Journal of Engineering Issues and Solutions

Utilizing alluvial deposits in Tamor River, Eastern Nepal: construction material suitability and extraction impact

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Received: March 30, 2024; Revised: June 01, 2024; Accepted: June 30, 2024

doi: https://doi.org/10.3126/joeis.v3i1.64336

Abstract

The Tamor River, a tributary of the Koshi, has a potential to contribute construction raw materials for ongoing infrastructure development initiatives of the Koshi Province in the Eastern Nepal. However, due to the dynamic nature of river morphology and varying quality of alluvial deposits, it demands a rigorous testing of their suitability for construction purposes. This study aims to locate potential sites for material extraction, assess physical properties of available floodplain deposits, and evaluate potential adverse effects of extraction. Data were collected from field observations, structured interviews with local stakeholders, and consultation with experts/professionals. Field study encompassed an 85-kilometer stretch of the Tamor River, from Dovan to Mulghat. Results indicated the presence of alluvial deposits along the river's entirety, with optimal extraction sites identified between Majhitar and Phalametar. Material available in the stretch from Limbunighat to Phalametar meets acceptable quality standards, albeit declining in the lower stretches of the study section. Adverse effects of extraction appear minimal and manageable with appropriate precautions. Consequently, it is recommended to extract materials for small-scale construction projects, ensuring adherence to safety protocols and confirming suitability through testing. Further investigations into Tamor River's primary tributaries are advised to comprehensively assess resource potential.

Keywords: *Availability, construction materials, suitability, Tamor river.*

1. Introduction

Continued urbanization and industrial expansion have resulted rise in demand for construction aggregates over the years and will continues to rise (Kisku, et al., 2017). However, sustainability challenges persist, with concerns about supply shortages and environmental degradation. Rivers have been the source of construction materials across the globe, which have both adverse impacts on environment as well as advantages (Rinaldi, et al., 2005). The main aim of material extraction is to utilize natural resources. In addition to this, it reduces the bed load of the rivers that can further result in flood inundation. A few commercial advantages are employment generation, market development, business growth of machines and equipment, market price reduction of construction material, and ultimately revenue generation for the Government. The adverse effect of material extraction needs mitigation measures to prevent the river and surroundings from degrading.

Particularly, the Tamor river in the Koshi Province requires careful resource management due to its significant sediment contribution to the Koshi River (Bhattarai and Conway, 2020). Unmanaged extraction activities of river bed materials for infrastructure development have led to adverse impacts on river morphology, habitat disruption, and ecosystem stability. Comprehensive management strategies are imperative to mitigate these impacts and ensure the sustainable availability of essential construction materials for future generations.

A sediment budgeting in Tamor river indicates a large volume of sediment being accumulated in the channel belt over the period of time. An estimate suggests that western tributaries (i.e., Indrawati and Tamakoshi) and eastern tributary (i.e., Tamor) contribute more than 40% and 16%, respectively, of the total sediment load at Chatara (101 MT/yr) and the remaining 44% of the sediment load is contributed by Arun, Dudhkosi, and Sunkosi, from which no independent sediment load data are available (Sinha, et al., 2019). It indicates a notable contribution of Tamor river in the bed load of the Koshi River. Estimates for the last 54 years (post-embankment period) suggest that the total mass of sediments accumulated in the channel belt between Chatara and Birpur could be ~1080 MT, which translates to an accumulation rate of about 5.31 cm/year (Sinha, et al., 2019). The average thickness of sediments accumulated in the channel belt over the period of 54 years is computed as 2.87 m in this stretch (Sinha et al., 2019). This is attributed to the relatively narrow channel belt (and a smaller area) available for sediment accommodation (i.e. 142 km^2 between the two stations). The rate of sedimentation, however, is extremely variable and is controlled by local slopes and hydrological conditions. Therefore, local sedimentation rates and thickness may be much higher, as reported by Sinha et al. (2019) that the river bed around Kusaha is estimated to be 2–3 m higher than the adjoining flood plain.

In the context of potential risk of river bed accretion to flooding in nearby areas as well as potential wear and tear of hydro-mechanical equipment of hydropower projects, as there are several hydropower projects under development and/or planning in the Tamor basin, and increasing demand for construction materials, it is imperative to study potential of extracting those sediment with the aim of using as construction materials. However, to assess suitability of a site for material extraction, some conditions need to be fulfilled which includes but not limit to abundance of material availability, suitability of those materials for construction works, and whether adverse impacts on the river and surrounding areas can be mitigated with preventive activities. Therefore, this paper aims at addressing following specific objectives: i) to assess the availability and extraction of alluvial materials in the Tamor river; ii) to evaluate suitability of the alluvial deposit materials for road and concrete works; iii) to identify potential adverse impacts (of alluvial deposit) and solution measures.

2. Study Area and Data

2.1 Study area

This study focused on the entire Tamor River (198 km) passing Taplejung, Panchthar, Tehrathum, and Dhankutta districts with 16 municipalities/rural municipalities. A desk study revealed alluvial deposits extractable from Kabeli-Tamor to Leuti-Tamor confluence. Eighty-five kilometers of this section, touching 12 municipalities was considered as a study area as shown in Figure 1.

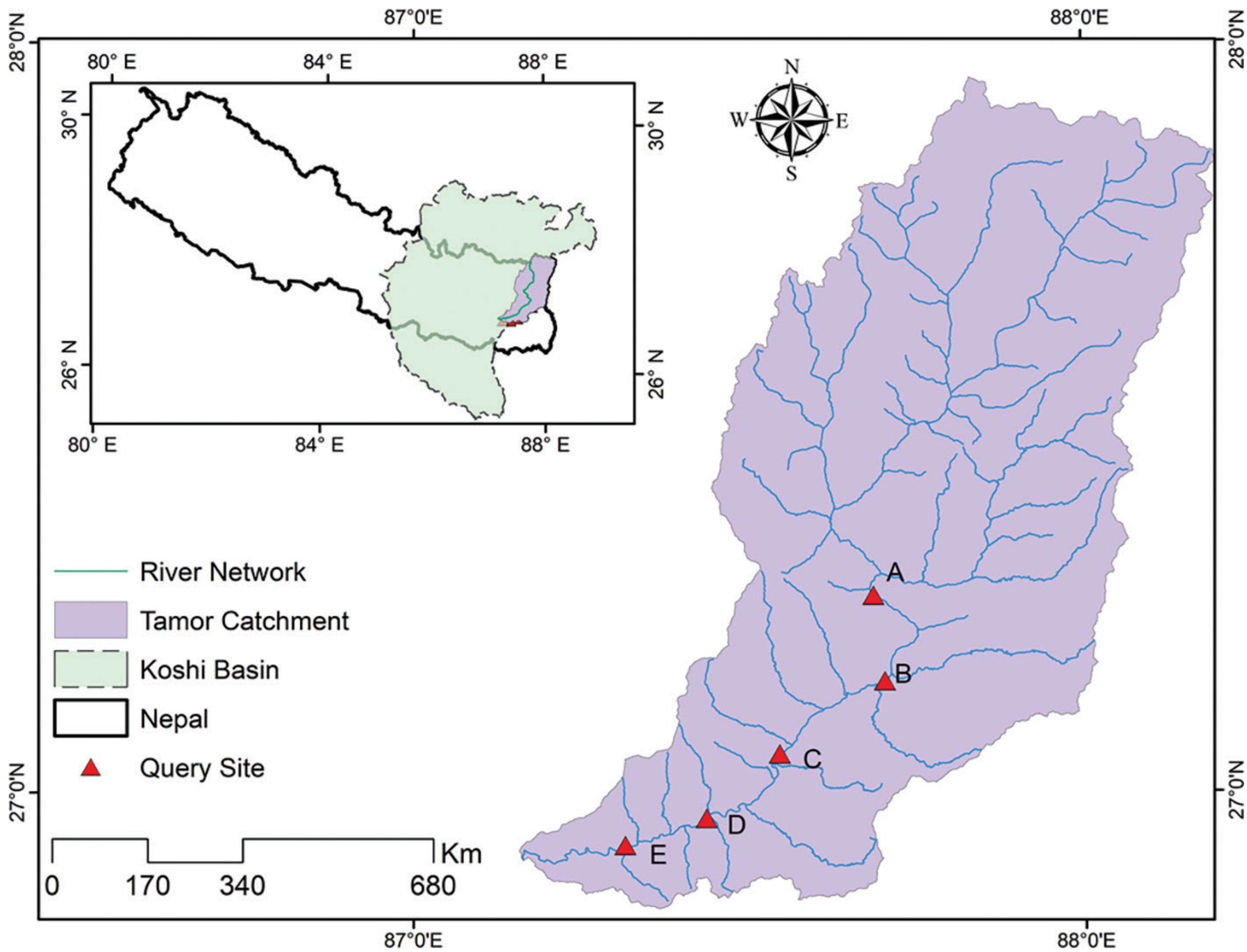

Figure 1: Tamor river-basin showing the potential locations for the materials extraction

2.2 Data source and types

Data were collected using questionnaires for engineers, key informant interviews with experts, and structured interviews with sub-engineers, supervisors, skilled laborers, and residents of the study area. Primary data collection methods included surveys, structured interviews, and field observations along the 85 km Tamor river stretch, while secondary data were sourced from local government offices, Department of Roads, Division Road Offices, Department of Irrigation, Water Induced Disaster Management Program Office, progress reports, journals on river morphology, hydrology, geology, and government publications on river studies and quarry sites.

The study includes 79 participants: 40 engineers/sub-engineers, 25 local residents, 4 experts, and 10 skilled workers/supervisors from municipality and rural municipality offices, irrigation offices in three districts, Division and project offices under the Department of Roads, the Tamor corridor road project office, contractor working sites, and roadside and riverbank villages. Table 1 provides details of these locations.

Table 1: Details of study location

S. N.	Location Detail	Municipality	District	Coordinates		Location Code
				Longitude	Latitude	
1	Limbunighat	Aathrai	Taplejung	27^{0}15'44.97"	87^{0}41'7.58"	"A"
2	Majhitar	Phidim Municipality	Panchthar	27^{0}8'54.25"	87^{0}42'7.28"	"B"
3	Jayrampati/ Simraghat	Phedap	Terhathum	27^{0}3'6.22"	87^{0}32'41.58"	"C"
4	Phalametar	Chaubise	Dhankuta	26^{0}57'57.07"	87^{0}26'8.82"	"D"
5	Mulghat	Sangurigadhi	Dhankuta	26^{0}55'48.90"	87^{0}18'53.46"	"E"

3. Methods and Data Analysis

3.1 Quantifying availability and extraction of alluvial deposit materials

Firstly, observations were conducted to gather information on the abundance of materials in the river, its morphology, surrounding geography, road network, access roads, and an inventory of river elements. Field measurements were taken, and secondary data regarding the quantity of alluvial materials extracted was collected from local government offices.

3.2 Suitability assessment of the materials for road and concrete works

The extracted alluvial deposit material is regarded as suitable based on the following four indicators, namely, quantity of availability, accessibility, quality with respect to physical properties, and environmental effect. Field observation was carried out and aggregate sample from each location were collected for lab test in Kathmandu as per Indian Standard (IS). As moving downstream in the river channel, many tributaries meet and the material washed downstream from these tributaries. They are the key reason for the change of quality of material of any river. Five key locations were identified for the study based on stakeholder consultation as well as field observation (see Table 1). Samples from the floodplain of the river were taken for each location. These samples were tested as per IS 2386 Part 3, Part 4, and Part 117 for physical properties of the aggregate material. Observations at each location, influenced by tributaries, watershed characteristics, and longitudinal gradient, determined quantities of extractable material. Lab tests for Aggregate Impact Value (AIV), Aggregate Crushing Value (ACV), and Los Angeles Abrasion Value (LAA) assessed suitability. The Relative Importance Index (RII) and Spearman rank correlation coefficient (ρ) analyzed the advantages and disadvantages of material extraction and assessed correlations between different groups' perceptions.

$$\text{AIV \%} = \frac{\text{Wt. of sample retained on 2.36 Sieve (w) X 100\%}}{\text{Total Wt. of sample taken (W)}}$$

$$\text{ACV \%} = \frac{\text{Wt. of sample retained on 2.36 Sieve (w) X 100\%}}{\text{Total Wt. of sample taken (W)}}$$

$$\text{LAA \%} = \frac{\text{Wt. of sample retained on 1.7 Sieve (w) X 100\%}}{\text{Total Wt. of sample taken (W)}}$$

3.3 Identification of potential adverse impacts and solution measures

Engineers and riverbank residents were surveyed for their views on the impact of material extraction from the river. Data was collected using two methods: mailed questionnaires to 24 engineers from various municipals, road, and irrigation offices, and structured interviews with residents and workers near the Tamor river. Both groups were asked about the benefits and adverse effects of extracting alluvial materials from the river's floodplain. The responses to the questionnaire were based on a Likert scale of five ordinal measures which were from one to five arranged in ascending order according to the degree of contribution to each question. The data obtained from the questionnaire survey were analyzed by using the Relative Importance Index (RII) technique. Likert-type scale was used in analyzing qualitative data obtained from the questionnaires, which was suitable for ranking the statements of respondents' views by using the relative important scale (RII). The RII for each variable was computed by using the following formula from Kalkani and Malek (2016):

RII = ∑W/A*N = (1*n1+2*n2+3*n3+4*n4+5*n5) / (A*N)

Where: RII = Relative Important Index; W = Scale for weight in the scale (ranges from 1 to 5); A = Highest weight on the scale (equal to 5); N = Total number of respondents concerning each factor.

The Spearman rank correlation coefficient (ρ) was also analyzed to check the correlation between perceptions of different groups. The Spearman (ρ) rank correlation coefficient for any two groups of ranking is given by the following formula:

$$\rho = 1 - \frac{6\Sigma\, d_i^2}{n(n^2-1)}$$

Where, d = Difference between two ranks of each observation; N = Number of observations.

4. Results and Discussion

4.1 Availability and extraction of alluvial deposit materials

The material quantity estimated in the studied section of the Tamor river is estimated as 953,403 m^3. from field observation, which indicates relatively abundant materials availability. Its abundance, however, varied across the five locations (Table 2) according to the feeding rate from tributaries, leading to inconsistent deposition across the floodplain. Aging and degrading river segments with deposition blocks are confirmed by field observation.

Table 2: Quantity calculation of alluvial deposit material during field visit

Locations	Quantity (m^3)	Average number of blocks in the vicinity	Quantity available in the vicinity (m^3)
"A" Limbunighat	11185.49	5	55927.45
"B" Majhitar	14108.16	7	98757.12
"C" Jayrampati	9673.45	7	67714.15
"D" Hansmarang	84050.7	8	672405.6
"E" Mulghat	19532.8	3	58598.4
Total	138550.6		953402.7

Table 3 shows road access is available on the left bank from C to E, both banks at B, and right bank near A. Extraction occurs at B, D, and E, but not at A and C. The stable riverbank and nature of the river flow support extraction. The riverbed's slope is steeper at A and B, levelling off after B, making extraction favourable. The river valley is narrow from A to B and wider after B, providing floodplains for deposits. Suitable extraction areas are from Majhitar to E, ensuring extraction is at least one kilometre away from bridges and structures.

Table 3: River morphology and access to the riverbed

S.N.	Parameters	Limbunighat	Majhitar	Jayrampati	Hansmarang	Mulghat
1	Access to river	Right Bank	Both bank	Left bank	Left bank	Left bank
2	Status of extraction	Not in practice	Crusher plant	Not in practice	Manual extraction	Manual extraction
3	Flow nature	Feebly turbulent	Feebly turbulent	Laminar	Turbulent	Turbulent
4	Bed nature	Slight meandering	Straight	Meandering	Meandering	Straight run
5	Valley nature	Narrow	Narrow	Wider	Wider	Wider
6	Longitudinal gradient	Mild slope	Mild slope	Fair slope	Fair slope	Fair slope
7	River bank condition	Stable	Stable	Stable	Stable	Stable
8	Inventory of structure	Suspension bridge, RCC under construction	Suspension bridge, RCC under construction	Suspension bridge	Settlement on left bank	RCC Bridge
9	Tributary	Kabeli, Hewa	Hewa, Shiva	Lakhua, Kambuwa	Chharuwa, Raghuwa	Leuti
10	Dominancy of rock type	Gneiss, Quartzite, Schist and Dolomite	Gneiss, Quartzite, Schist and Dolomite	Gneiss, Quartzite, Schist and Marble	Gneiss, Quartzite, Schist and Meta sandstone	Gneiss, Quartzite, Schist and Dolomite

Based on information collected from the local government (municipality/rural municipality) offices, average rate of extraction of different types of materials in the past year (2020 – 2023) is shown in Table 4. Material extraction peaked at Majhitar (Location B) and was the lowest at Bhangitar (near Location D). Extraction occurred near Locations B, C, D, and E, but not at Location A. Records show inconsistent extraction quantities, indicating unplanned extraction based on ease to access in the river. Also, it was found that there was no material extraction practice near location A for different purposes. Quantity of material extracted from the flood plain was found much more than from river itself in the past year. It can be seen that the availability of material are adequate from location C to D. But adequate material has not been extracted from this location. The quarry site can be established at this location on the basis of material availability.

Table 4: Quantity of material extracted in past days as obtained from record

Location	Boulder (Truck)	Gravel (Truck)	Sand (Truck)	Total (Truck)	Quantity (m^3)	Purpose
Mulghat area near "E"	150	25	25	200	1000	Commercial use
Bhangitar area near "D"	15	15	25	55	275	For local use
Kambua area near "C"	40	25	5	70	350	For bridge construction
Majhitar area near "B"	300	50	10	360	1800	For road project
Total	505	115	65	685	3425	

4.2 Suitability of alluvial deposit materials for road and concrete works

Aggregate samples from five locations were tested in Kathmandu as per IS guidelines. Toughness was highest at location C and lowest at E, indicating variable material quality. Table 5 synthesizes results of suitability of materials for different items of work.

Table 5: Suitability of material for different items of work

Acceptable values						
Items of work		**LAA %**	**AIV %**	**ACV %**	**FI/EI %**	**Water absorption %**
Road	Base	<40	<30		<35	
	Sub-base	<45	<40		<35	
Concrete	Ordinary	<45		<30	<25	<2
	High strength	<35		<45	<15	<2
S. N.	Location	Actual values at different locations				
1	A	37.50	25.2	30.98	15.46	0.88
2	B	38.20	22.5	31.18	22.36	0.85
3	C	35.50	21.5	24.02	15.21	0.74
4	D	39.14	15.94	32.98	32.28	0.21
5	E	47.7	35.48	39.37	18.14	0.98

Materials from Tamor river locations A to D are suitable for road sub-base, base, and normal concrete work, but not high-grade concrete. Downstream of D to E, materials show poor abrasion resistance and are only suitable for base course. Compared to other sources, Tamor river materials vary in quality. Trishuli river materials are suitable for lean concrete and road work, while Chalal Ganesh, Kalo Dhunga, and Nepalthok provide materials for flexible pavement. Tamor river materials, especially around location C, are of class D quality, suitable for sub-base, base layer, and normal concreting in roads, bridges, buildings, and other structures, but not for high-standard works.

4.3 Impacts of material extraction and potential solution measures

Extraction of alluvial deposit materials has both advantages of disadvantages in the context of the study area/region.

4.3.1 Advantages of extraction

Field observations revealed several advantages of extracting alluvial materials from the river. Primarily, the extraction process provides essential raw materials for construction projects, including sand, gravel, and stones, which are fundamental for building infrastructure like roads, bridges, and buildings. This contributes significantly to local economic development by creating jobs and supporting local businesses involved in construction and transportation. Moreover, increase in revenue and scope of employment generation are at the top ranking of advantages of extraction by RII. Similarly, business growth of machines is at the least ranking of advantages of extraction. A combined ranking of both data sources is merged and presented in Table 6 to see the overall ranking of advantages of extraction of alluvial deposits from the flood plain of Tamor river. The Spearman's correlation of 0.99 indicates a strong agreement between the opinions of respondents from both groups.

Table 6: Combined ranking of advantages of material extraction

S.N.	Parameter	Structured Interview		Questionnaire		Combined	
		RII	Rank	RII	Rank	RII	Rank
1	Increase in revenue	0.80	1	0.52	1	0.71	1
2	Scope of employment generation	0.75	2	0.47	2	0.66	2
3	Development of local market	0.70	3	0.41	6	0.60	3
4	Enhance infrastructure development	0.65	4	0.44	4	0.58	5
5	Business growth truck and tractor	0.64	5	0.47	2	0.59	4
6	Reduces the cost of transportation	0.63	6	0.42	5	0.56	6
7	Cohesion between social people	0.60	7	0.41	6	0.54	7
8	Business growth of machines	0.51	8	0.40	8	0.47	8

4.3.2 Adverse effects of extraction

Field observations revealed several negative effects of extracting alluvial materials from the river. One of the primary concerns is the degradation of riverbanks, which can lead to increased erosion and loss of land. This not only threatens the habitats of various aquatic and terrestrial species but also poses risks to infrastructure and human settlements near the river. Moreover, water contamination and air pollution are at the top ranking of probable effects by RII. It is found that these are the major adverse effects of material extraction from Tinau river Rupandehi Nepal (Dahal et al, 2015). Bed depletion ranks third and is primarily caused by extraction within the stream flow bed rather than the floodplain. This study focuses on alluvial deposit extraction from floodplains, highlighting the need for mitigation measures to address these effects. A combined ranking of both data sources is merged and presented in Table 7 to see the overall ranking of adverse effect of extraction of alluvial deposits from floodplains of Tamor river. The Spearman's correlation of 0.998 indicates a strong agreement between the opinions of respondents from both groups.

Table 7: Combined ranking of adverse effects of extraction

S. N.	Parameter	Questionnaire		Structured Interview		Combined	
		RII	Rank	RII	Rank	RII	Rank
1	Depletion of river bed.	0.70	1	0.57	5	0.59	3
2	Air pollution	0.53	2	0.78	1	0.69	2
3	Contaminate water in the river	0.49	3	0.59	4	0.70	1
4	Adverse effect on plants and trees	0.48	4	0.69	2	0.54	4
5	Adverse effect on aquatic life	0.43	5	0.64	3	0.53	6
6	Meandering in the river	0.42	6	0.52	7	0.45	8
7	Morphology of the river	0.42	6	0.57	6	0.54	5
8	River bank erosion	0.37	8	0.46	8	0.47	7
9	Chances of flood inundation.	0.28	9	0.39	9	0.35	9

4.4 Potential solutions for reducing the adverse effects

A combined ranking of both data sources is merged and presented in Table 8 to see the overall ranking of mmitigation measures to reduce the adverse eeffects of mmaterial extraction. Table 8 shows that limited depth extraction ranks the highest, followed by manual tool extraction. This suggests respondents view extraction in the Tamor river as environmentally sensitive, recommending against using heavy equipment and large-scale extraction. The Spearman's correlation of 0.990 indicates a strong agreement between the opinions of respondents from both groups.

Table 8: Combined ranking of suggested mitigation measures

S.N.	Mitigation measure	Structured interview		Questionnaire		Combined	
		RII	Rank	RII	Rank	RII	Rank
1	Extraction is limited to isolated areas	0.80	1	0.32	1	0.68	4
2	Spraying water frequently	0.7710	2	0.29	5	0.53	7
3	Extracting only for deposited depth	0.73	3	0.31	3	0.70	3
4	Constructing check dams	0.71	4	0.32	2	0.47	8
5	Prohibit vehicles from entering water	0.69	5	0.28	6	0.55	6
6	Limiting the quantity of materials extraction	0.53	6	0.30	4	0.75	1
7	Limiting to manual extraction	0.51	7	0.27	7	0.73	2
8	Extracting only at night time	0.44	8	0.26	8	0.66	5
9	Banning extraction	0.34	9	0.13	9	0.32	9

5. Conclusions

This study aimed at identifying, quantifying, and suitability assessment of an appropriate source of construction material to support infrastructure development in a region experiencing shortages of construction materials, thereby contributing to the national economic growth.

Focused on the Tamor river in Nepal's Koshi Province, this research concludes that the entire stretch of the Tamor river floodplain, from Dovan to Mulghat, contains alluvial deposits. However, due to the narrow river valley between Dovan and Majhitar, establishing quarry sites in this area is challenging. Conversely, from Majhitar to Mulghat, numerous feasible locations for material extraction exist.

Comparing the results of each sample for road and bridge work shows that materials from location-A (Limbunighat) to location-D (Phalametar) are suitable for use in road sub-base, base, and concrete work up to M25 grade. However, materials from location-E (Mulghat) are only suitable for sub-base work.

The study also reveals that potential benefits of extraction include revenue collection, employment generation, and market development. On the other hand, possible adverse effects include water contamination, air pollution, and layer depletion. Respondents recommended conducting extraction away from residential areas, using manual methods instead of heavy equipment, and limiting the depth of extraction.

In a nutshell, while challenges exist, this study suggests manageable strategies to leverage the Tamor river's resources for constructive purposes while minimizing the adverse impacts.

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