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Taxonomic approach and potential anthropic indices to understanding cross-sectional morphology and landscape modification of a tropical river Basin, India

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ABSTRACT

During the Anthropocene, human modifications to fluvial landscapes have become a common aspect of their progress and development. The primary objective of this research is to delve into the human-induced alterations on fluvial landscapes at both the channel and basin scales. For channel scale investigation, we classify the channel cross-sections in terms of human interventions and relate them with the potential anthropic (or anthropogenic) geomorphology in the Kopai River basin (KRB) in India. A total of 35 cross-sections (CS) were surveyed at an interval of ~3 km from source to mouth, and a perceptual survey was executed among randomly selected 960 respondents in the seven community development blocks. The CS are classified into natural (alluvial and bedrock) and anthropogenic (monatogenic – mining-influenced, traffic- road-stream crossings, hydrogenic-influenced by hydrological projects like dams, and agrogenic- agriculture-influenced) categories following Szabo's (1971) taxonomic approach. The statistical difference between natural and anthropic cross-sections is measured using seven hydromorphological characteristics. Basin scale investigation adopting Nir's index (1983) of potential anthropic geomorphology (I_{PAG}) from 1961 to 2021 depicts that the I_{PAG} is progressively decreasing with time, although the reality is different. We propose to extend the basic notion of the I_{PAG} by incorporating more relevant parameters.

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Introduction

Humans have become effective geomorphological agents in the era of the Anthropocene. Steffen et al. (2007) suggested that the world is moving towards the Anthropocene from the Holocene and the three stages of the Anthropocene are as follows: (1) the industrial era (stage 1) from 1800 to 1945, (2) the “Great acceleration period” known as second stage extending from 1945 to 2015, and (3) the third, and current, stage where human

becomes an active agent to alter the terrestrial system at an accelerated rate. The contribution of humans to reshaping the Earth's surface sometimes becomes more intensive than the geomorphic factors (Goudie & Viles, 2016). Nir (1983) investigated that the total earth material moved by humans for the year 1970 was 173×10^9 tons per year which was 173 times greater than the sediment carried by the Ganga-Brahmaputra system. A fluvial system is maintained by the law of minimization of energy i.e. a system intends to achieve equilibrium with a minimum investment of energy (Phillips, 2003). The energy level of a river is principally controlled by discharge characteristics and channel gradient (Leopold et al., 2020). The higher the discharge, the greater the scope for modifying the fluvial architecture (Piégay and Kondolf, 2016). Moreover, humans alter the nature and rate of the channel adjustments by modifying the temporal and spatial distribution of river forms and processes (Brierley et al., 2005).

For thousands of years, humans are engaged in producing and reshaping the landscape geomorphology by constructing e.g. roads, canals, settlements, and plough furrows which have distinct imprints on the landform produced by the natural processes (Tarolli et al., 2019). Globally, many works have been produced regarding anthropic geomorphology (Marsh, 1864; Bennett, 1938; Thomas, 1956; Nir, 1983; Szabó et al. (2010)), and how humans affected the physical environment as well as the landforms. After the 1960s, many geomorphologists started paying attention to the effect of flow regulation modification and its impact on the river and floodplain morphology (D. Mondal, 2020). Scorpio and Rosskopf (2016) addressed the channel adjustments in the Mediterranean rivers for the last 150 years due to both natural and anthropogenic factors. Yang et al. (2019) studied the evolution of the Pearl River estuary in China emphasizing the role of intensive human interventions in recent decades. M. Mondal and Satpati (2019) discussed the impact of human interventions on river longitudinal and cross-sectional profiles of the Ichamati River, India. Ferreira et al. (2017) demonstrated that anthropogenic factors are responsible for the degradation of river water quality and its eventual effect on riverine biodiversity. Gopal (2020) explained the hydrological, geomorphological, ecological, and socio-economic impacts of sand mining and its management for the Yamuna River. Gopal and Chauhan (2007) demonstrated that the Damodar River channel has been altered from braided to straight due to the sand mining from the river. They have also observed that the channel width has been reduced due to the excessive excavation of sand from the river bed. Moreover, Sreebha (2008) exhibited that over-excavation accelerates river bank erosion. Over-excavation on river beds may also lead to downstream erosion (Rinaldi et al., 2005). According to Dung and Le (2015), the total agricultural area along some sections of the Cau River has declined due to river bank erosion caused by the over-excavation of sand. In addition, with the rapidity of urbanization, the demand for sand also has increased manifold. Intense erosion and land use changes have modified fluvial patterns in humid tropics as shown in Costa Rica (Central America), bringing more intense flooding events during the last decades (Quesada-Román, 2022).

Thus, it appears that exploration of the anthropogenic landscapes of a river basin has drawn much attention from researchers worldwide. The two traditional frameworks for anthropogenic landscapes (1. channel-specific i.e. spatially smaller and 2. basin-specific i.e. relatively larger) are well known and widely used (de Boer, 1992; Phillips, 1988). The first relates to the taxonomic classification of the landforms by Szabó et al. (2010), and the

second is the “potential anthropic geomorphological index” (I_{PAG}) of Nir (1983). Szabó et al. (2010) embraced the principles of taxonomy and classified it into two fundamental types: (1) natural landforms and (2) anthropic (also known as anthropogenic) landforms. These classifications were further sub-classified based on the inherent characteristics of the concerned landforms. On the other hand, Nir (1983) attempted to quantify the human impacts on the modification of the landscape by inventing the “index of potential anthropic geomorphological index” (I_{PAG}). The index has been calculated based on the degree of development (DD) and the degree of perception (DP). The higher the development, the higher the chances of landscape modification as well as damage to the environment. The DD is quantified using the percentages of the urban population (UP). Besides, the DP is represented by the Degree of Illiteracy (DI), as education is the base for developing perceptions. Nir (1983) determined the anthropic geomorphological process by averaging the UP and DI multiplied by the combined score of two constants, Kc and Kr, that indicate the climatic and relief conditions.

Therefore, it has become imperative to assess landscape modification due to anthropogenic stressors using the taxonomic landform classification and Nir’s index. However, there are some loopholes in Nir’s work, such as the two basic indicators, i.e. UP as DD and DI as DP, which are not enough to quantify the intensity of human impact on the landscape. The absence of an urban population does not necessarily indicate zero development. Similarly, literacy or illiteracy cannot be completely equated with people’s care for the environment, as the degree of education failed to indicate the people’s feelings for nature. Even in a review of available data, Nir (1983) stated that agriculture is the predominant human activity for landscape modification, but he did not include this factor while calculating the I_{PAG} . Many scholars also questioned the parameters of Nir’s index (Nir, 1983; Rózsa, 2007; Rózsa & Novák, 2011). Therefore, modification of the I_{PAG} with some more relevant factors may increase the acceptability of the index. Thus, we have tried to modify this index in the present work in the context of the Kopai River Basin (KRB).

The KRB (546 km²) is perhaps one of the best examples that experienced see-saw changes in the recent decades due to different anthropogenic activities such as barrages, embankments, brickfields, sand mining, and profuse alteration of land use and cover. Previous literature indicates that a lot of work has been done before regarding human interventions in the river throughout the world and in India. Chakrabarti (1985) worked on the evolution of the Mayurakshi Basin focusing on the natural evolution of the Kopai River on a very small scale as a sub-basin of the Mayurakshi River; however, the anthropogenic interventions are missing in that work. Islam et al. (2021) elaborately portrayed different anthropogenic signatures in the Mayurakshi River basin and their impacts on river forms and processes. M. Das and Mukhopadhyay (2015) studied the distribution of ponds in the Kopai River Basin. T. Das (2019) studied the impact of brickfields on the riverine environment of the Kopai River. P. Das (2013) studied the hydro-geomorphic characteristics of the Kopai River and mentioned that the Kuye River is the combined flow of the Kopai River and Bakreshwar River. Nandi (2018) explored the challenges of water management in the wake of human interventions in the Kopai River basin. Though as a part of the Mayurakshi River basin, some anthropogenic characteristics are already documented, the classification of landforms and the potentiality of anthropic

geomorphology have not been assessed previously. Thus, the present work would be a novel contribution to the context of the Kopai River basin vehemently altered by human activities. Moreover, the limitation of the Nir's index to study the anthropic landscape would be extended to portray the landscape modification in the Anthropocene. Therefore, we will (i) classify and characterize cross-sectional morphological forms (channel scale analysis) using Szabó et al. (2010) taxonomic approach, and (ii) assess the potential anthropic geomorphology of the Kopai River basin (basin scale analysis) using Nir's index (Nir, 1983) and the modified potential anthropic index proposed in the present study. The present study carried out using rigorous field investigation and robust secondary data and methods would be a baseline assessment in the context of anthropogenic interventions that would help planners and researchers across the world.

Geographical setting

The Kopai River originates from a large pond in Khajuri Villages, Jharkhand, and after flowing about 107 km in the southeast direction near Sahurapur to the confluences with the Bakreshwar River. The basin area of the Kopai River is about 546 km² (about 37 km² in Jharkhand and 509 km² in Birbhum district of West Bengal) within the coordinates 23° 37' 10'' N to 23° 56' 11'' N and 87° 14' E to 87° 47' 50'' E (Figure 1). Kopai River basin is the southernmost sub-basin of the Mayurakshi River. The upper portion of the basin consists of the granite-gneisses rock of the Proterozoic age while older alluvium is found mainly in the middle and lower reaches (P. Das, 2013). The Kopai River basin is a part of *rarh* plain. The maximum elevation of the basin is 156 m and the minimum elevation is about 20 m. The basin experiences a hot and humid monsoon climate and the climatic character is largely determined by the Chotanagpur plateau situated in the northwest portion of the basin. The 35 cross-sections were collected at a 3 km distance from the source to the mouth to understand the coupling effect of natural forcing and anthropogenic interventions (Figure 1).

Database and methodology

Database

An extensive field survey was executed from the source to the confluence in the Kopai River from 26 March to NaN Invalid Date . A total of 35 cross-sections were surveyed from 35 locations at an equal distance of 3 km with Auto Level instruments and accessories. The anthropogenically modified stretches have been intensively studied. For example, road-stream crossings have been taken immediately 10 m upstream and downstream of the bridges (Roy & Sahu, 2018). The length of the river is about 107 km, and to get a statistically significant sample size > 30, we decided to take CS at a 3 km distance. Thus, we finally considered 3 km equal distance methods, taking into account the statistically significant sample size on the one hand and the field constraint and feasibility of the work on the other. However, a few cross-sections were collected based on judgmental sampling considering different anthropogenic factors, such as sand

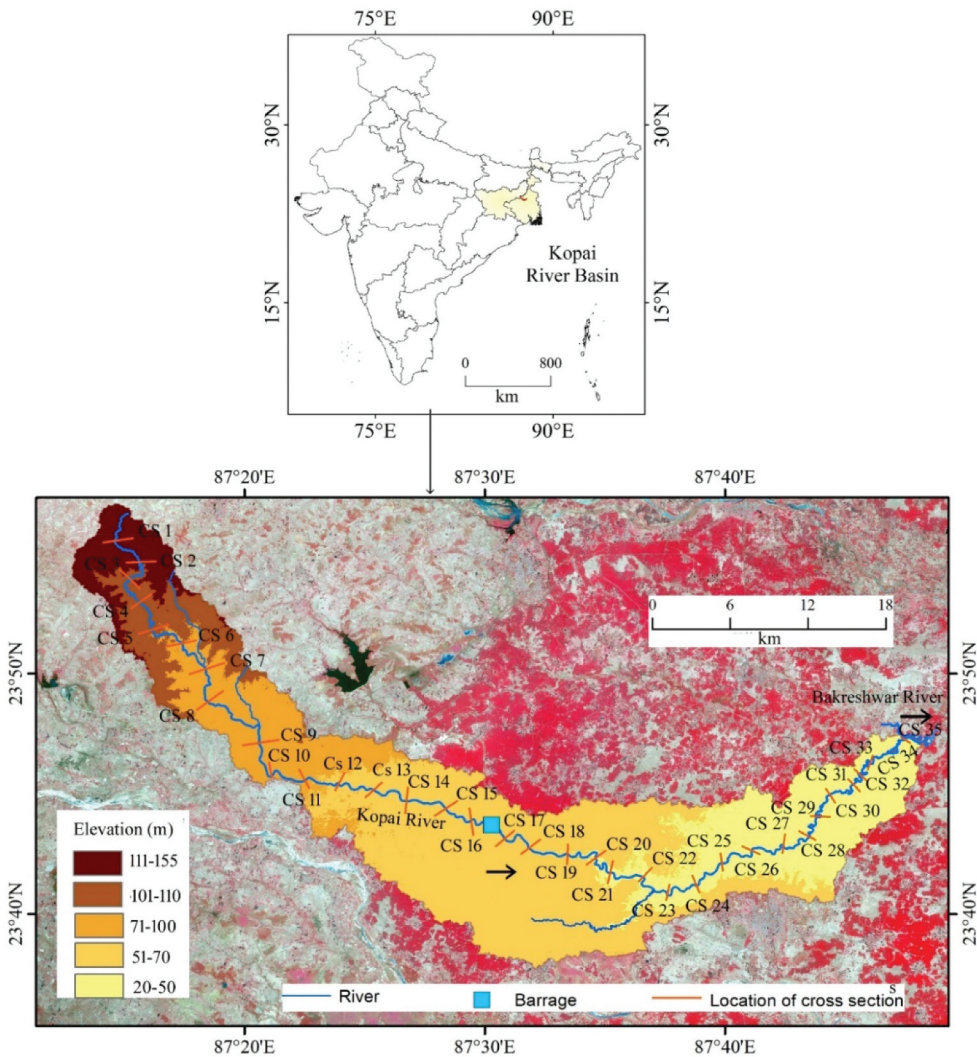


Figure 1. Location of the Kopai River basin and elevation.

mining, brick kilns, and agricultural practices. A similar principle was adopted in the works of Islam et al. (2022).

Kopai River is a non-perennial river, and during the pre-monsoon season (February to May), the river becomes dry. Water only flows in the lower reaches near the confluence zone. Immediately upstream of road-stream crossings, the river water becomes stagnant. However, in both cases, the highest water depth is about 1 m. Therefore, the pre-monsoon season was more convenient for taking the CS compared to the monsoon or post-monsoon seasons because of the higher magnitude of the flow and discharges. The distance between surveying points (sounding distance) along a specific cross-section varies between 3 and 0.5 m depending on the length of the wetted perimeter and slope characteristics. Cross-sectional measurements (width, depth, and CS area) were done based on the bankfull stage of the river.

For assessing the anthropogenic impact on the Kopai River basin, some primary data and secondary data have been used. Primary data regarding channel geomorphology, piers geometry, and field photographs were collected from the field survey. The district census handbook (Birbhum, West Bengal), topographical map (73 M/13, 73 M/5, 73 M/1, 73 M/14, 73 M/10), Sentinel 2B satellite images, Google earth imageries, and an SRTM DEM (30 m) were the secondary data sources used for the study.

Methodology

Measuring channel configuration

Channel form ratio

The width/depth ratio is the relation of the surface width to the average depth at the bankfull stage to understand the energy distribution within the channel. Channel width index, channel depth index, and channel form index are measured using Eq. 1, 2, and 3, respectively (B. C. Das, 2015).

$$I_w = \frac{w}{w'} = \frac{w}{1.595\sqrt{A}} \quad (1)$$

$$I_d = \frac{d}{d'} = \frac{d}{0.627\sqrt{A}} \quad (2)$$

$$Cfi = \frac{w/d}{Fr} \quad (3)$$

where w is the actual channel width and w' is the expected channel width (the width achieving maximum channel efficiency with a given cross-sectional area), d is the actual depth and d' is the expected depth (the depth achieving maximum channel efficiency with a given cross-sectional area), and A stands for cross-section area. Fr stands for the ideal form number (2.544 for semicircular and 2.31 for triangular).

Hydraulic radius

To understand the degree of channel efficiency, the hydraulic radius is measured using Eq. 4.

$$R = \frac{A}{Wp} \quad (4)$$

where R represents the hydraulic radius, A is the cross-sectional area and Wp is the wetted perimeter.

Channel asymmetry index

Assessing the channel dynamics of cross-sectional asymmetry is an important tool. The channel asymmetry is measured using the formula given by Knighton (1981) as expressed in Eq. 5

$$A* = (Ar - Al)/A \quad (5)$$

where A^* represents the asymmetry, A_r represents the area of the right side, and A_l represents the area of the left side, A is the total cross-sectional area.

Classification of channel cross-sections using a taxonomic approach

Taxonomy is a scheme of classification based on the hierarchical order of any organism, object, or concept. Though originally it was applied to classify the organisms based on their genotypical and phenotypical traits, it was applied to other fields including soil taxonomic classification by the USDA (1999) as reported by Baillie (2006), and landform classification by Szabó et al. (2010) because of the scientific spirit (collectivism based on similarity and individualism based on dissimilarity between the units of the classification called taxa).

In the present context, the classification of the cross-sections based on their anthropic transformation is attempted following the scheme of Szabó et al. (2010). The channel CS are classified into two broad categories, natural and anthropic (Figure 2). Natural CS are classified into bedrock CS and alluvial CS while anthropic CS are classified based on the scheme of Szabó et al. (2010). Each of the interventions is responsible for direct (constructive, hydrological, and excavation) or indirect (slope failure, acceleration of erosion, subsidence, others) anthropological processes.

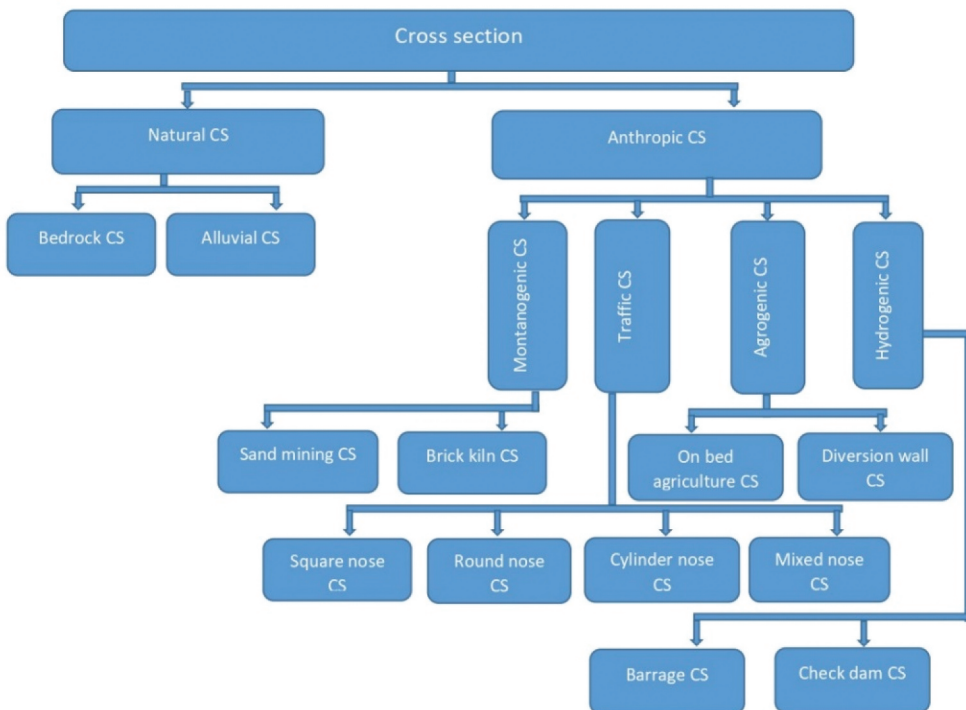


Figure 2. Taxonomic principles of landform classifications. We applied the Szabó et al. (2010) scheme of landform hierarchy for conducting the present study to show the intensity of anthropogenic interventions on the river cross-sections (CS).

Index of potential anthropic geomorphology (I_{PAG} index)

The quantification of potential anthropic geomorphology is not so easy, however, Nir (1983) developed a model based on the Degree of Development (DD) and Degree of Perception (DP). This index can assess how much the potential geomorphological processes are harmful to a particular region. Based on the rate of the Anthropogenic Geomorphological Processes (AGP), Nir (1983) classified AGP into five different categories ranging from 1 to 0 (Disastrous AGP to AGP non exists). In Figure 3a the correlation between DD and AGP is shown. In Figure 3, three

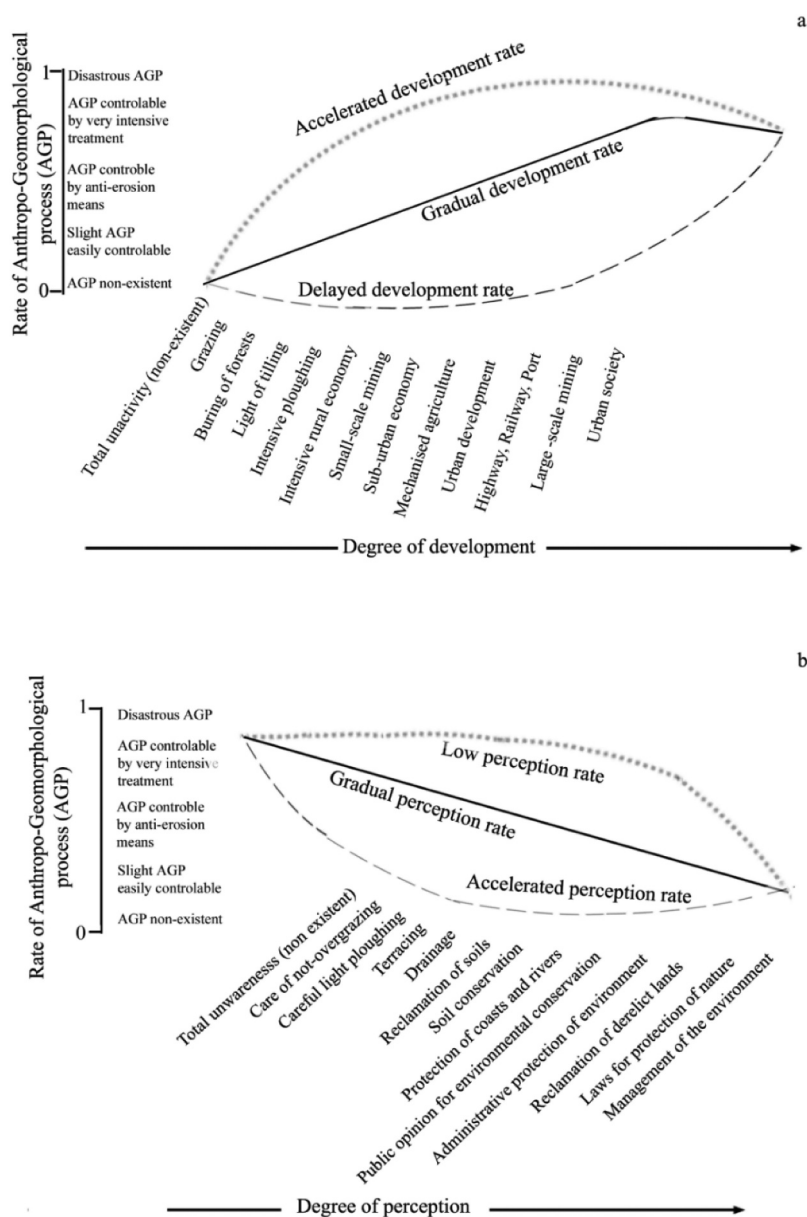


Figure 3. Correlation between a. DD to AGP and b. DP to AGP (Based on Nir, 1983).

curves reflect the three main possibilities for the impact of DD on AGP i.e. accelerated development rate, delayed development rate, and gradual development rate. Similarly, in [Figure 3b](#) the relation between DP and AGP is portrayed. The degree of development increases the chance of landscape modification. Generally, three types of relationships may state between DD and DP– (1) if DD is more than DP, a higher rate of AGP results indicating the necessity of the anti-erosive measures, (2) if DD and DP are equal, the rate of AGP is moderate and no correction measures are urgently needed and (3) if DD is lower than DP, the rate of AGP is also low.

According to Nir (1983), DD represents the degree of Urban Population (UP), and DP is represented by the Degree of Illiteracy (DI) which causes a lower perception. Nir (1983) proposed that the AGP is the average value of the two variables i.e. UP and DI. Moreover, Nir (1983) considered the physical conditions which influenced anthropogenic activities. Therefore, he incorporates Kc and Kr as two constants for climate and relief to represent the anthropic geomorphological sensitivity (Rózsa & Novák, 2011). Nir (1983) measured the I_{PAG} using Eq. 6.

$$I_{PAG} = \frac{(UP + DI)}{2} \times \frac{1}{100} \times (Kc + Kr) \quad (6)$$

UP= % of the urban population, DI= percentages of illiteracy, Kc= climatic constant, Kr = relief condition constant, Kc value ranging from 0.4 to 0.8, and the Kr value from 0.2 to 0.8. The constants Kc and Kr can be debated in the context of climate change and the large and diverse geomorphic regions of the world. The climatic constants are based on the Koppen system which dates to the 1930s (Rózsa & Novák, 2011). The incidences of climate change necessitate the updation in the Kc. For the present study, we used the same Kc and Kr constants as Nir proposed because the study region (KRB) is a small basin (546 km²) with a minimum imprint of climate change (P. Das, 2013) and lesser geomorphic diversity and relative geomorphic stability due to its location on the fringe of the stable peninsular region (P. Das, 2013). Therefore, we used Kc as 0.8 for the monsoonal climate and Kr as 0.2 for the *rarh* plain region. The index value ranges from 0 to 1 and if the value is < 0.3 it indicates lower human geomorphological activities, 0.3–0.49 indicates the hazard is not negligible and the protection measures are required, and if is > 0.49 then it may cause severe damages and urgent measures are needed.

Estimating the intensity of land transformation

Different types of anthropogenic activities are present in the Kopai River Basin (KRB) e.g. check dams, barrages, brick kilns, sand mining, and agricultural practices. Sand mining is the major anthropogenic activity followed by the development of brick kilns. Thus, the land transformation has resulted from sand mining, the development of brick kilns, and on-bed agricultural practices. The intensity of land transformation is measured at all 35 cross-sections from the source to the confluence of the river. The channel bed length of the CS affected by sand mining, brick kiln, and agricultural activities is measured. The bed length has been measured as a summation of the hypotaneous distance of “n” number of trapeziums formed in particular cross profiles drawn in the field.

Perception survey

Apart from the physical survey, a vivid perception survey was executed to portray the knowledge of inhabitants of the C.D. blocks regarding their awareness of the damages due to anthropic geomorphological interventions. Previously, a preliminary field survey was conducted from 12th to NaN Invalid Date for the pre-testing of the questionnaire for assessing the rationality of the question and whether it works for the final survey or not. After collecting the result of the questionnaire survey, the detailed field survey was conducted with the finalized questionnaire ([Appendix 1](#)) from 20th to NaN Invalid Date to acquire information regarding indigenous knowledge. The sample size of each C.D. block has been determined with the help of the Cochran (1977) formula using Eq. 7 and 8.

$$n^0 = \frac{(t)^2 * (s)^2}{(d)^2} \quad (7)$$

$$n = \frac{n_0}{(1 + n^0 / \text{Population})} \quad (8)$$

where t is the value for the selected alpha level of 0.025 in each tail = 1.96, (the alpha level of .05 indicates the level of risk the researcher is willing to take that true margin of error may exceed the acceptable margin of error); s is the estimate standard deviation in the population = 1.167 (estimate of variance deviation for 7 point scale calculated by using 7 (inclusive range of scale) divided by 6 (number of standard deviations that include almost all (approximately 98%) of the possible values in the range); d is the acceptable margin of error for mean being estimated = 0.21 (number of points on primary scale * acceptable margin of error; points on primary scale = 7; acceptable margin of error = .03 (error researcher is willing to accept), n^0 = required return sample size according to Cochran's formula; n^1 is the required return sample size because sample > 5% of the population.

Based on this formula, 120 persons were surveyed for Bolpur-Sriniketan, 140 for Sainthia, 180 for Dubrajpur, 150 for Illambazar, 160 for Labhpur, 170 for Khoyrasole, and 40 for Rajnagar, for a total of 960 households and 960 respondents. The questionnaire survey was carried out using the 7-point Likert scale (1 represents completely disagreed while 7 represents completely agreed) to get the perceptions of the local people in different CD blocks, taking both rural and urban populations into account. The higher perceptual rating in each item of the questionnaire reflects a higher level of agreement and environmental awareness. First, the perceptual rating of an individual respondent was measured based on the average ratings of the 10 questions ([Appendix 1](#)). Then, the average rating of all the respondents from a CD block constitutes the level of indigenous knowledge of that area.

Measurement of percentages of the settled area

For measuring the modified I_{PAG} , the percentages of the settled area have been added as an additional indicator. The settled area has been calculated from the land use and land cover map which has been prepared globally with the help of Sentinel 2 (10 m) (European Space Agency, 2022). First, the two scenes covered in the study area have

been downloaded and mosaic with the help of Arc GIS (v.10.4). The .shp file of each C.D. block is clipped from mosaic data and reclassified the 255 land use and cover class to 10 class and calculate the area of built-up area and then calculate the percentage area.

Computation of modified index of potential anthropic geomorphology (modified I_{PAG})

The Nir method for I_{PAG} is extensively used by researchers but there is a lot of inadequacy of data. He used two indicators for portraying the potential anthropogenic pressure i.e. degree of development and degree of perception. The degree of development was measured with the help of percentages of the urban population by which he tried to measure the human impact while the degree of perception is analyzed with the degree of illiteracy by which he tried to portray the concerns of people to the damages of anthropic geomorphological process. The problem is that solely the urban population failed to portray the rate of development. There are many blocks where the urban population is nil. Therefore, does the absence of an urban population indicate zero development in those blocks? Does rural development not impact geomorphology? Moreover, feelings towards the environment are more important than mere educational qualification (literacy/illiteracy) for the behavioral pattern of humans to their environment. We found that rather illiterate people damaged channel geomorphology the least while so-called educated people having lower pro-environmental behaviour as expressed through the rampant economic development for the environment did the most.

To avoid these limitations, four parameters have been introduced to assess the intensity of development in the study area i.e., (1) population density, (2) percentage of the settled area, (3) the extension of agricultural land, and (4) the reduction of forest cover. All four parameters are positively related to development. Still, Khoyrasole C.D. block has no urban population and in the other blocks like Illambazar, Labhpur, and Rajnagar the urban population is comparatively less. Increasing population density intensifies the demands which impact the geomorphology e.g. the increasing population pressure demands more houses for living which increases the demand for sand and mining activities also increase. The increase of settled areas also alters the natural landscape at an accelerating rate. The extension of agricultural land and reduction of forest cover both reflect the human intervention on earth due to the development. Similarly, Nir only used illiteracy as the indicator of perception; however, only illiteracy cannot determine the environmental awareness of the people as most of the tribal people in the present study are not literate (skill of reading and writing) but based on their close contact with nature and indigenous knowledge they are better performers about the environmental protection compared to the so-called literate people. For example, in the tribal region, environmental degradation is often less because the tribal people intend to protect nature, although their literacy is lower than that of urban people. Field studies show that urban people are less sensitive to damage-induced channel geomorphology because they are more focused on technological development. The survey results show an almost neutral relationship ($R^2 = 0.051$) between illiteracy and indigenous knowledge, indicating that formal education cannot predict environmental consciousness. Therefore, indigenous knowledge (environmental awareness) has been considered to measure the

perception of the inhabitants of the study area and an alternative index i.e. modified potential anthropic geomorphology index (MI_{PAG}) has been proposed for the study area.

For calculating the modified index for the study area, the degree of development was measured with the help of the four mentioned parameters. First, the C.D. blocks of each class have been divided into four classes based on the quartile value and rank them based on the quartile values. For example, the population density has been divided into four classes: first-class value lower than the first quartile i.e. lower than 563 persons/km² is ranked 1 and the value between the first quartile and median (563 to 644 persons/km²) is ranked 2. Similarly, the value between the median and third quartile (645 to 791 persons/km²) is given rank 3 while population density greater than the third quartile (>791 persons/km²) is given rank 4. The other three factors were also assigned and ranked in this way, i.e. the percentage of the settled area lower than 6.1% is ranked 1 while 6.1% to 9.8%, 9.9% to 10.8% and > 10.8% respectively rank as 2, 3 and 4. Similarly, regarding the extension of agricultural land, ranks 1 to 4 are assigned for <-2.06%, -2.06 to 1.16%, 1.17 to 3.35%, and > 3.35% and for the reduction of forest cover, < 0.002% rank as 1, 0.002 to 0.685%, 0.686 to 1.962%, and > 1.962% rank as 2, 3, and 4, respectively. The weights were given to each of the four parameters as per the Analytic Hierarchy Process (AHP) method of Saaty (1980). First, the pairwise comparison matrix was constructed, and the pairwise comparison matrix was normalized by eigenvector techniques. Second, the normalized weights were examined for consistency through the consistency ratio as proposed by Saaty (1980). For measuring the relative importance, 10 experts' opinions and 40 local people's opinions were considered. The highest relative importance i.e. 1 is given to the population density, and 2, 3, and 4 are assigned to the percentage of the settled area, an extension of agricultural land, and reduction of forest cover. The criteria weight worked out 0.466, 0.277, 0.161, and 0.096 for population density, % of the settled area, the extension of agricultural land, and reduction of forest cover, respectively. In this context, about 0.8% signifies the consistency of weights worked out. Similarly, assessing the degree of perception of indigenous knowledge and degree of illiteracy has been used. Firstly, the C.D. blocks are divided into four classes based on the quartile values. Then, rank is assigned. The experts give the highest importance to indigenous knowledge and then illiteracy. The criteria weight assigned for indigenous knowledge is 0.667 and 0.333 for illiteracy. For this context, 80% signifying the consistency of weight has been applied. Like the Nir index to consider the physical condition K_c and K_r the two constants have been used for the representation of climate and relief. The modified I_{PAG} value has been measured using Eq. 9. The equation is almost the same as I_{PAG} , only one change has been introduced, i.e. the average value of DD and DP is multiplied by 1/10 whereas in I_{PAG} it is multiplied by 1/100. Nir (1983) multiplied 1/100 for ranging the value of I_{PAG} between 0 and 1 (Rózsa, 2010) and to compare the MI_{PAG} to I_{PAG} we multiplied by 1/10 in our study.

$$MI_{PAG} = \frac{W_{DD} + W_{DP}}{2} \times \frac{1}{10} \times (K_c + K_r) \quad (9)$$

where, MI_{PAG} = modified potential anthropic geomorphology index

W_{DD} = total weighted score of the sub-parameters of the degree of development

W_{DP} = total weighted score of the sub-parameters of the degree of perception

K_c and K_r are the climatic constant and relief constant as mentioned in Table 1.

Table 1. Values of climatic and relief constants by Nir (1983).

Kc		Kr	
Climate	Constant	Relief	Constant
Equatorial	0.6	Plains	0.2
Monsoon-Savana	0.8	Hills	0.4
Arid and semi-arid	0.6	Plateau	0.5
Temperate	0.4	Medium high mountain	0.6
Cold	0.6	High (Alpine) mountain	0.8
Arctic	0.4		

Source: Nir, 1983.

Anova

A set of one-way Analysis of Variance (ANOVA) was run using MS Excel 2013 to detect the role of human activities on the channel morphological parameter i.e channel width index, depth index, hydraulic radius, wetted perimeter, W/D ratio, channel asymmetry, channel form index, and CS area. The cross-section of the channel has been divided into two groups i.e. natural and another one is anthropic cs. For segregating into two groups the 5% bed length affected by human activities is considered the threshold value. However, in 13 CS, the bed length is affected less than the threshold value and the rest of the 22 CS are having a bed length of more than the threshold value. The CS from the source and mouth is more natural and the middle stretch is more affected by human activities.

Computation of PCA z score

The indices used in this study will show the dynamics of the CS morphology. It is vital to segregate the natural CS from anthropic CS based on the cumulative assessment of the CS morphology. In the present context, three indices (1. w/d ratio as an indicator of channel shape, 2. A* as an indicator of cross-sectional asymmetry, and 3. Cfi as a measure of channel efficiency) will show the cumulative effects of three indices on the spatial location of cross-sections. Transformation of component values to principal component analysis (PCA) composite score (i.e. putting the value on space) is the reflection of each CS based on the interplay of aforesaid variables. Following Ghosh et al. (2016), each PCA composite score for the first principal component loading can be defined using Eq. 10.

$$\text{PCA composite score of profile} \times 1 = \sum [V_i \text{ PC}_1 / \alpha \text{ PC}_1^{0.5}] (10)$$

where V_i is the actual values of variables ($i = 1, 2, 3 \dots n$) in section $\times 1$, PC_1 are the component loadings of variables and $\alpha \text{ PC}_1$ is the Eigenvalue of PC_1 . In calculating the PCA composite score of PC_1 and PC_2 , Z-score has been employed to standardize data and plotted in X, Y coordinates to find out the clustering.

Results

Taxonomy of cross-sections

Natural CS

The natural valley of the Kopai River basin is characterized by vegetation on both banks and the thalweg is near the middle point of the cross-section. About 12 km from the source point and about 20 km from the confluence point Kopai River have a natural configuration of CS while the CS of the middle stretch is highly disturbed by human interventions. The CS from the upper and lower portions represent the natural CS configuration while the middle stretch of Kopai is extensively exploited by human activities.

Bedrock controlled CS. The upper catchment of the Kopai River basin consists of granitic gneiss rock (P. Das, 2013). Mainly the portion lying in Jharkhand. Nearly 12 km from the source point containing its natural shape of cross-section (Figure 4a,b). The

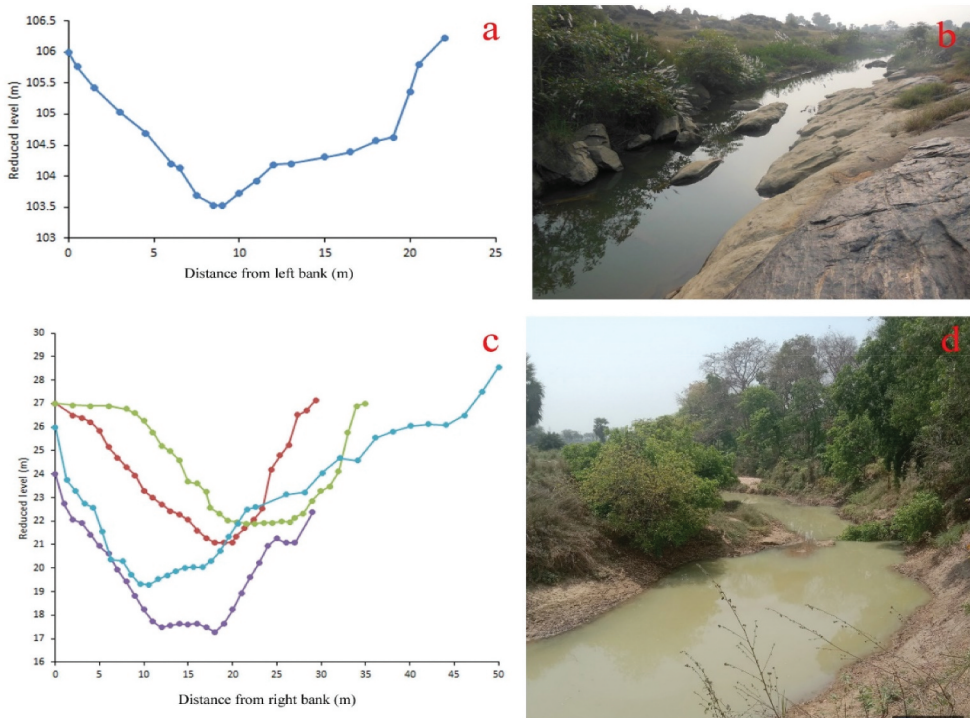


Figure 4. a. The bedrock-controlled CS in Jharkhand is about 8 km downstream from the river's headwaters, with a benchmark or BM (known elevation point measured from triangulation survey with respect to mean sea level) of 106 m. Note: the other elevation points (reduced levels) of the cross-section are computed from the BM. b. Field photo of bedrock control channel (photograph taken on 11 Dec 2021) c. Representative CS of undisturbed alluvial CS – the violet CS was taken from Moutara, about 6km upstream from the confluence, with a BM of 24m; the sky blue CS was taken near Arrar, about 9km upstream from the confluence with a BM of 26m; Red CS was taken near Langalgram about 12 km upstream from the confluence with BM 27m and the green CS was taken from Keudaha about 15km upstream from the confluence with BM 27m. d. The undisturbed alluvial channel in the vicinity of Moutara (photo taken in March 2022)..

average CS area is 4.34 m^2 , the average depth of CS varies between 0.33 and 1.41 m while the width/depth ratio is 12.45. The wetted perimeter ranges from 6.31 m to 7.90 m, and the average width is 6.67 m.

Alluvial CS. The middle and lower stretch of Kopai is composed of older alluvium (P. Das, 2013). It is very difficult to find natural CS in the middle stretch due to intensive sand mining, brick kiln, and other anthropogenic disturbances. The CS near the source point contains its natural shape on the newer alluvium (4c,d). The CS area ranges from 76.52 m^2 to 140.89 m^2 . The average wetted perimeter is 36.06 m while the width ranges from 27 m to 40 m. The average width–depth ratio is 9.73.

Anthropic CS

Szabó et al. (2010) specifically identified seven types of human interventions of anthropic landforms and processes taxonomy i.e. a. monatogenic, b. industrogenic, c. urbanogenic, d. traffic, e. hydrologic, f. agrogenic, and g. recreational. The cross-section of the Kopai River has been classified based on Szabo's principle of anthropic landforms classification. The major types of anthropogenic interventions of the Kopai CS noticed are classified into monatogenic, traffic, hydrologic, agrogenic types according to Szabo's scheme. The interventions of sand mining and brick kiln are monatogenic interventions, 21 road bridges and two rail bridges are crossing over the Kopai River known as traffic interventions, the agriculture adjacent to river bed i.e. in the right bank, upstream of Hetampur bridge known as agrogenic. Hydrologic interventions such as the Kultore barrage interrupted the longitudinal flow of the Kopai River. Besides, the South Kopai main canal also drains out the river water is classified as hydrogenic. Kopai is famous for its recreational value. Near Prantik, several Kopai viewpoints are found due to the tourists' attraction and Sonajhuri is a famous place for tourism but there are no such imprints observed on the river cross-section.

Monatogenic. The demand for sand is increasing due to the rapid rate of urbanization. In the Kopai River basin, sand mining is a dominant activity. In the middle reach about 36 km linear stretch from Patalpur to Paschim Islampur and 86 discrete locations are in the upper, middle, and lower reach.

Kondolf (1994) stated that there are three types of in-stream sand mining i.e. dry pit mining, wet pit mining, and bar skimming. Mainly dry pit sand mining is observed in the Kopai River basin. Sand is extracted both from the river bed and river bank (Figure 5a,b). The majority of cross-sections from the middle stretch have been influenced by sand extraction. The sand is collected from the river bank and river bed using a tractor (Figure 6b). It is seen in the sections that the river bed is remarkably altered and several sand mining pits are produced on the river bed. Extracted sand from the bottom portion of the river bank destabilizes the upper portion and causes bank failure and widens the river channel (Figure 6a). About 36 km stretch is extensively affected by sand mining. The average width of the CS is 60.73 m (maximum 83 m; minimum 44 m), and the mean depth ranges from 0.50 to 2.98 m. The CS area varies from 21.70 m^2 to 175.08 m^2 , for width/depth ratio it is 18.58 m to 87.30 m. Three representative CS are shown in Figure 6c.



Figure 5. a. River bed before sand mining (November 2013) b. River bed after sand mining (November 2018) near Dhagram in the middle stretch of the Kopai River.

The brickfield industry impacts the cross-sectional morphology of the river channel as the main raw material of the brickfield industry is silt or clay. Therefore, brick kilns are attracted to the river bank. According to B. C. Das (2014), brick kilners collect silt from the river bank which is responsible for the river bank erosion. Though the silt or clay collection from river banks has been banned, they collected the raw materials from other places. The brick kilners create shallow depressions along the river bank to trap silt or silt clay during the flood time and afterward collect them.

About 78% of the brick field industry is situated in the lower reach of the Kopai River Basin (Figure 7a). Two brick kilns are situated in the upper reach, 10 in the middle reach, and 26 in the lower reach. In 2009, the District Land and Land Reforms Office (DL & LRO) of Nadia estimated that a single large-scale brick field can move $133,110 \text{ ft}^3$ of earth material for a year (T. Das, 2019). Thus, a total of $5,058,180 \text{ ft}^3$ of earth materials have been transferred due to the anthropogenic processes in the Kopai River basin. The morphological change along the river bank is remarkable and to find out the changes two cross-sections have been drawn near the brick kiln (Figure 7b) and it is observed that the excavation of a shallow depression to trap the sediment disrupted the natural valley configuration (Figure 7c). Naturally from channel towards bank the elevation becomes higher but in the cross-section, two sharp depressions are found due to the sediment

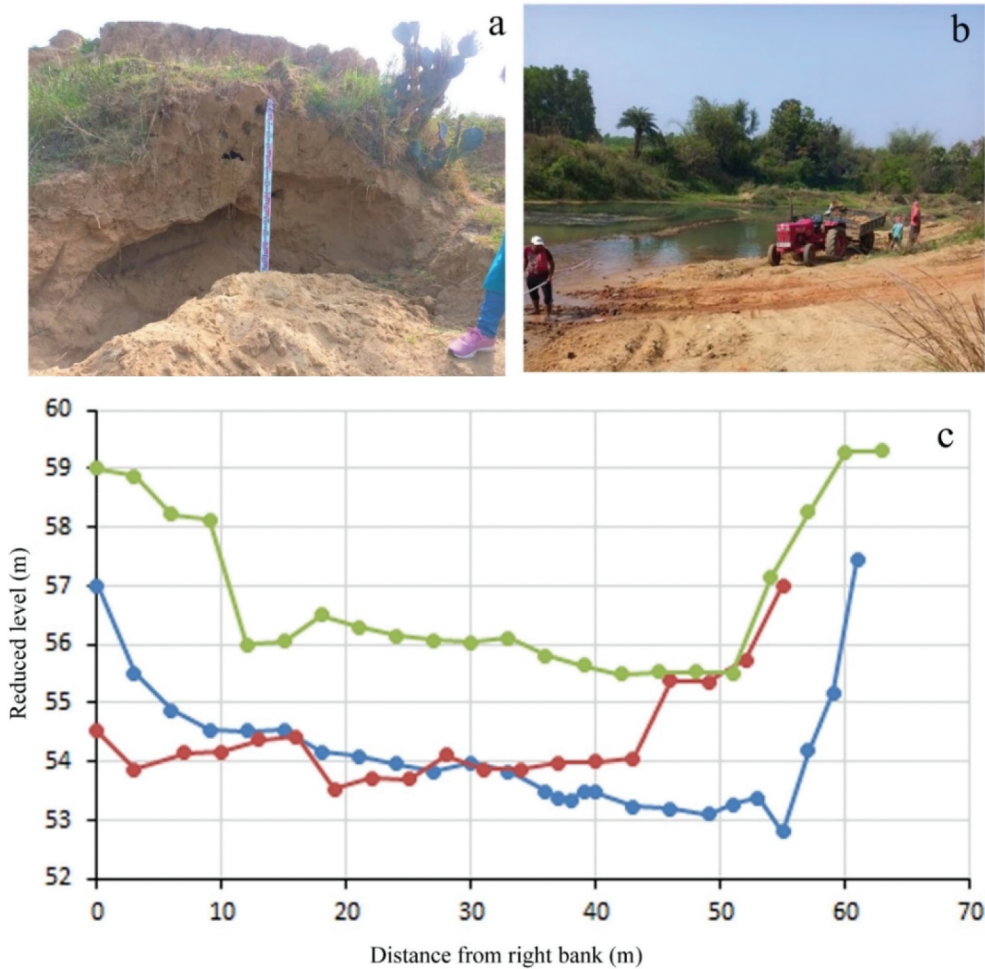


Figure 6. a. Supportless upper layer due to river bank sand mining near Demuria, b. Sand is collected from the river bank near Sultanpur, c. Three representative CS have been drawn from the extensive mining sites of the Kopai River to show how the mining altered the CS morphology. The green CS was taken from Dhargram with a BM 59m, the red CS was taken from 2km downstream of the Kultore barrage with a BM 57m, and the blue CS was taken from 4km downstream of the Kultore barrage with a BM 57m.

cutting. The CS area of the two CS is 20.96 and 90.06 m², respectively, for the second CS the cross-sectional area is enlarged by about 7 m², and the sediment is used as the raw material, and for the first CS one is shallow and one deep depression is found and the original width is 16 m and it is enlarged to 44 m. The width/depth ratio is comparatively high (29.38 and 34.96).

Traffic. Over the Kopai River, 21 road-stream crossings and 2 rail bridge crossings are present, 11 in the upper reach, 7 in the middle reach, and 5 in the lower reach (including one rail bridge in the middle and lower reach) (Figure 9a). Two rail bridges cross Kopai River near Dubrajpur and Prantik. The modification of the river cross-

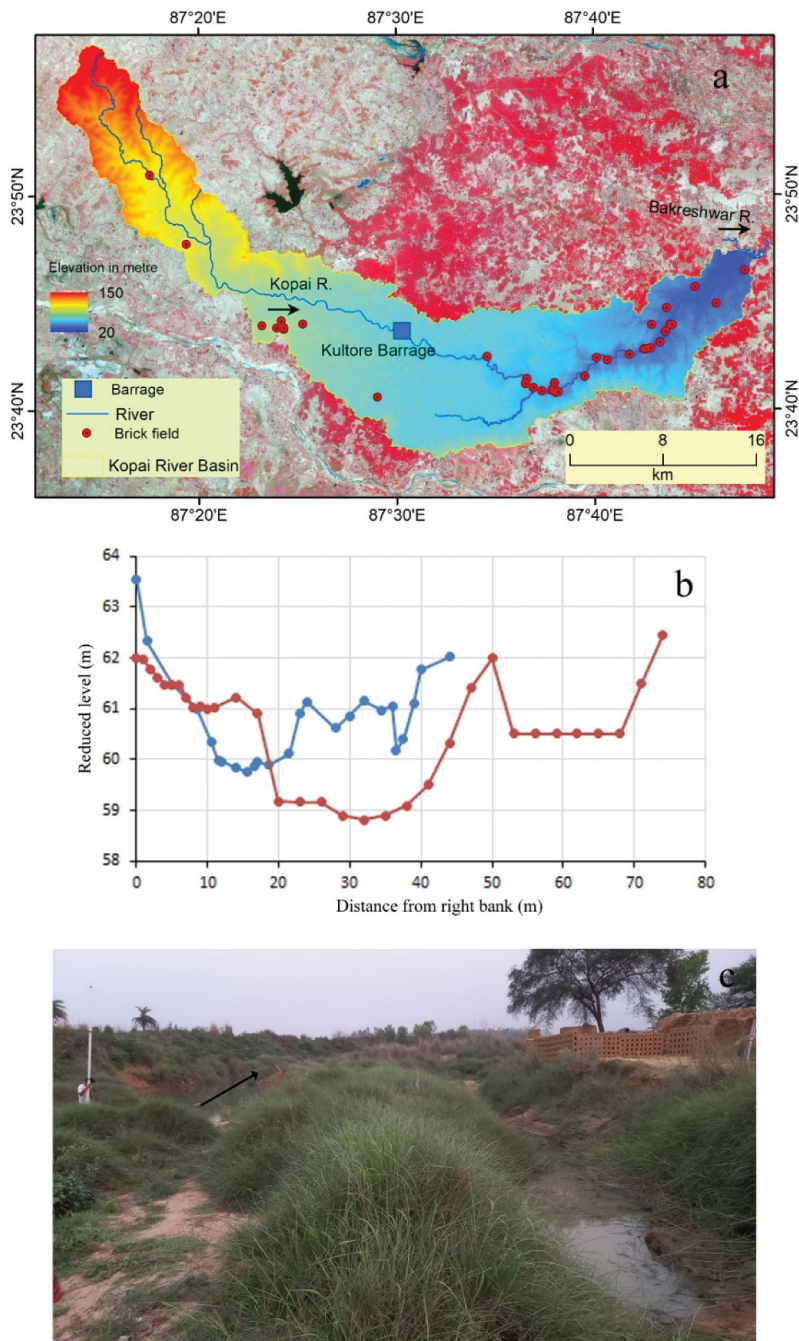


Figure 7. a. Location of the brick fields scattered in the Kopai River basin, b. Two CS have been drawn near the brick kiln adjacent to the river, the blue CS was taken from just downstream of the Hetampur bridges with a BM of 65m and the red CS was taken near the Khoj Mahammadpur with a BM of 62m, c. The field photo was taken from downstream of the Hetampur bridge from where the CS has been taken where we noticed the left bank of the river excavated and formed shallow depressions.



Figure 8. Different types of piers and their locations observed on the Kopai River: a. Box nose piers near Khajuri, b. Round nose piers near Chandipur, c. Mixed nose (round and box) near Galtia, d. Cylinder nose piers near Adityapur, e. Nose piers near Ballavpur, f. Cylindrical and Sharp nose piers near Taltor Prantik rail bridge crossings.

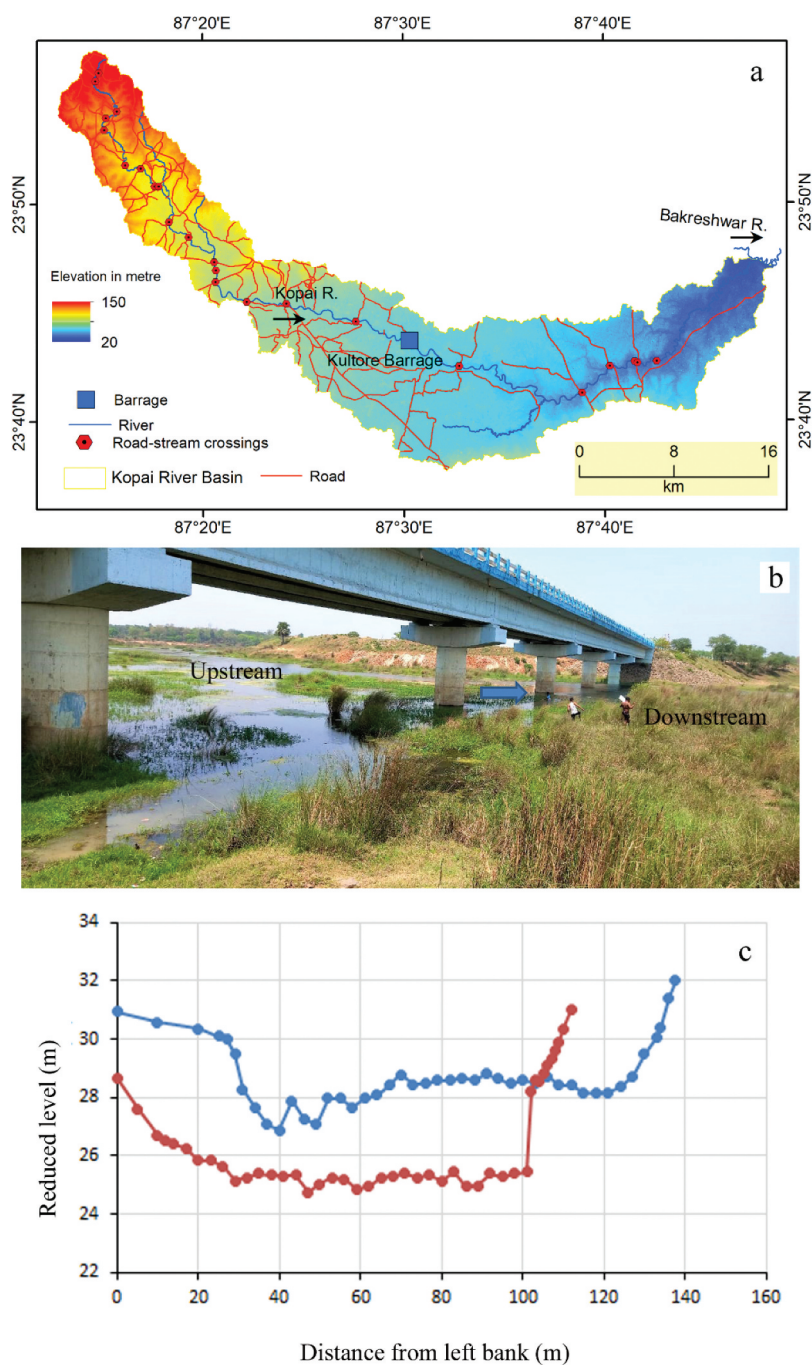


Figure 9. a. Location of road-stream crossings and the river networks on the basin has been portrayed, b. Adityapur road bridge is one of the major bridges on the Kopai River taken for the case study to detect the upstream and downstream changes of cross-sectional morphology, c. The red-coloured CS represents the upstream CS of Adityapur bridge and the blue CS is the downstream CS, both CS were taken from the 10m upstream and downstream of the bridge with a BM of 31 m.

sections varies as per the nature of pier geometry. Over the Kopai River different geometrical piers have been found like square nose, cylinder nose, sharp nose, round nose, rectangular and prism (Figure 8a-f). The Amar-Ahmedpur road bridge is the perfect example of cylindrical piers having a perimeter of 5.6 m. There are five piers from the left bank to the right bank, with a distance of 22 m between two consecutive piers. During pre-monsoon and post-monsoon periods, four piers are in contact with water and the left bank pier stands above water level (Figure 8d). Prantik rail bridge has consecutively two sets of piers, the older one is cylindrical having a perimeter of 5.6 m and a newer one is prism (Figure 8f). Bridges near Chandipur have a round nose with diameter 1.15 m having 45 round noses (Figure 8b). Galtia bridges having mixed pier types (round and rectangular) (Figure 8c). The bridges in the upper parts of the basin are mainly rectangular (Figure 8a).

The road-stream crossing affects the channel morphological behaviour. Different pier geometries affect differently. To find out the effects of cylindrical piers, two cross-sections have been drawn – one from the upstream of Adityapur bridge and one from downstream of the bridge. The cross-section area of the downstream is 294.34 m² while 311.97 m² for the upstream (Figure 9c). The river has widened downstream (downstream width 136 m; upstream width 102 m). The wetted perimeter of the downstream is 137.38 m and 107.53 for the upstream. Bed scouring and bed deposition are portrayed from the downstream cross-section (Figure 9b). Bed scouring is found near both the right bank and left bank and bed deposition is found near the right bank.

Hydrogenic. In the era of the Anthropocene, the construction of dams and barrages are major human intervention in fluvial processes. Dams and barrages are constructed for fulfilling wide purposes such as agriculture, flood control measures, hydropower generation, flood control measures, and commercial purposes (Collier et al., 1996). Apart from serving all these purposes, dams and barrages are responsible for changing the river characteristics by trapping the sediments and altering the river flow distribution (Pal, 2016). Apart from the dams and barrages, the check dams are also responsible for reshaping the channel morphology. There are six check dams in the Kopai basin and limited in the upper reach. The only barrage constructed upon the Kopai River is the Kultore barrage, about 53 km downstream from the source point, located in the Rarh region and divided the Kopai River almost into two halves (Figure 10a-c). This barrage encompasses about 212 km² of catchment area and with a flood danger level of 55.16 m. The barrage has an important role in irrigation as the irrigation canals are constructed downstream of the Kultore barrage i.e. South Kopai Main Canal (length 83 km and the irrigated area is between Kopai and Ajay River, 87.211 km²) and Kopai Bakreshwar Main Canal joins Kopai River with Bakreshwar River (length 18.11 km, irrigated between Bakreshwar and Kopai River, 27.692 km²).

Agrogenic. Humans act as geomorphic agents and directly create and modify landforms to a large extent (Li, Yang, et al., 2017). In the upper reach, mainly fishermen obstructed the river flow due to fishing. In the upper reach, the river channel is narrow about 20 m. The fishermen have frequently obstructed the flow but it remains for a few days in the middle reach about 2 km upstream of Hetampur bridges the farmers are constructing a

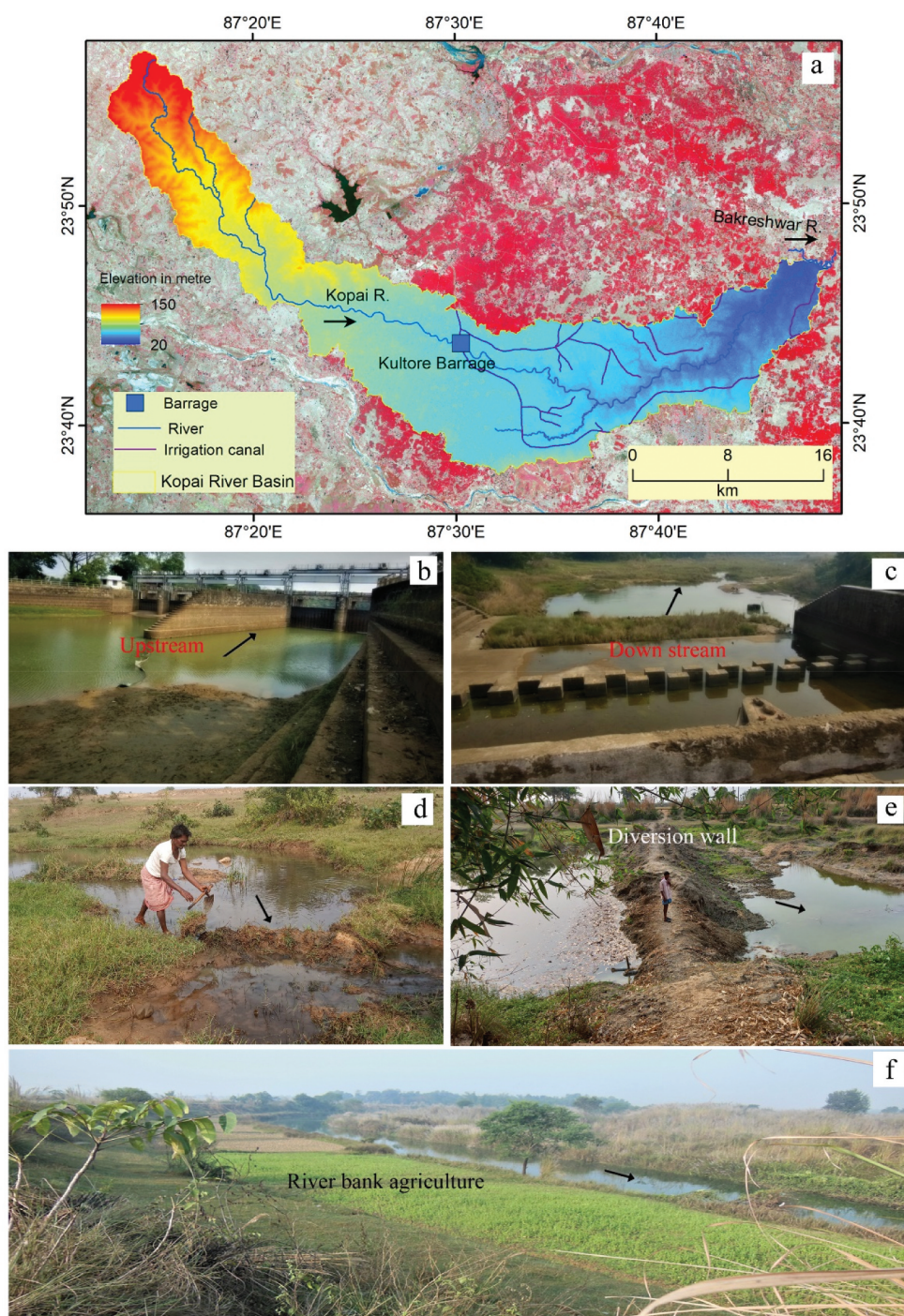


Figure 10. Hydrogenic and agrogenic interventions a. location of Kultore barrage and irrigation canal in the lower basin b and c. Upstream and Downstream of the Kultore barrage (field photograph was taken on 12th December 2021). d. the fisherman obstructed the river flow by earth near Valka, Singapore ((field photograph was taken on 11th December 2021), e. a group of farmers constructed a diversion wall on the river bed and restricted the natural water flow near Hetampur (photograph was taken on 26th March 2022). f. agricultural practices by cutting the right bank of the river during the post-monsoon season (photograph was captured on 13th December 2021).

diversion wall collecting silt from the river bed (Figure 10d). The farmers spend nearly INR 35,000 on wall construction. Upstream, the river water creates depression and they use the water for irrigation purposes (Figure 10e). During the monsoon, the diversion wall washed out with the river flow but during December–January they again constructed the wall. At about 500 m upstream of the Hetampur bridge, agriculture has been practiced by cutting the river bank (Figure 10f).

Variation of cross-sections

From source to mouth, a total of 35 CS have been categorized based on the CS types whether it is natural or anthropic. A total of 37% of CS are natural types and 63% are anthropic. The natural CS is located nearly to the source and confluence point, while CS located in the middle stretch is an anthropic type. The average CS area of natural CS is 64.59 m^2 (SD = 44.07, Med = 79.77, IQR = 80.17), for anthropic it is 119.442 m^2 (SD = 66.76, Med = 121.53, IQR = 61.19) (Figure 11a). It is also noticed that the channel asymmetry is slightly higher for the natural CS (Figure 11b). On the contrary, the wetted perimeter is higher for the anthropic CS (Figure 11c). Regarding the anthropic CS, the width/depth ratio ranges from 12.53 to 87.30 which is far greater than the natural channel (Table 1; Figure 11d).

The higher width/depth ratio indicates a declining trend in channel efficiency. Due to the sand mining, the channel width increases, and the average depth decreases, which

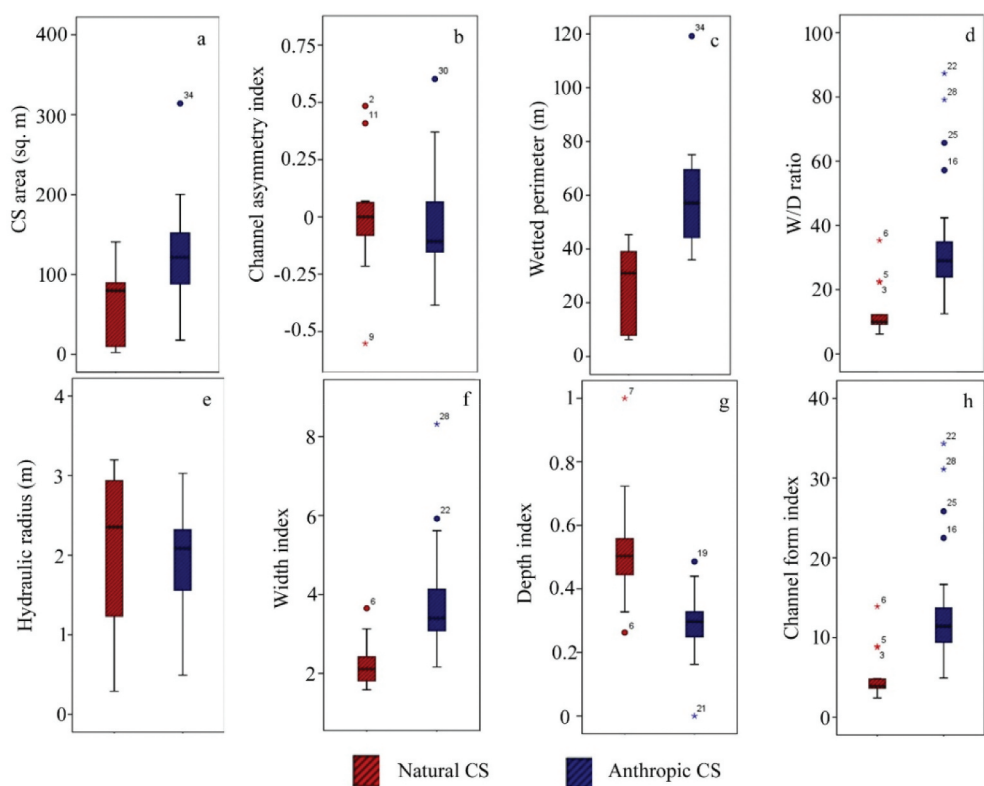


Figure 11. A-h variations of natural cs and anthropic cs of different cs parameters.

Table 2. Anova showing the variation of channel morphological parameters of natural and anthropic types.

<i>Cs parameter</i>	<i>F</i>	<i>P-value</i>	Remarks
Cs area	6.578499	.015056	Alternative
asymmetry	0.366623	.548993	Null
Wetted perimeter	26.29763	1.26E-05	Alternative
W/D ratio	14.77329	.000523	Alternative
Hydraulic radius	0.000218	.988301	Null
Width index	15.43234	.000412	Alternative
Depth index	31.57642	2.96E-06	Alternative
Form index	14.77329	.000523	Alternative

**df*=1; *F critical* = 4.139.

makes the channel more inefficient (Figure 11 f,g). The comparatively higher channel form index of anthropic CS indicates that the CS is shallow and wide types (Figure 11h). The single-way ANOVA has been run to assess the significant difference among the natural and anthropic CS types at one degree of freedom at a 0.1 significance level. Most of the factors (except channel asymmetry and hydraulic radius) have a statistically significant difference between natural and anthropic CS (Table 2).

Categorization of the cross-section using prins-score

The CS of natural and anthropic origin has been clustered with the help of discriminant analysis based on the z score of PC₁ and PC₂. Three measures have been considered for the analysis including (1) W/D ratio which portrays the shape of the channel, (2) channel form index which reflects the channel efficiency, and (3) channel asymmetry. It has been observed that most of the natural CS (69%) fall into quadrant 4 while 23% into quadrant 2 and about 8% in quadrant 3. Regarding the anthropic CS, 77% points fall into quadrant 3 while 14% in quadrant 1 and 9% in quadrant 2 (Figure 12). A reversal trend has been noticed regarding the natural and anthropic CS.

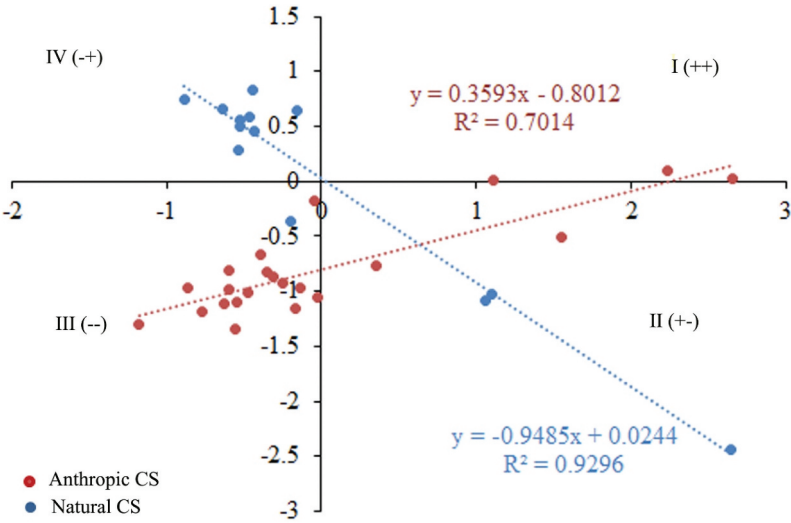


Figure 12. Discriminant analysis of river CS.

Potentiality of anthropic geomorphology of Kopai River Basin

Spatio-temporal variation in I_{PAG} index (1983)

In the present study, the degree of human interventions at the basin scale has been analyzed by using the index of potential anthropic geomorphology (I_{PAG}). The study area spreads over 7 C.D. blocks of Birbhum districts i.e. Khoyrasole, Rajnagar, Dubrajpur, Illambazar, Bolpur-Sriniketan, Sainthia, and Labhpur. About 90% of the basin is spread over Khoyrasole, Dubrajpur, Illambazar, and Bolpur-Sriniketan blocks. The I_{PAG} has been calculated from 1961 to 2021 and it has been observed that the I_{PAG} progressively decreased for almost all the C.D. blocks. I_{PAG} is highest in 1961 because of the higher illiteracy. The I_{PAG} index depends upon the urban population and illiteracy, though the extent of the urban landscape is lower compared to 2021 while the higher rate of illiteracy increases the index value as the negative modification of landscape is more near the region having a higher rate of illiteracy. In 1961, Dubrajpur (0.444) registered the highest I_{PAG} while Labhpur (0.38) registered the minimum value. From 1961 to 2021, the maximum ranges were recorded for Illambazar (0.404 to 0.095) and the minimum recorded for Bolpur-Sriniketan (0.434 to 0.247). This is due to the rapid decline in illiteracy (1961: 80.79%; 2021: 14.45%). A similar picture has been found for Bolpur (1961: 65.95 %; 2021: 15.91 %). From 1961 to 2001, there is no urban population in the C.D. blocks of Khoyrasole, Illambazar, Labhpur, and Rajnagar while in 2011 and 2021 there is no urban population in the block Khoyrasole. It is found that there is a decreasing trend over the year (1961 to 2021) (Figure 13a-h; Table 3).

Performance evaluation of the potential anthropic geomorphological indices

The potential anthropic geomorphology index is a theoretical measure of the intensity of anthropogenic activities on the surface. Here, in this section, the relation of potential anthropic geomorphology with land transformation has been assessed. The land transformation in the channel cross-sections is basically due to the extensive sand mining and brick kiln in the basin while near Hetampur land transformation also occurred due to agrogenic purposes. Farmers collect the silts from the river bed and construct an obstruction wall in the river bed to accumulate the water upstream and then uses it for agriculture purposes. This type of division wall is mainly constructed during the post-monsoon periods. Figure 14a depicts that there is a positive relationship between the I_{PAG} value and land transformation, although the relation is very poor ($R^2 = 0.047$). However, this does not depict the actual situation of the study area.

Figure 14c portrays the spatial variation of the modified I_{PAG} value. It is observed that the Dubrajpur, Illambazar, and Sainthia blocks have come under the higher I_{PAG} while Khoyrasole and Rajnagar blocks are the least potentials for anthropic geomorphological processes while Labhpur and Bolpur are moderately potential. It is also observed that the modified value of I_{PAG} is more strongly related to the land transformation ($r^2 = 0.2722$) (Figure 14b). Therefore, in this study area, the modified I_{PAG} portrays reality more accurately than the Nir methods of I_{PAG} . Figure 14d depicts that there is a difference between the I_{PAG} value of Nir and the modified I_{PAG} . Regarding the seven C.D. blocks, the six C.D. blocks have a higher modified I_{PAG} while Rajnagar has a lower modified I_{PAG} value than the original I_{PAG} . The difference is higher for the Illambazar block as the percent of the settled area, an extension of agricultural land, and reduction of forest area are higher than in other blocks, and therefore the higher rank assigned increases the index value. For the Rajnagar block, the agricultural

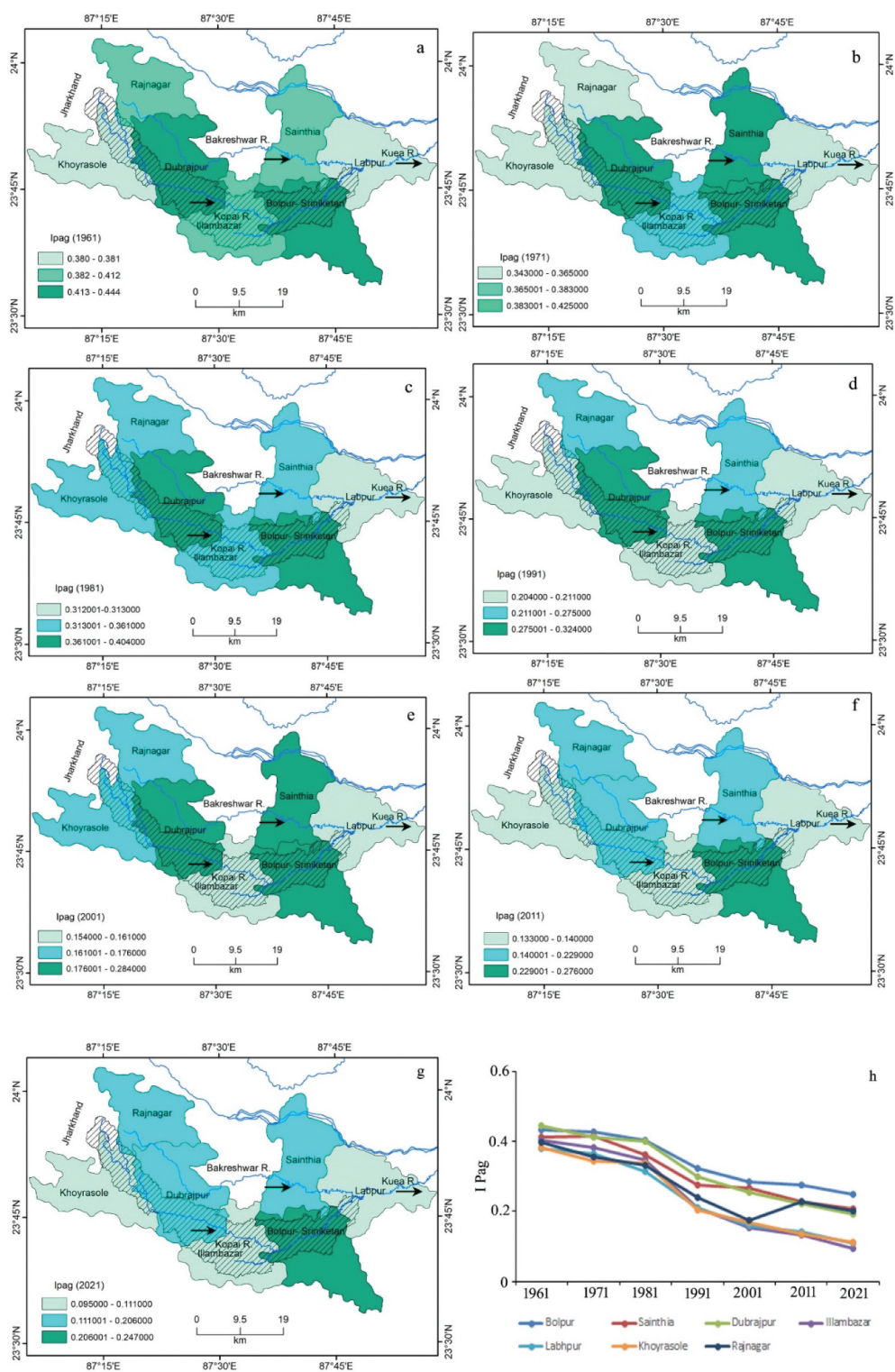


Figure 13. The index of potential anthropic geomorphology of different C.D. blocks of Kopai River basin a. 1961, b. 1971, c. 1981, d. 1991, e. 2001, f. 2011, g. 2021 h. comparative representation of decreasing trends of I_{PAG} .

Table 3. Spatial variation in I_{PAG} index.

C.D. Blocks	1961	1971	1981	1991	2001	2011	2021
Bolpur	0.434	0.425	0.404	0.324	0.284	0.276	0.247
Sainthia	0.413	0.415	0.361	0.275	0.266	0.229	0.206
Dubrajpur	0.444	0.412	0.401	0.299	0.254	0.221	0.191
Illambazar	0.404	0.383	0.346	0.211	0.154	0.133	0.095
Labhpur	0.380	0.365	0.313	0.209	0.161	0.140	0.110
Khoyrasole	0.381	0.343	0.336	0.204	0.168	0.136	0.111
Rajnagar	0.396	0.357	0.333	0.240	0.176	0.229	0.202

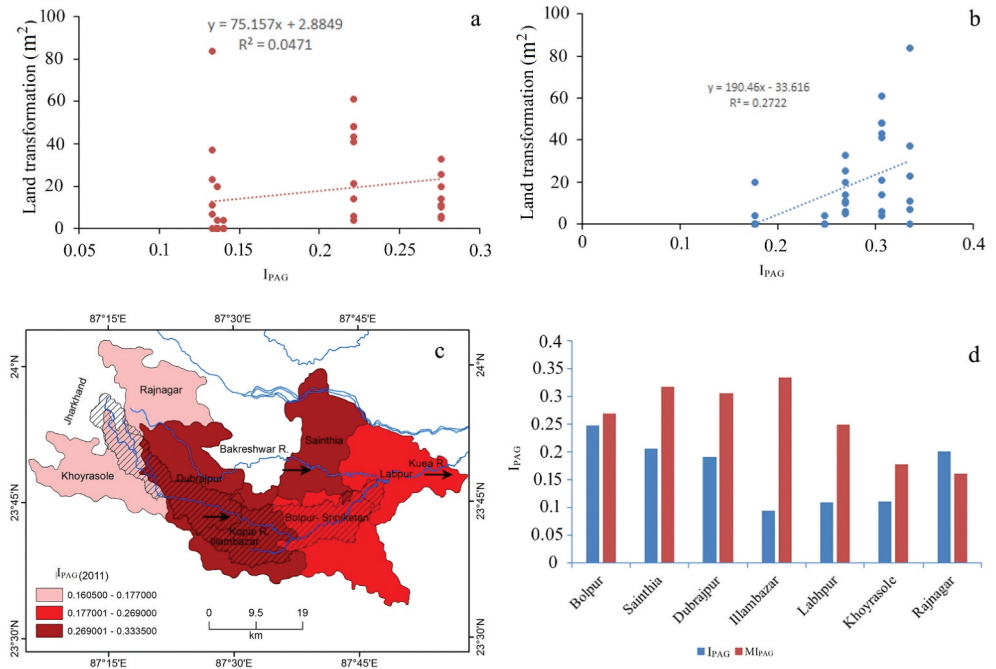


Figure 14. Relation between land transformation and I_{PAG} a. Nir method) b. MI_{PAG} (modified method) c. Spatial variation of MI_{PAG} d. comparison between I_{PAG} and MI_{PAG} .

land has decreased (about 30%) with a lower percentage of the settled area. Moreover, the low population density is responsible for a comparatively lower modified I_{PAG} . Therefore, the Nir index sometimes overrates compared to the actual scenario, and sometimes it also underrates.

Discussion

Application of taxonomic principles in channel scale anthropic geomorphology

In this study, we attempted to classify the anthropogenic interventions as per the scheme of Szabó et al. (2010). Monatogenic, traffic, and hydrological interventions are very common in a tropical river basin. Monatogenic interventions (here, sand mining and brick kilns) destabilize the river bank as sand is excavated from the bottom portion of the bank, which enhances the bank failure and makes the channel widen (Islam et al., 2021). The same results have been observed for our study. B. C. Das (2014) explored that direct silt or clay collection from the river bank for the brick kiln increases the channel width. Islam et al. (2021) showed that

shallow depressions have been found in the cross-sections of the Mayurakshi River near the brick kiln industry, just like in the Kopai River cross-sections (Figure 7b), due to the silt collection from the bank. In terms of traffic, Roy (2020) demonstrated that the channel depth upstream of road-stream crossings of NH 31 to the Buribalason River located in the Terai region of eastern India is lower than downstream. However, our study indicated a reverse scenario in this regard. The channel depth and cross-sectional area are higher for the upstream segment of the Adityanaranpur bridge over the Kopai River (Figure 9c). This is due to bed deposition along the right bank while scouring along the left bank. A similar observation has been made in the study of Sarkar et al. (2020) regarding the Shinibas bridge over the Churni River, India. It is important to note that most of the previous studies applied the scheme of Szabó et al. (2010) in the classification of typical landforms. Our study demonstrated the classification of fluvial cross-sections using taxonomic principles based on morphological features. Furthermore, the classification of the CS into natural and anthropic classes based on this principle has increased knowledge in the field.

Applications of the potential anthropic geomorphological indices to basin scale analysis

Globally, many scholars used the Nir's I_{PAG} in their studies (Kar et al., 2020; Rózsa, 2007; Rózsa & Novák, 2011; Uncu & Karakoca, 2021). Rózsa (2007) calculated the I_{PAG} for 37 countries spread across the world between 1970 and 2000 and the I_{PAG} of 2015 was calculated based on the predicted value of illiteracy and urban population. The lower I_{PAG} is recorded in Hungary (0.16) in 1970, Thailand (0.18) in 2000, and Poland (0.19) in 2015 while the higher I_{PAG} was recorded for Algeria (0.76) in 1970, Morocco (0.65, 0.61) in 2000 and 2015. Uncu and Karakoca (2021) used the I_{PAG} to reveal the potentiality of the anthropic geomorphology of the Bilecik region and the I_{PAG} was computed to be 0.45 categorized as medium-scale threat but the region had been affected by increasing mining activities from 2003 to 2016. Kar et al. (2020) applied the Nir (1983) index for the entire lower deltaic West Bengal across 116 C.D. blocks spread over nine districts of West Bengal where Kolkata and Uluberia recorded a higher I_{PAG} of more than 0.6. However, the areas in the Sundarban portrayed a relatively low score.

Though globally the Nir (1983) index has been applied by scholars, the Nir's method suffers from methodological limitations, especially when applying this method to developing nations as our findings for the present case. The study by Rózsa (2007) and Rózsa and Novák (2011) also found the limitations of the Nir's index. They arise questions relating to the two parameters i.e. percentages of urban population as an indicator of development and percentages of illiteracy as the indicator of perception. Rózsa (2007) stated that urban population is not a sufficient indicator that indicates the magnitude of development as the lower limit of the population spatially varies e.g. 200 population in Denmark, Norway, and 50,000 in Japan. Similarly, Rózsa and Novák (2011) also supported this and also questioned whether the level of illiteracy is enough to indicate the level of education which may develop people's perceptions. Perception of people does not always have a good bonding with literacy. Previously, many scholars used different indices as well as models to quantify the intensity of human footprints on natural landscapes (Ayram et al., 2020; Balthazar et al., 2013; Dang et al., 2020; Etter et al., 2011; Islam et al., 2022; Li, Zhang, et al., 2017) where the applicability of modified I_{PAG} is higher than that of I_{PAG} .

The potential anthropic geomorphology especially in the tropical region is less explored, especially using the approaches of taxonomic principles and Szabo's scheme. Though many works are focused on the intense nature of anthropogenic alternation on the geomorphic landscape in Asia, Africa, and Latin America, Nir's index as originally envisaged becomes less appropriate because of the rapid urbanization in the developing nations. Thus, the direction of the present study on modified Nir's index definitely will be gainfully employed for a better portrayal of the potential anthropic geomorphology. However, the selection of the parameters and their weightage to construct the MI_{PAG} in the different developing nations spatially vary, and hence there is a need to explore these dimensions in future research attempts.

Conclusions

The present study portrays that the Kopai River basin has been altered extensively by anthropogenic activities in terms of barrages, irrigation canals, brickfields, sand mining, road-stream crossing, and agriculture. The road-stream crossing modified the channel bed morphology by creating bed scouring and bed deposition. Sand mining also reshapes the channel bed morphology by pit formation. Sand extraction from the bottom layer of the river bank destabilizes and bank failure happens which is responsible for channel widening. The shallow depression has been excavated in a brick kiln for sediment trapping which disrupts the natural valley configuration. The study employed a taxonomic approach of Szabo to classify the channel cross-sections and characterize them in terms of channel shape, asymmetry, and efficiency. Moreover, alteration in the basin-scale morphology is traced in the light of Nir's index (Nir, 1983) and modified indices. Thus, the major findings of the present study are mentioned below.

- A total of 37% of CS are natural while 63% are anthropic. The natural CS is located nearly to the source and confluence point, while CS located in the middle stretch is an anthropic type.
- The major types of anthropogenic interventions of the Kopai CS observed are classified into monogenic, traffic, hydrologic, agrogenic types according to Szabo's scheme.
- Most of the factors (except channel asymmetry and hydraulic radius) have a statistically significant difference between natural and anthropic CS.
- It has been observed that most of the natural CS (69%) fall into quadrant 4 while 23% into quadrant 2 and about 8% in quadrant 3 while regarding the anthropic CS 77% points fall into quadrant 3 while 14% in quadrants 1 and 9 % in quadrant 2.
- The I_{PAG} has been calculated from 1961 to 2021 which exhibits that the I_{PAG} progressively decreased for almost all the C.D. blocks. However, I_{PAG} is highest in 1961 because of the higher illiteracy.
- Though there is a positive relationship between the I_{PAG} and land transformation, the relation is very poor ($R^2 = 0.047$) which does not depict the actual situation of the study area. It is also observed that the modified value of I_{PAG} (MI_{PAG}) is more strongly related to the land transformation ($R^2 = 0.2722$).
- Of the seven C.D. blocks, the six C.D. blocks have a higher MI_{PAG} while Rajnagar has a lower MI_{PAG} value than the I_{PAG} .
- The MI_{PAG} seems to be more relevant than I_{PAG} to exploring the potential anthropic landscape, especially in the context of developing nations.

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Data availability statement

The data that support the findings of this study are available from the corresponding author, [AI], upon reasonable request.

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Appendix 1: Questionnaire for perception survey regarding indigenous knowledge

(Rating scale: 1 represents completely disagreed while 7 represents completely agreed)

- (1) I frequently visit the Kopai Kopai River.
- (2) I have attachments to the river for socio-cultural reasons.
- (3) I depend on the river for livelihood options.
- (4) I use optimum water from the river or other sources to avoid over-extraction of river water.
- (5) I never extracted sand or gravel from the riverbed.
- (6) I think sand mining induces massive changes in the cross-sectional morphology of the river.
- (7) I believe that river plays a crucial role in maintaining good ecological balance.
- (8) I attend meetings for increasing public awareness among inhabitants regarding the adverse effect of excessive sand mining or over-exploitation of the river.
- (9) I take the initiative to aware the local people not to add pollutants to the river.
- (10) I unite my friends to protect the river from anthropogenic interventions.