis

Some univariate (correlation matrix) & multi-variate statistical analysis (Cluster Analysis & Principal Component Analysis) were carried out using PAST 4.0 software.

RESULTS & DISCUSSION

A. Water Quality Assessment

No significant influence on pH Values of the river water from both downstream and upstream sites was noticed, the values are found to be within range 6.5-8.5 (Fig. 2). No significant impact of sand mining on DO/BOD/COD trends from summer'21 to Monsoon'22 is observed in both upstream & downstream stations. Both upstream stations (Umiew & Wah-Khillon) and Downstream station (Umtyngar) almost conformed the CPCB criteria for drinking water source without conventional treatment in terms of DO ($\geq$ 6 mg/L) & BOD5 (20◦ C) ($\leq$ 2 mg/L). Only during winter'21 & winter '22 timeline, the BOD5 value for downstream stations is slightly greater than 2 mg/L (Fig. 3, Fig. 4 & Fig. 5). The value of Turbidity increases significantly on summer & monsoon season for the downstream station. Moreover, conductivity of the water in both downstream & upstream stations has increased in post monsoon season because of the fact that rainfall causes more rocks to dissolve, which increases the amount of conducting ions in water samples. The sharp rise of values for the parameters-conductivity, turbidity & TSS in downstream station during the Summer, Monsoon, Post-Monsson seasons compared to the upstream stations may be an indication that the downstream station Umtyngar is influenced by the effect of any external activities (Fig. 6, Fig. 7 & Fig. 8).

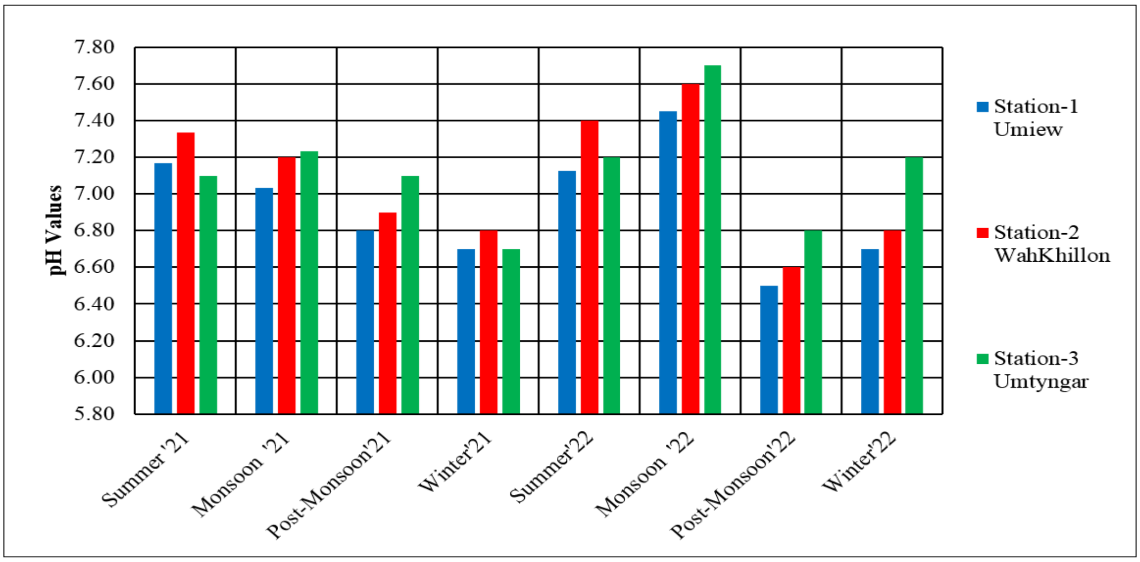

Fig. 2. Seasonal Variation of pH Values at upstream & downstream stations.

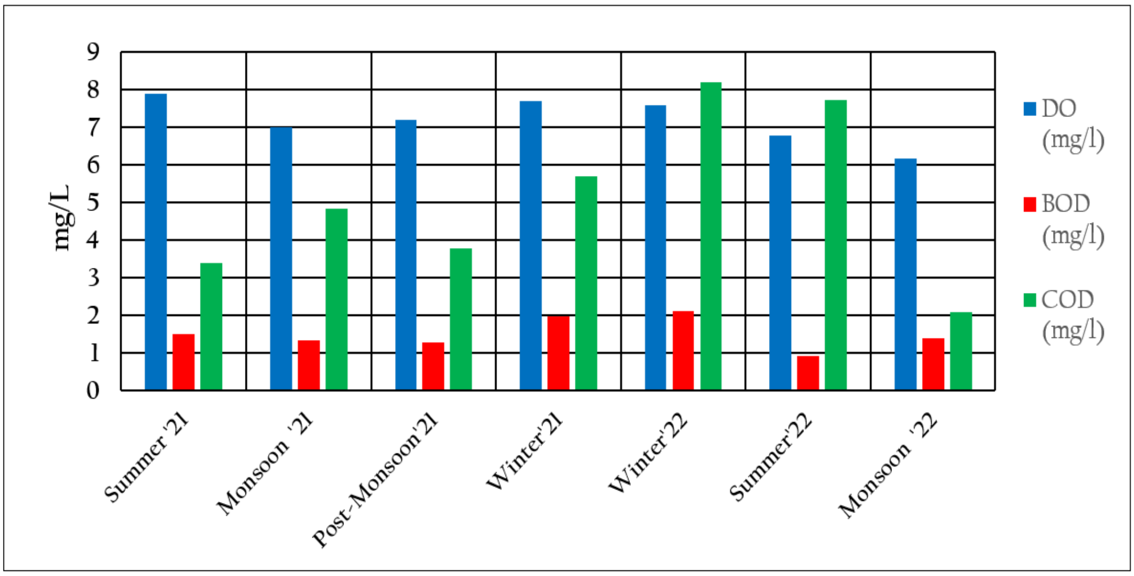

Fig. 3. Seasonal Variation of DO/BOD/COD Values at Umiew (upstream station).

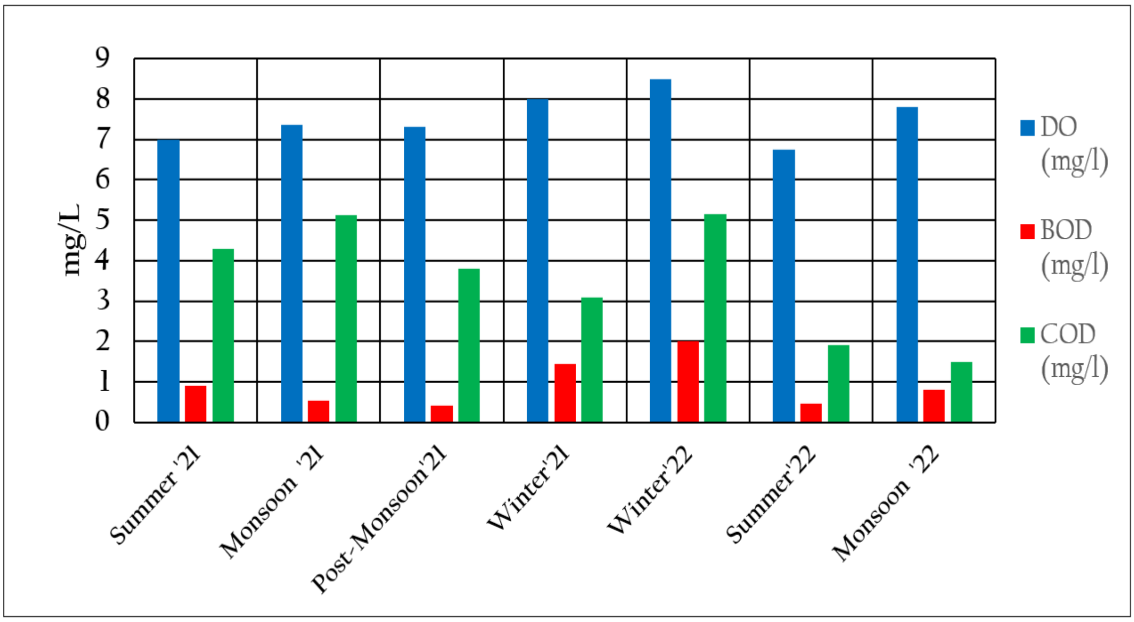

Fig. 4. Seasonal Variation of DO/BOD/COD Values at Wah-Khillon (upstream station).

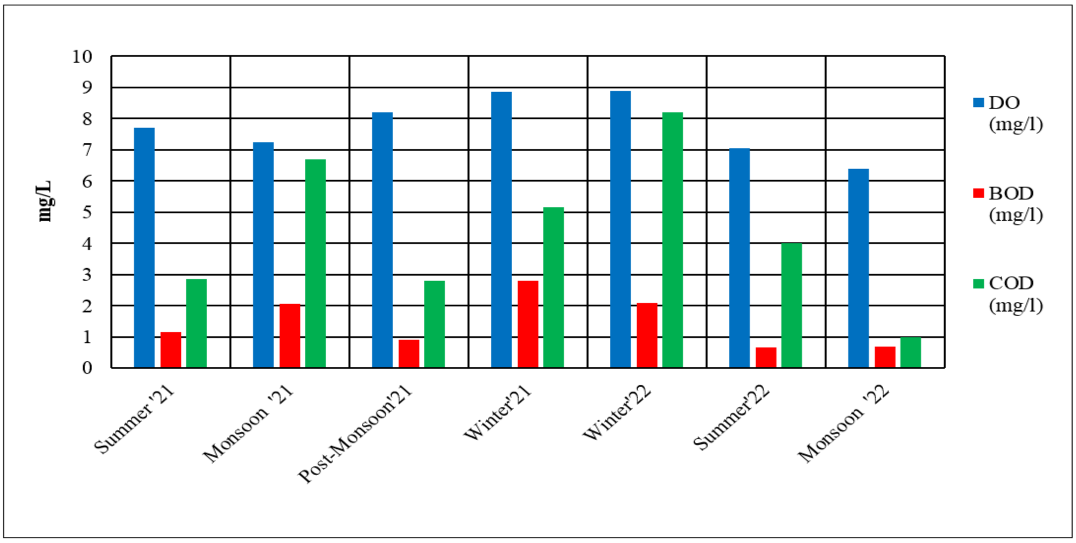

Fig. 5. Seasonal Variation of DO/BOD/COD Values at Umtyngar (down-stream station).

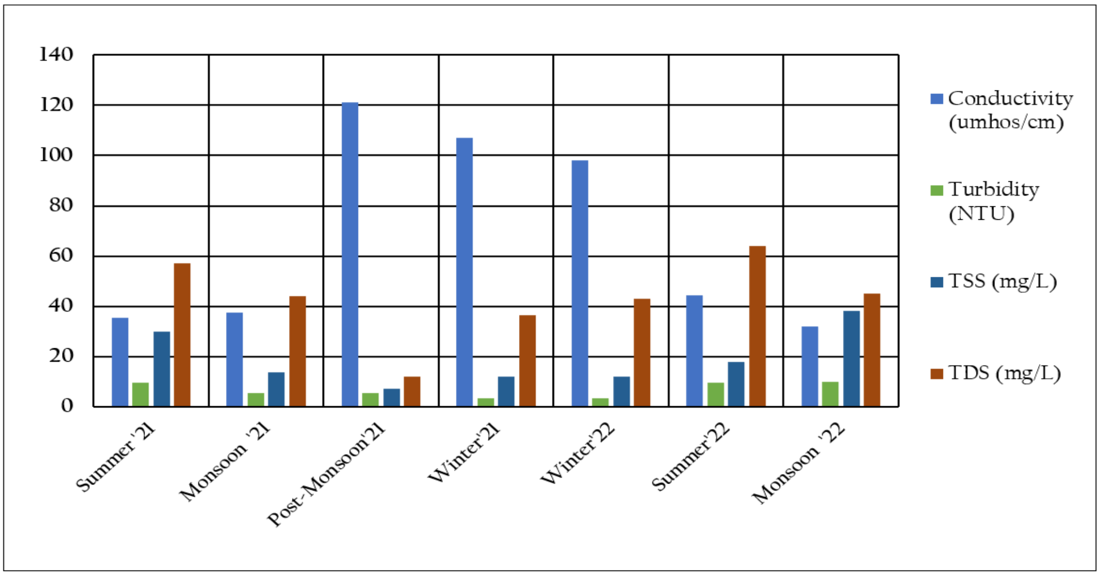

Fig. 6. Seasonal Variation of Conductivity/Turbidity/TDS/TSS Values at Umiew (upstream station).

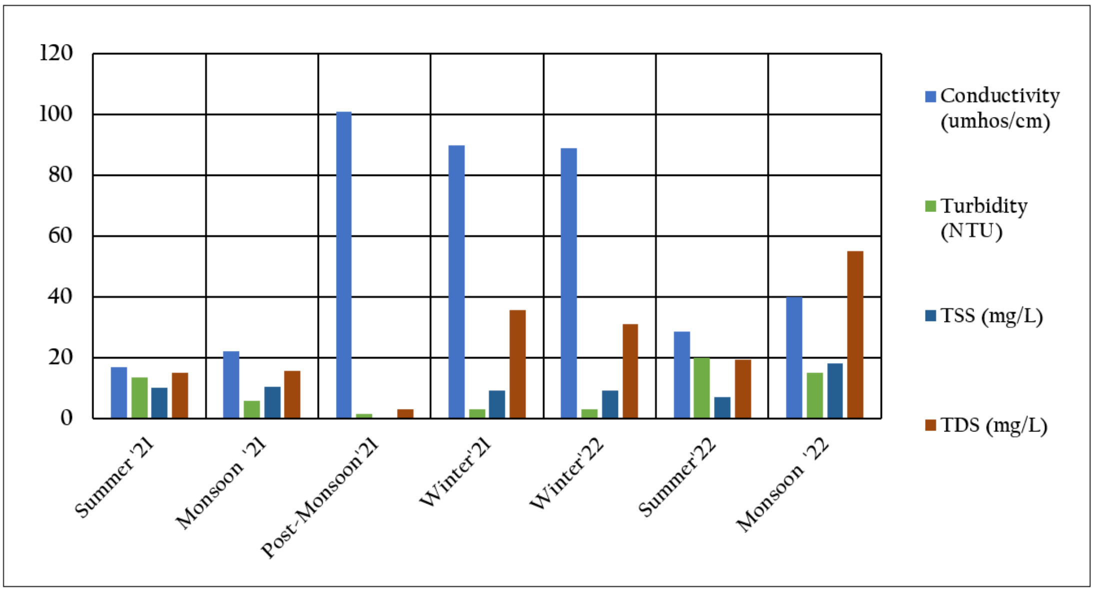

Fig. 7. Seasonal Variation of Conductivity/Turbidity/TDS/TSS Values at Wah-Khillon (upstream station).

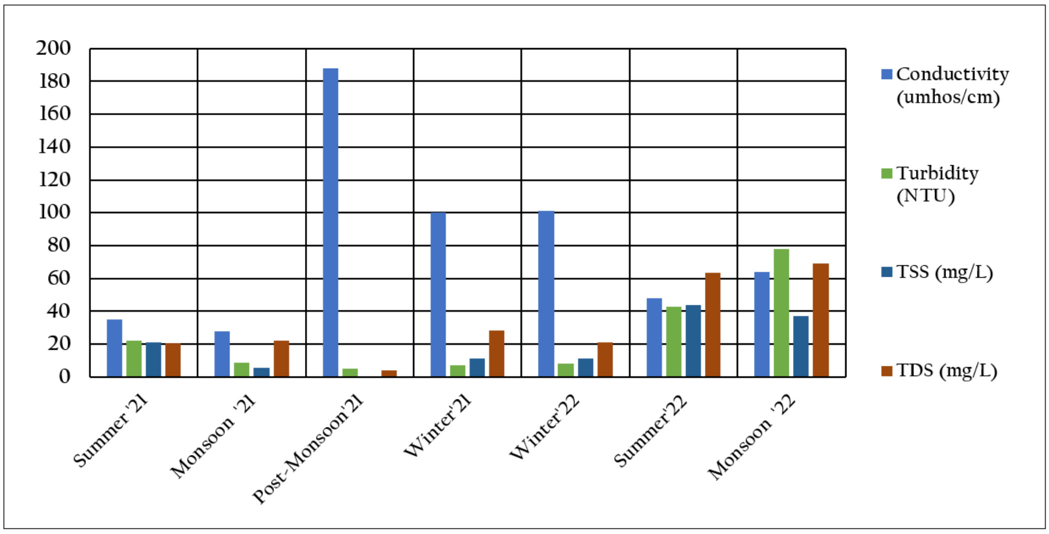

Fig. 8. Seasonal Variation of Conductivity/Turbidity/TDS/TSS Values at Umtyngar (down-stream station).

During field visit, it was confirmed from the local communities that majorly sand mining activities happens around the Summer & Monsoon season of the year. However, we need to explore relationship between sampling stations & seasons to be able to comment on the effect of sand mining in the water quality. Station wise Cluster Analysis is required to understand more clearly seasonal similarly of the water quality data and hence, the impact of Unscientific Mining on the water quality.

B. Cluster Analysis

Cluster Analysis (CA) is the task of grouping of set of data points in such a way that data sets in the same group are more similar to each other than those in other groups. As a result, it is a very useful tool for assessing water quality data and determining the relationship between sampling stations and seasons. In order to potentially simplify our description of observations by allowing us to recognize the structure or patterns in the midst of muddled data, CA analyses groupings and sets of variables with similar qualities. The most popular method of CA is Bray-Curtis cluster analysis, which is frequently represented by a dendrogram and demonstrates the apparent similarities between each sample and the entire dataset. A visual depiction of the clustering operations, the dendrogram provides a picture of the groups and their proximity with a significant reduction in the dimensionality of the original data (Shrestha & Kazama 2007).

In present assessment, Cluster analysis (CA) was performed to find similarities between the upstream & downstream sampling sites and the four seasons during the course of the study. By grouping all three seasons and sample locations according to the degree of similarity and dissimilarity between water quality parameters, CA created a dendrogram. Fig. 9, 10 and 11 shows the dendrogram of the similarity index (value ranges from 0-1) of all four seasons with sampling sites based on physico-chemical parameters. The similarity index closer to one (1) signifies there is ~100% similarity between the data sets.

Dendrogram for the upstream stations (Wah-Khillon & Umiew) shows only two clusters (Fig. 9 & 10). In both the stations, Summer-Monsoon datasets are forming clusters with almost 75%-85% similarity whereas Post-Monsoon –Winter (2021-2022) cluster has almost 90%-95% similarity. This trend is as per our general understanding of seasonal variation of water quality. In contrast, the dendrogram for the station downstream (Umtyngar) displays three clusters, namely: the Summer'22 and Monsoon'22 data sets form one cluster; the Summer'21, Monsoon' 21 & Post Monsoon'22 data sets form second cluster; and the Winter'21, Winter '22 & Post Monsoon'21 data sets form third cluster. More specifically, there is only about 65% similarity between the post-monsoon of 2021 and the winter of 2021–2022 in the third cluster previously indicated. Two distinct clusters of data sets of summer-monsoon seasons in two different years (2021 & 2022) can be explained by the road construction operations in the area around the downstream station during the monsoon/summer season of 2022. The dendrograms' tendencies indicate that something unusual activity occurred in the months of summer, monsoon, and post-monsoon of the year 2021 & 2022, that has completely disturbed the similarity index (Fig. 11).

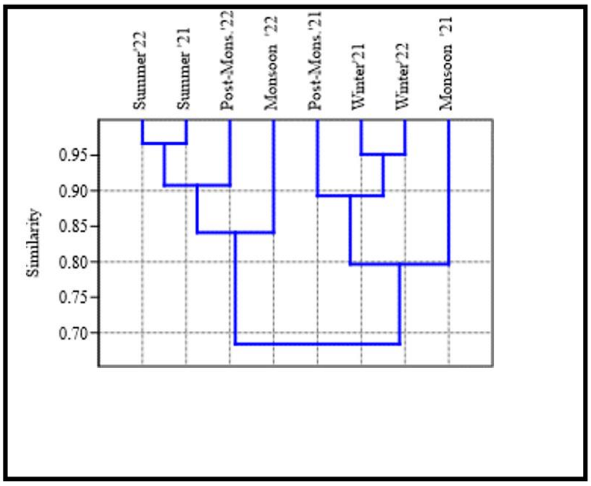

Fig. 9. Bray-Curtis cluster analysis at Umiew (up-stream station).

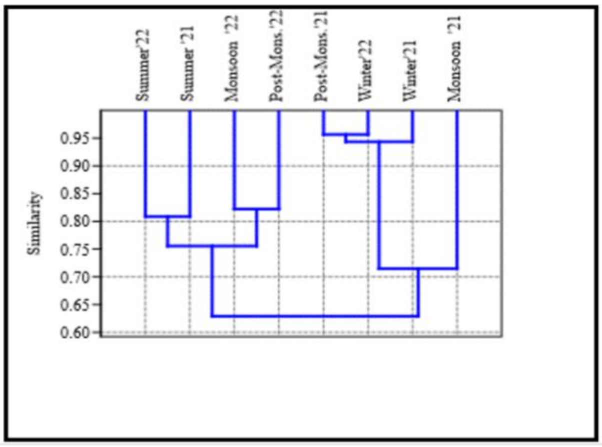

Fig. 10. Bray-Curtis cluster analysis at Wah-Khillon (up-stream station).

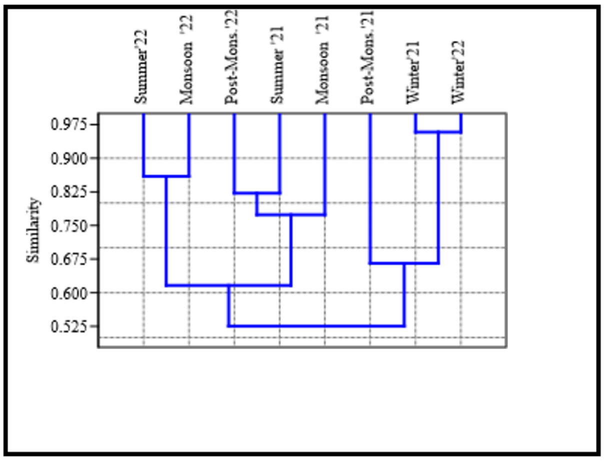

Fig. 11. Bray-Curtis cluster analysis at Umtyngar (down-stream station).

Additionally, a field investigation of the region also supports the cluster analysis findings. During the winter months, it is found that sand mining along the riverbank is suspended. Therefore, the downstream station Umtyngar is more affected by the unscientific sand mining at the river catchment area during the summer, monsoon, and post monsoon seasons of the year.

C. Principal Component Analysis (PCA)

Complexity of high dimensional data is reduced via PCA but trends and patterns are preserved. It accomplishes this by reducing the number of dimensions in the data. This will give us an idea about cumulative data variability. Table 3 tells us that for upstream station (Wah-Khillon) PC1 represents 35 % data variability with strong relation with DO, BOD & Conductivity and PC2 represents ~24% data variability with strong relation with TSS; whereas Table 4 depicts that fact that for downstream station (Umtyngar) PC1 represents 41.2 % data variability with strong relation with Turbidity and TDS, & PC2 represents ~19.1% data variability with strong relation with conductivity.

Current Practices & Recommendations of Sustainable Practices

Unscientific sand mining is more prevalent in the Umtyngar downstream station. Current practices involve digging out a small (~ 1m × 1 m × 1 m) pond on the bank of the river, where water is stored and pumped for washing clay, sand, and gravel from the Umtyngar River catchment region to remove the clay using a large gritted chamber/stage and separate the useful sands and gravels. Following that, the water that has been rinsed off is immediately released into the river (Fig. 12). The water discharge during peak seasons of summer and monsoon is approximately 500-1000 liters per hour.

Table 2: Principal Component Loadings for water quality parameters in Umiew (up-stream station).

	PC 1	PC 2	PC 3
Eigen Value	3.116	1.698	1.387
% Variance	38.952	21.226	17.340
Cumulative	38.952	60.178	77.518
pH	-0.449	0.330	-0.063
DO (mg/l)	0.241	0.628	0.185
BOD (mg/l)	0.407	0.350	0.050
COD (mg/l)	0.378	-0.167	0.401
Conductivity (µmhos/cm)	0.412	0.084	-0.436
Turbidity (NTU)	-0.428	-0.102	0.104
TSS (mg/L)	-0.277	0.555	0.200
TDS (mg/L)	0.047	-0.148	0.747

Table 3: Principal Component Loadings for water quality parameters in Wah-Khillon (up-stream station).

	PC 1	PC 2	PC 3
Eigen Value	2.796	1.949	1.234
% Variance	34.951	24.362	15.431
Cumulative	34.951	59.313	74.744
pH	-0.676	0.586	0.010
DO (mg/l)	0.828	0.395	-0.084
BOD (mg/l)	0.761	0.392	-0.105
COD (mg/l)	0.293	-0.166	0.883
Conductivity (µmhos/cm)	0.740	0.107	-0.424
Turbidity (NTU)	-0.601	0.002	-0.448
TSS (mg/L)	-0.283	0.858	0.194
TDS (mg/L)	0.047	-0.148	0.747

Table 4: Principal Component Loadings for water quality parameters in Umtyngar (down-stream station).

Eigen Value	PC 1	PC 2	PC 3
% Variance	3.297	1.531	1.289
Cumulative	41.217	19.136	16.114
pH	41.217	60.353	76.467
DO (mg/l)	0.380	-0.125	0.691
BOD (mg/l)	-0.649	0.009	0.483
COD (mg/l)	-0.707	0.531	0.191
Conductivity (µmhos/cm)	-0.401	0.820	0.225
Turbidity (NTU)	-0.396	-0.612	0.529
TSS (mg/L)	0.858	0.069	0.317
TDS (mg/L)	0.690	0.311	0.332
Eigen Value	0.837	0.289	-0.018

As a result, the water downstream becomes extremely murky, which makes it difficult to process the water from the Mawphlang Dam. The wash water can be treated before discharging the same into the river. To stop the downstream river water quality from declining, an alternative sustainable dry separation technology must be implemented.

A. Separating Sand & Gravel @ River bank

B. Discharging of rinsed water directly into the river (downstream station)

Fig. 12. Current Sand Mining Practices at Catchment areas of Umtyngar River (down-stream station).

Soils consisting of sand, gravel & clay from different sites of Umtyngar River Catchment Area (down-stream station) have been collected for better understanding of particle size distribution in these downstream regions. This data will help us in recommending dry separation technology for separating sands & gravels instead of wet separation technology of washing the sands, gravel & clay with water. Sieve analysis of soil is one of the straightforward procedures of determining particle size distribution. It divides an aggregate sample into fractions, each containing particles of the same size.

To avoid lumps of small particles, eliminate moisture, and prevent clogging of the finer sieves, the collected soil was air dried before sieving. Fig. 13 illustrates the gradation curve of the collected soil samples from different sites of downstream station catchment areas of Umtyngar river. From the curve, it is very much evident that the analyzed material is well graded i.e. the soil sample has a considerable range of particle size. (C_u =5.6 & C_c=1.197). The sieved sample contains ~ 52% of gravel (diameter >2 mm), ~ 38% of coarse sand particles (diameter 0.5mm-2mm) and ~10% of fine sand & clay/silt particles (<0.5 mm). Considering the high percentage of gravels in the downstream section catchment areas, dry separation technology like rotary sieving drum (manual/automatic) may be used to separate sand and gravels of desired size using customized sieves of desired mesh size.

The motor, frame, funnel, reducer and hexagonal drum are the five components that make up the rotary sand and gravel screening machine. On the one hand, while the drum turns, the shattered stone that has entered it is screened. On the other hand, the large-particle stone moves ahead up the drum's slope and is gradually filtered out by screens with various mesh sizes. Small stones are sieved out and dropped into the appropriate hoppers; from there, they are moved manually or by gravity to the pile of finished goods. These rotary sieving machines may be customized based on the need of the sand miners and can be a good viable option rather than using wet separation technology using water.

In spite of strict regulations by government and local authorities, it is evident that mining of sand & gravels is still being practiced to some extent unlawfully & unsustainably by local communities to make their livings (Dolbear, 2012; Eggert, 2001). Apart from imposing strict regulations, mass awareness campaigns regarding sustainable sand mining process should be practiced among the local villagers & communities. In addition to that, already piled-up clay materials at the river bank of Umtyngar station should be disposed of in a more productive means like using the clay materials in making useful items such as pottery/utensils, bricks for village house construction etc. The local authority can also help the villagers to make a separate washing pond and effluent washing water treatment unit to ensure minimal impact on river water quality as well as villagers' livelihood. The distance between sand and gravel mining locations will be based on the river's frequency of replenishment. The extracted amounts of sand and gravel should be compared to the sediment rating curves created for the potential sites. Prior to beginning mining, the mining area should be marked off with pillars and geo-referenced.

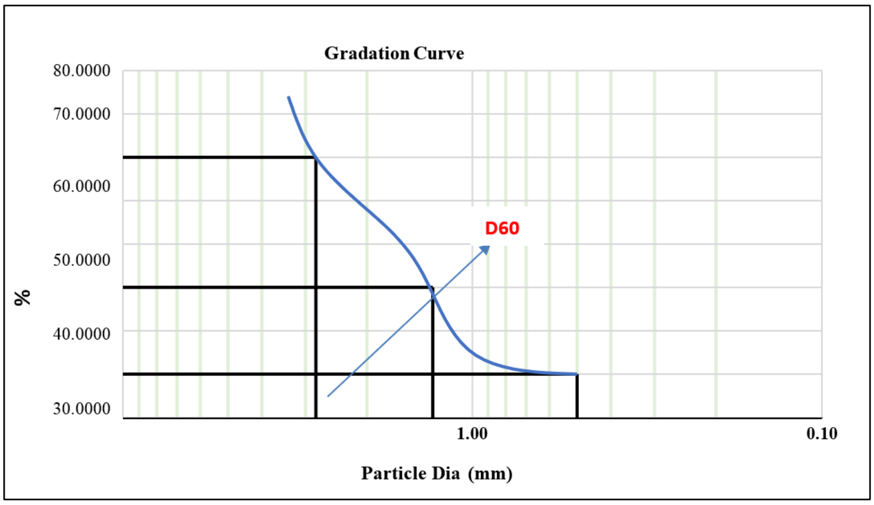

Fig. 13. Gradation curve of soil sample from different sites of downstream station (Umtyngar).

CONCLUSION

The land, water, biotic, social and human environments have all suffered irreparable harm as a result of large-scale sand and gravel extraction from river banks. This is especially true of the rivers in Meghalaya in Northeast India, which are small and have few resources for riverbeds. In the present study undertaken, Physicochemical characteristic analysis of Umtyngar river water at different upstream & downstream stations throughout different seasons of the year and subsequent statistical analysis indicated that unscientific Mining of sands and gravels at the surrounding (East Jaintia) hills on the river bank of Umtyngar river is posing a great threat in water quality majorly in downstream station i.e., Umtyngar. The river water quality at downstream station Umtyngar is worst during the time of summer and monsoon. Apart from illegal mining, road construction activities in surrounding downstream stations (station-3) during the summer and monsoon of the year 2022 have also contributed in the deterioration of the water quality in terms of turbidity and TSS.

It can be said that there is a pressing need to learn more about the intricate problems caused by sand mining activities on the way of life of nearby local communities. All stakeholders in the sand mining industries must work together to develop strategies for implementing sustainable mining practices. The information gathered during this inquiry, along with its analysis and interpretation, will help people better understand the condition of the water and the effects of unreliable sand mining on the Umtyngar River's catchment areas. More of these core investigations will be needed in the future, along with appropriate scientific monitoring techniques, in the Umtyngar Catchment area to keep the physico-chemical parameters under control for the benefit of the river's biotic components as well as for the greater good of humanity.

FUTURE SCOPE

The future scope of the study entails conducting further investigations and employing scientific monitoring techniques in the Umtyngar Catchment area to assess the physicochemical parameters of the river water, aiming to mitigate the detrimental effects of unscientific sand mining and related activities on water quality. Collaboration among stakeholders in the sand mining industry is imperative to develop sustainable mining practices, while studying the intricate issues caused by sand mining activities on local communities is crucial. This study will contribute to a better understanding of water conditions and the impacts of unreliable sand mining, which will act as a guidance for future to safeguard catchment areas of the Umtyngar River for the well-being of the river's ecosystem and humanity at large.

Conflict of Interest. The Authors declare no conflict of Interest.

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