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Livelihood Dynamics of Transboundary Riverine Inhabitant's in Acid Mining vs Non-Mining Affected Areas of Sunamganj, Bangladesh

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Abstract

Rivers are vital freshwater resources that support human livelihoods, yet they are increasingly impacted by upstream flows, anthropogenic activities, and waste discharge from riverside settlements. This study assessed and compared the livelihood status of transboundary riverine communities along the Jadukata and Nawagang rivers in the acid mine-affected and non-mine-affected regions of northeastern Bangladesh. Data were collected from 200 households using structured interviews, focus group discussions, and key informant interviews. Livelihood status was evaluated through five capitals namely human, physical, natural, social, and financial using an equally weighted composite index, the Livelihood Assessment Index (LAI). The overall LAI was 0.487, with individual capital scores of 0.61 (human), 0.72 (physical), 0.36 (natural), 0.55 (social), and 0.198 (financial). When disaggregated, Jadukata riverine areas (mine-affected) had lower scores across most capitals (LAI: 0.449) compared to Nawagang areas (non-mine-affected) (LAI: 0.522). Statistically significant differences were observed in physical, natural, and financial capitals particularly in indicators such as soil erosion protection, air quality, transport infrastructure, hospitality, and income. Although the overall livelihood status in both regions remains low, the Jadukata riverine inhabitants are disproportionately affected by socio-economic vulnerabilities due to acid mining. These findings can inform future research and policy interventions. Targeted awareness programs and environmental safeguards are recommended to mitigate pollution and protect the biodiversity of the Surma River

system, to which both rivers are connected.

Keywords

Transboundary River, Human Capital, Physical Capital, Social Capital, Livelihood Assessment Index, Riverine Inhabitants

1. Introduction

Water is an inevitable element for the subsistence of humans, plants, animals, and all other living organisms (Gleick, 1996; UNESCO, 2019). It plays a critical role in various aspects of life, including drinking, cleaning, cooking, firefighting, and manufacturing (Shiklomanov, 1993). Additionally, access to clean water is a fundamental determinant of quality of life; approximately 2.2 billion people lack safely managed drinking water services (WHO & UNICEF, 2021). Inequalities in access to clean water are evident between rural and urban populations, where urban areas generally have greater accessibility (World Bank, 2020; Hanjra & Qureshi, 2010). Water quality serves as a crucial indicator of an ecosystem's health. It supports ecological processes by maintaining habitats for aquatic organisms, wetlands, birdlife, and vegetation (UNEP, 2016). However, despite its critical importance, water quality is often poorly managed on a global scale. Currently, industrialization, urbanization, and agrochemical use are major contributors to water quality degradation (Meybeck, 2003; Vorosmarty et al., 2010). Water contamination occurs through chemical and biological pollutants, negatively impacting humans, animals, and aquatic species (Allan et al., 2012). Pollution-induced water degradation not only threatens biodiversity but also contributes to severe public health crises (WHO, 2017; Pacheco & Fernandes, 2016). Water bodies like lakes, rivers, ponds, and estuaries are crucial sources of water for domestic, industrial, and agricultural activities (Gleick, 2000). Rivers, in particular, are a vital freshwater resource. In Bangladesh, rivers and their tributaries are the predominant sources of freshwater, playing a critical role in sustaining human life and biodiversity (Gain et al., 2017). A healthy river ecosystem supports livelihood activities such as fishing, tourism, and transportation while also holding significant cultural and religious values (Mukherjee et al., 2018). However, many rivers in Bangladesh are facing environmental degradation due to anthropogenic activities, including domestic waste disposal, industrial effluents, and agricultural runoff (Majumder, 2009). Riverbank erosion and pollution from upstream activities are escalating challenges in the area (Islam et al., 2017; Bhaduri et al., 2011). Bangladesh has approximately 700 rivers, 57 of which are transboundary, with 54 shared with India and three with Myanmar (Ahmed et al., 2017).

In Sunamganj District, the transboundary rivers include the Jadukata, Damalia, Nawagang, and Umium rivers. Jadukata is known as Kynshi at its source in the western Khasi hills of Meghalaya. It originates from the kynsew village under

Sohiong Block in the West Khasi Hills district at a height of 1748 m ASL. It flows south up to Ranikor, covering the distance of 139 km, and exits into Bangladesh. At Ranikor the Jadukata enters the Bangladesh plains through Uttar Badaghat Union under Taherpur Upazila of Sunamjanj district. As it flows further south through Jamalganj Upazila, named Rakti, till Jadukata Rakti falls into the Surma in Sylhet district (Rahman et al., 2017). Pollution from coal mining in Meghalaya, India, poses a significant threat to the Jadukata River (Karar et al., 2017). Many local communities rely on coal collection from the river as their primary source of income. During the rainy season, runoff from mining activities increases pollution levels downstream, negatively impacting aquatic ecosystems and water quality (Hatje & Bidone, 1998). Acid mine drainage (AMD) from coal mining significantly impacts to water pollution in the northeastern region of Bangladesh (Farukh et al., 2022; Karar et al., 2017). Direct discharge of AMD into transboundary rivers has resulted in significant losses of fish and agricultural productivity (Karar et al., 2017). Impurities from mine drainage can persist long after mining operations cease, posing long-term ecological threats (Demchak et al., 2004). High acidity levels in contaminated water adversely affect fish growth and reproduction (Pandey et al., 2014). The Nawagang River rises from southwest of Mawsynram in the East Khasi Hills district of Meghalaya, where it flows south-easterly named Khashimara river and descends on the foothills bordering Bangladesh. The Khasimara, or Khaimara enters Bangladesh with a new name of Nawagang through Deorabazar Upazila of Sunamganj district and flows towards the south and meets the Surma in the same direction (Rahman et al., 2017). Its gradual degradation throughout time has been caused by pollutants from industry, urbanization, and agricultural activities (Islam et al., 2017; Singh et al., 2010). The impact of water pollution is not limited to aquatic ecosystems but extends to human health and socio-economic stability. Unregulated urban expansion, excessive use of agrochemicals, and improper waste disposal have severely affected riverine communities in Bangladesh (Akhie & Dipta, 2018). The deterioration of river water quality has led to declining fish populations, disruptions in the food chain, and increased health risks among local inhabitants (WHO, 2019; Bartram & Cairncross, 2010). Furthermore, socio-economic challenges, such as high illiteracy rates, inadequate educational institutions, and poor transportation infrastructure, continue to affect the well-being of riverine communities (Khanum, 2013; Rahman et al., 2021).

Communities residing along polluted rivers face critical challenges in accessing essential services such as healthcare and clean water. The scarcity of adequate medical facilities and the absence of nearby hospitals further intensify the hardships of these river-dependent populations (Ahmed et al., 2021; Hutton & Chase, 2016). Livelihood defined as the capabilities, assets, and activities required for a means of living is deeply intertwined with access to clean water and environmental sustainability (Chambers & Conway, 1992). A sustainable livelihood strategy encompasses income-generating activities, effective resource management, and asset accumulation (Chambers & Conway, 1992; Rahman & Hickey, 2020). Rural communities often adopt diverse socio-economic strategies to enhance their living conditions (Davis et al., 2010; Jiao et al., 2017; Khatiwada et al., 2017; Uddin et al., 2018). Ensuring sustainable livelihoods for riverine populations requires a holistic approach that integrates access to clean water, quality education, healthcare, and economic opportunities. Sustainable development, supported by improved infrastructure, environmental conservation, and responsible resource management, is crucial to improving living standards (Rockstrom et al., 2014). In northeastern Bangladesh, water pollution has remained a longstanding concern. However, its socio-economic impact on riverine households has yet to be systematically examined. A scientific assessment of livelihood conditions in both AMD affected and non-affected areas is essential for informing targeted interventions and effective policy responses. This research, therefore, aims to evaluate the livelihood status of riverine communities by considering the effects of AMD and other forms of pollution. Using livelihood capital indices, the study compares and contrasts the livelihood conditions of communities in mining-impacted and non-mining-impacted areas to provide a clearer understanding of the challenges they face.

2. Methodology

2.1. Study Area

The study was carried out in fourteen transboundary river-bank villages of two local administrative units (Tahirpurn and Sunamganj Upazila) in Sunamganj district, Bangladesh (**Figure 1** and **Figure 2**). The study focuses on assessing livelihood status in Jadukata and Nawagang transboundary riverine inhabitants of extreme northeastern Bangladesh. The regions are marked by extreme isolation, sandy soil, and hazard-prone conditions. The climate of this area is humid-subtropical with a predominantly hot and humid summer and experiences a relatively cool winter. The area also belongs to the monsoon climatic zone, with the annual average highest temperature of 23˚C (August-October) and the average lowest temperature of 7˚C (January). Nearly 80% of the annual average precipitation of 3800 mm occurs between May and September (Farukh et al., 2020).

2.2. Study Sites

The Jadukata River-bank area, situated in Tahirpur Upazila, spans between 25˚01' and 25˚12' north latitude and 91˚02' and 91˚19' east longitude, bordering Bishwambarpur Upazila on the east, Dharmapasha Upazila on the west, Jamalganj and Dharmapasha Upazilas on the south, and Meghalaya on the north (**Figure 3**; Bangladesh Census, 2011). The entire study area consisted of the following areas: Sahidabad, Lawrer Ghar, Daler Par, Razer Gaon, and Mader Gaon on the eastern side of the Jadukata River; Barek Tilla, Gagodia, and Gagra on the western side of this river (**Figure 4**).

The Nawagang River, originating in Meghalaya's East Khasi Hills district, receives 11,500 mm of rainfall annually and joins the Surma in Bangladesh through Sunamganj Upazila (**Figure 3**; Rahman et al., 2017). Sunamganj Sadar Upazila, spanning 290.71 square kilometers, is located between latitudes 24˚49' and 25˚10' north and longitudes 91˚14' and 91˚27' east. It is bordered by Meghalaya and Bishwambarpur Upazila, Dakshin Sunamganj Upazila, Dowarabazar Upazila, and Bishwambarpur Upazila (Bangladesh Census, 2011). **Figure 5** shows the sampling locations from the Nawagang River-bank areas, which include Dolora, Kalipor Dolora, Kalipor, Kair Gaon, Adang, and Porun Motorkandi on both sides of the river.

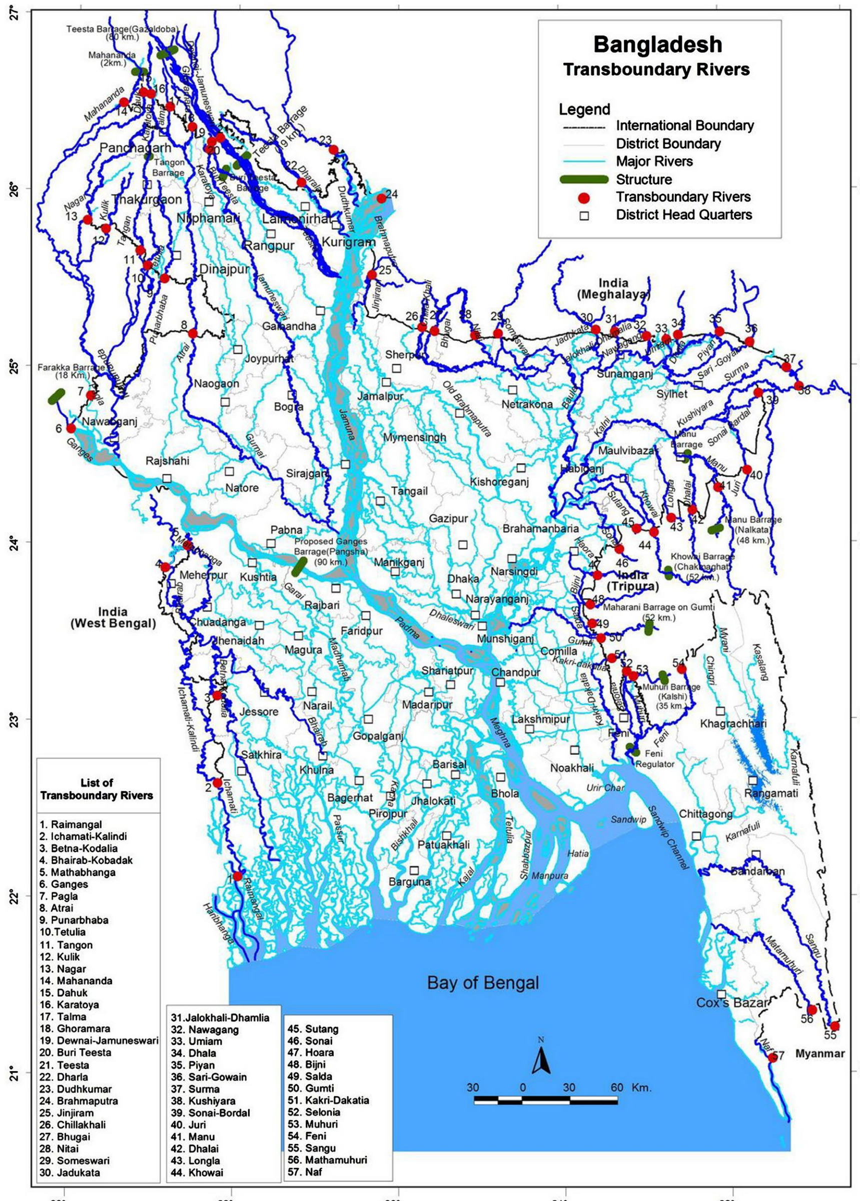

Figure 1. Transboundary rivers among Bangladesh, India and Mayanmar (Curtesy Join Rivers Commission-Bangladesh, Ministry of Water Resource, GoB, 2013).

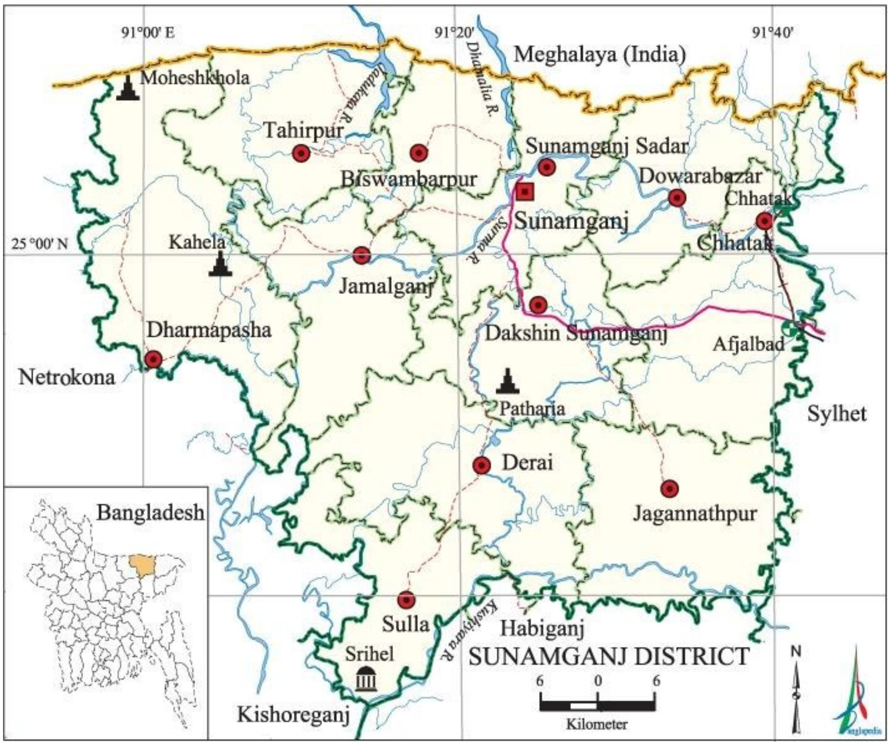

Figure 2. Transboundary rivers at Sunamganj District, Bangladesh.

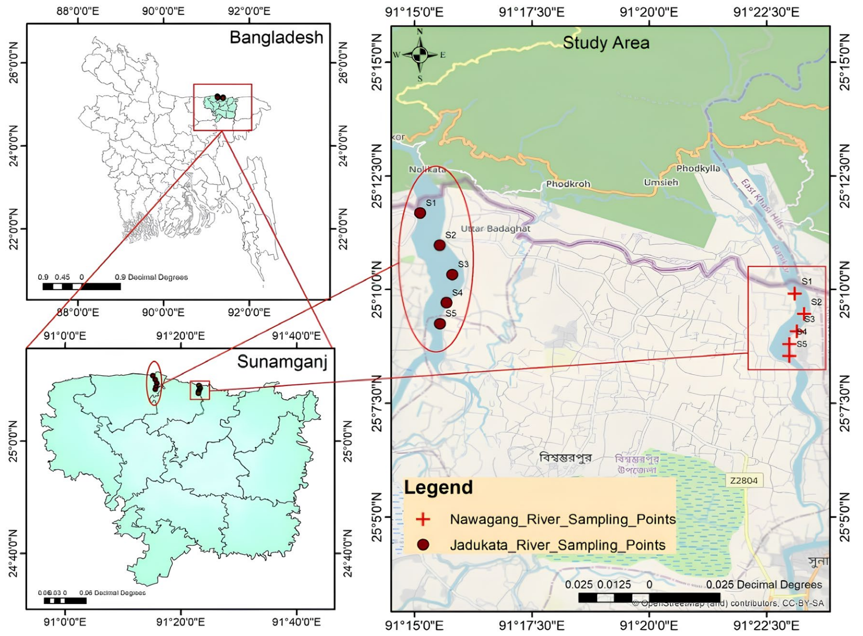

Figure 3. Map of study area.

2.3. Determination of Sample Size

The sample size calculation was conducted for an infinite population using the below Cochran's (1977) formula (1) and adjusted for a specified population (Kothari, 2004).

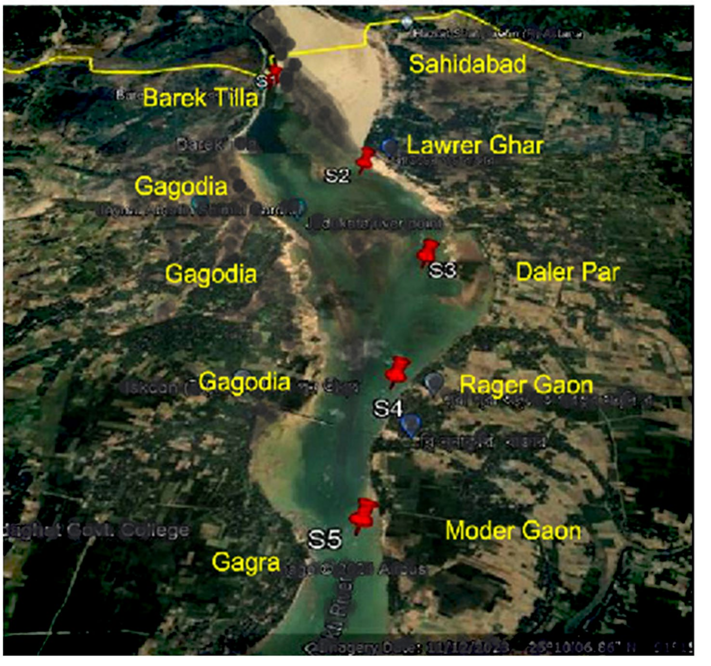

Figure 4. Jadukata riverine area for collecting survey data.

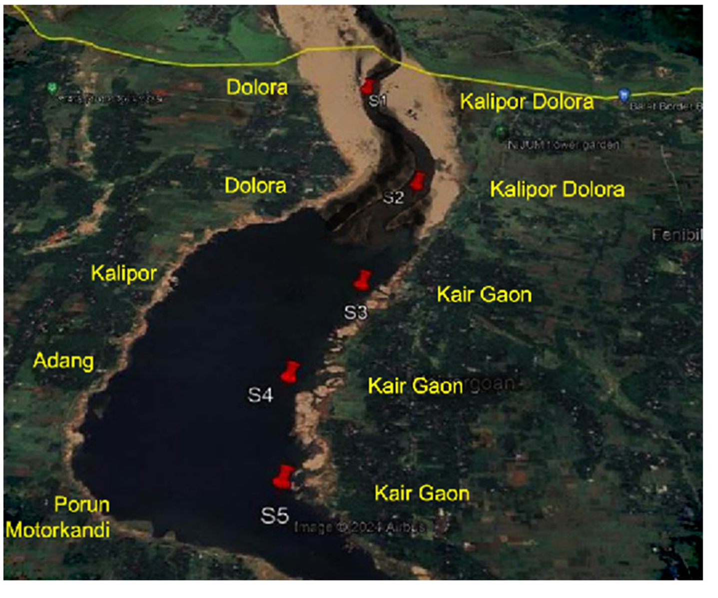

Figure 5. Nawagang riverine area for collecting survey data.

$$n_0 = \frac{z_{\alpha/2}^2 pq}{d^2} \quad (1)$$

The sample size (n_0) for an infinite population is determined using a z score of 1.96, with a population proportion (p) of 0.5 and a margin of error (d) of 4 to 8%, based on a 95% confidence level. The total households (N) in two Upazilas were 87,488 (BBS, 2015), and a sample size of 201 was calculated from this finite population by the following Cochran's modified formula (Sarmah et al., 2013) to reduce the sample size for correction of population proportionately:

$$n = \frac{n_0}{1 + (n_0 - 1)/N} \quad (2)$$

Finally, the sample size for 87488 populations was determined to be 200, purposively along the riverside (Table 1).

2.4. Sampling Method

Fourteen villages nearer to the Jadukata and Nawagang Rivers under the Tahirpur and Sunamganj Upazila were purposively selected (Table 1) on the basis of the number of households. A list of crop cultivation and fishing dependent people from the Upazila Agriculture Office was collected and updated list was prepared with the help of local leaders like chairman, members, SAAO (Sub-Assistant Agricultural Officer) and local NGO (Non-Government Organization) workers. About 87488 household heads (BBS, 2015) was considered as the population and using formula of sample size (n) for estimating sample proportion, 200 household heads was randomly selected as sample. A reserve list of 30 household heads was also prepared to use only if a respondent in the original list would not be available for interview. Data were gathered following face-to-face interviews using a semi-structured questionnaire from January to February 2022.

Table 1. Households from required villages at different riverine areas.

Jadukata riverine areas			Nawagang riverine areas		
Villages	Number of household	Sample household	Villages	Number of household	Sample household
Barek Tilla	28	2	Dolora	210	22
Sahidabad	115	12	Kalipor Dolora	215	22
Gagodia	345	28	Kalipor	78	8
Lawrer Ghar	110	12	Kair Gaon	285	31
Daler Par	95	9	Adang	85	9
Rager Gaon	85	10	Porun Motorkandi	75	8
Gagra	90	11			
Mader Gaon	120	16			
Total	988	100		948	100

2.5 Measuring Respondents' Living Status

Farming activities, environmental, financial, and social questionnaires related to their living opportunities were collected by asking ten questions. The all-up opportunities were measured by respondents as 1 narrating to "strongly agree", 2 narrating to "agree", 3 narrating to "neutral", 4 narrating to "disagree", and 5 narrating to "strongly disagree" against ten statements. The range of possible mean scores for the main statements was 1 to 5, where less than 2.5, 2.5 to 3.5, and greater than 3.5 indicate statement contributions in all-up situations are positive, neutral, and negative, respectively. For assessing the livelihood index, the respondents were investigated about their livelihood status by asking twenty-seven modern questions that were designed in five capitals (Table 2). Respondents were assessed on their living status by answering questions with a score range of 0 to 1, with a positive response indicating a positive status and a negative response indicating a negative status.

Table 2. Variable used for livelihood Capital assessment of transboundary riverine habitants.

Capitals	Components	Subcomponents	Reference
Human	Health status	Access to different physical and mental activities	Shill et al. (2016)
	Knowledge and skill	Respondents able to read, write and perform families required works	Ahmed et al. (2021); Islam (2018); Sunny et al. (2019)
	Ability to labor	Labor force capacity of households member	Tran et al. (2020)
	Attitude and Humanity	Respondents having well behavior with humanity	Mishra (2017)
	Leadership quality	Respondents have capacity to motivate others	Campos et al. (2020)
Physical	Transport	Transport facilities is adequate	Tran et al. (2020)
	Drinking water supply	Pure Drinking water is sufficient	Sufian et al. (2017)
	Sanitation	Sanitation facilities is available	Roy et al. (2020); Kamruzzaman & Hakim (2016)
	Housing structure	Respondent having concrete house	Billah et al. (2018); Baki et al. (2015)
	Energy	Das et al. (2015)	Das et al. (2015)
	Health Centre	Hospital and health care Centre are available	Mishra & Das (2015)
Natural	Water quality	Deteriorates water quality	Mishra & Das (2017)
	Natural Forest	Respondents having scope to use natural forest	Ahmed et al. (2021); Islam et al. (2014)
	Land use	Per capita land use in decimal	Ahmed et al. (2021); Sunny et al. (2019)
	Soil Erosion	Soil erosion protection is sufficient	Flanagan et al. (2018)
	Air quality	Air pollution is increasing	Mishra & Das (2017)
Social	Networking	Sharing socially held knowledge	Islam & Chuenpagdee (2018); Islam et al. (2014)
	Association	Respondents are member of NGO, union council, local institute etc.	Sunny et al. (2019); Mozahid et al. (2018); Shill et al. (2016); Islam et al. (2014)

Continued

Social	Social features	Respondents having amusement by club, playground and community center	Mishra & Das (2015)
	Relationship with neighbors	Respondents having good relations with neighbors	Islam & Chuenpagdee (2018); Islam et al. (2014)
Financial	Accessible stocks (Saving)	Respondents have cash, Bank Deposit, Liquid assets etc.	Sunny et al. (2019); Mozahid et al. (2018); Shill et al. (2016); Islam et al. (2014)
	Regular inflow of money	Respondents having money from jobs and abroad (Remittance)	Sunny et al. (2019); Mozahid et al. (2018); Shill et al. (2016); Islam et al. (2014)
	Income from farming	Respondents have Agricultural, Fisheries and livestock production	Sunny et al. (2019); Ahmed et al. (2021)
	Income from wage jobs	Respondents earning money by laboring, Driving, helping and business activities	Sunny et al. (2019); Ahmed et al. (2021)
	Income from Business	Respondents earning money through business	Sunny et al. (2019); Ahmed et al. (2021)
	Loan from NGOs (Tk)	Respondents renting money from NGOs and others	Sunny et al. (2019); Ahmed et al. (2021); Mozahid et al. (2018); Islam et al. (2014)
	Loan from informal Institute (Tk)	Respondents renting money from relatives, neighbors and social institutes	Sunny et al. (2019); Ahmed et al. (2021); Mozahid et al. (2018); Islam et al. (2014)

2.6. Data Analysis and Area Mapping

The IBM SPSS program (Version 20) was used to perform proportion tests, box plots, spider diagrams, and cluster analysis through a laptop computer in the Central Lab, Bangladesh Agricultural University, Mymensingh. MS Excel (Version 2010) was used to calculate the livelihood assessment index by equal weighting. Arc GIS software (Version 10.8) was used to draw a research area map in the Central Lab, Bangladesh Agricultural University, Mymensingh. GPS Coordinates were used to measure latitude, longitude and altitude of the research areas in the selected field.

2.7. Livelihood Assessment Index (LAI)

The Department for International Development's (DFID) Sustainable Livelihood Framework served as the foundation for the development of the LAI (DFID, 2000). The transboundary riverine inhabitant's livelihood can be specified as follows: The livelihood of a transboundary riverine inhabitant is determined by their human, financial, physical, natural, and social capital.

The livelihood status of transboundary riverine inhabitants was assessed using five livelihood capitals, based on a literature review and revisions after a pre-test. Table 2 displays the livelihood indicators that were taken into consideration. The five capitals' indicators were assessed using equal weighting to determine their livelihood status among transboundary riverine inhabitants, and a combined index was created. The balance weighting was used to ensure equal distribution of indicators across all capitals in the all-up index, despite different scales and units (Ahmed et al., 2021; Hahn et al., 2009). Standardization was achieved using Equation (3):

$$Index_s = \frac{S - S_{\min}}{S_{\max} - S_{\min}} \times 100 \tag{3}$$

where, the original value of indicators is S, the maximum and minimum values of indicators are $S_{\max}$ and $S_{\min}$, and 100 for the indicators measured as a percentage (Hahn et al., 2009). The average value of each capital was estimated using Equation (4) after standardizing.

$$M_{cj} = \frac{\sum_{i=1}^{n} Index_{si}}{n} \tag{4}$$

where, M_{cj} means the value of one major capital j; $index_{si}$ represents the index of i indicators, and n is the total number of indicators in each capital. Finally, the weighted average of LAI was estimated using Equation (5):

$$LAI = \frac{\sum_{i=1}^{5} W_{mj} M_{cj}}{\sum_{i=1}^{5} W_{mj}} \tag{5}$$

Equation (5) can be rewritten as

$$LAI = \frac{W_H H_c + W_F F_c + W_p P_c + W_N N_c + W_s S_c}{W_H + W_F + W_P + W_N + W_S} \tag{6}$$

where, LAI means the livelihood assessment index, W_{mj} means the weightage of element j, W_H, W_F, W_P, W_N, and W_S are the weight values of the human capital, financial capital, physical capital, natural capital, and social capital, respectively.

3. Results and Discussion

Livelihood status of transboundary riverine inhabitants was assessed with the measurement of human, natural, financial, physical and social capital's index based on 0 to 1; and approximately maximum capital indicator's score were measured in percentages. The comparison of livelihood status in relation to different capitals, including indicators for mine-affected and non-mine-affected riverine inhabitants were analyzed using z-test. The livelihood opportunities statements were measured by k-mean clustering to show the statements into distinct clusters for clarifying the advantage and disadvantage of statements for living situations.

3.1. Human Capital

Slaus and Jacobs (2011) define human capital as the combination of knowledge, skills, attitudes, education, mental and physical health, work capacity, and leadership qualities that enable individuals to achieve their livelihood goals. **Table 3** presents the human capital findings from the two riverine communities, showing an average physical and mental fitness rate of 80.50%, which is notably higher than the 74.2% reported in Colombia (Gomez et al., 2021). However, this level of fitness is still considered moderately low in the context of this study due to limited access to proper medical treatment and hospitality services (52.95%), inadequate sanitation facilities (78.33%) (**Table 4**), and a rising prevalence of waterborne diseases (rules: positive and neutral; **Table 9**). Mental well-being, a critical component of human capital, requires active engagement in recreational activities, which are currently lacking in the study areas (Goodman et al., 2017). The literacy rate among residents in the extreme northeastern part of Bangladesh was found to be 69.16%, aligning closely with the national average (BBS, 2020) and significantly higher than the 6% educational attainment reported among floating fishermen (Mushfique et al., 2021). While primary schools are available locally, access to secondary and higher education requires travel to the Upazila level, as no such facilities exist within the immediate locality.

Table 3. Human capitals of respondent's households.

Indicators	Capital indicator's score			Capital's index		
	Jadukata River	*Nawagang* River	Average	*Jadukata* River	*Nawagang* River	Average
Physically and Mentally fit (%)	77.00	84.00	80.50	0.57	0.64	0.61
Able to read, write and perform (%)	66.30	72.02	69.16			
Having labor force capacity (%)	73.50	87.50	80.50			
Having well behaved and humanity (%)	40.20	48.50	44.35			
Leadership quality (%)	26.90	28.50	27.70			

The communities demonstrated a strong labor force capacity, with 80.50% of respondents able to perform work effectively—higher than the 60% fishing capacity among floating fishermen (Mushfique et al., 2021) and the 46.74% labor force capacity observed among farmers (He & Ahmed, 2022a). Enhancing this capacity further would require improvements in public health, household wealth, and transportation infrastructure (**Table 9**). However, leadership qualities (27.7%) and interpersonal attributes such as good behavior and humanity (44.35%) were found to be low across both study sites, hindering effective collaboration and community-driven initiatives. The absence of training and skill development programs has contributed to this gap. Therefore, capacity-building interventions focusing on leadership and behavioral development are essential to strengthen their ability to work cohesively. The average Human Capital Index (HCI) for the study area was calculated at 0.61, which is considerably higher than the 0.3364 reported in poverty-stricken regions of southwest China (He & Ahmed, 2022b), reflecting comparatively better human capital conditions in the studied communities.

3.2. Physical Capital

The physical capital indicators (**Table 4**) reveal that 98.65% of respondents had access to electricity, 84.95% to safe drinking water, and 81.00% to transportation facilities. Approximately one-third of the respondents lived in semi-concrete houses. This aligns with earlier findings by Ali et al. (2008), who reported that 26% of fish farmers in Hamirkustia and Katabari unions resided in half-built homes, and Baki et al. (2015), who found that 34% of homes were semi-brick structures—figures comparable to those observed in the present study. The high electricity access rate (98.65%) is consistent with the findings of Ahmed et al. (2021) and Baki et al. (2015). Respondents reported that drinking water was readily available, primarily from nearby tube wells and other local sources. In contrast, Mushfique et al. (2021) noted that all floating fishers used fitkiri (potassium alum) to purify river water an unhygienic method. Transportation facilities were generally adequate, largely because roads and infrastructure in the study area are not submerged annually, unlike the haor regions. In monsoon-prone areas, agriculture and transportation infrastructure such as roads and culverts are often inundated for 6 - 7 months each year, posing significant challenges (BHWDB, 2012; CAN, 2017).

Table 4. Physical capitals of respondent's households.

Indicators	Capital indicator's score			Capital's index		
	Jadukata River	Nawagang River	Average	Jadukata River	Nawagang River	Average
Transport facilities is sufficient (%)	77.00	85.00	81.00	0.67	0.76	0.72
Drinking water source is tube well (%)	82.70	87.20	84.95			
Having semi concrete house (%)	31.4	36.23	33.82			
Have clean and affordable electricity (%)	98.20	99.10	98.65			
Hospitality is available (%)	37.10	68.80	52.95			
Sanitation facilities is available (%)	75.40	81.25	78.33			

Access to healthcare services among respondents was limited, primarily due to lack of awareness and financial constraints. Although 52.95% sought treatment from district hospitals or Upazila health complexes, 47.05% could not access competent medical care due to financial limitations, relying instead on village doctors or traditional healers (Kobiras) (**Table 4**). Similarly, Baki et al. (2015) reported that 54% of fishing households depended on village doctors with limited qualifications, 28% received treatment at Upazila health complexes, and only 18% consulted licensed MBBS doctors. Sanitation facilities in the study area were also inadequate. As shown in **Table 4**, 78.33% of respondents used pakka, semi-pakka, or kacha toilets, while 21.67% lacked any form of sanitary facility. Comparatively, Ali et al. (2009) found better sanitary access among fishermen in Mymensingh district, with 12.5% using pakka toilets, 62.5% semi-pakka, and 25% kacha. Overall, the physical capital index for the study area was calculated at 0.72, which is notably higher than the index value of 0.4279 reported in poverty-stricken districts of southwestern China (He & Ahmed, 2022a).

3.3. Natural Capital

The respondents can use open water for their livelihood purposes, but the qualified water (18.50%) is deteriorating, making it unsuitable for drinking. In another research it was found that 11% of fishermen used open water for drinking purposes and others (Das et al., 2015), which is lower than the result found in this study. However, they have minimal access to usable forest (11.605%), where they can use wood for building, repairing furniture, and other purposes (**Table 5**). This is a higher percentage than the results reported by others (Ahmed et al., 2021; Tikadar et al., 2022). They need to buy extra wood from the market for their own family's use. Per capita land use is 20.50 (decimal) for building houses and cultivation, which is more than the results reported by other researchers (Tikadar et al., 2022; Mushfique et al., 2021) because the respondents are not floating fishermen but riverine inhabitants. More importantly, their soil erosion protection (70.80%) is also good to protect their houses, roads, networks, and cultivations from flooding. There is no navigation in the rivers, but the surrounding air quality (55.70%) is good for living beings (**Table 5**). Dhaka's air quality index (AQI) is highest in winter months (January, February, and March) and lowest during the monsoon season (July, August, and September). This is due to increased pollution from anthropogenic sources and activities like brick kilns, motor vehicles, industries, and construction sites (Islam, Afrin, Ahmed, & Ali, 2015). The natural capital index of 0.36 is lower than the average of 0.4038 in southwest China, as reported by He and Ahmed (2022b).

Table 5. Natural capitals of respondent's households.

Indicators	Capital indicator's score			Capital's index		
	Jadukata River	Nawagang River	Average	Jadukata River	Nawagang River	Average
Water quality is good (%)	15.50	21.50	18.50	0.30	0.41	0.36
Usable forest (%)	10.40	12.80	11.60			
Per capita land use (decimal)	18.7	22.3	20.50			
Soil erosion protection is sufficient (%)	53.10	88.50	70.80			
Air quality is good (%)	52.90	58.50	55.70			
Navigability of the river (Dry season)	0.00	0.00	0.00			

3.4. Social Capital

Social capital is a crucial element that fosters trust, cooperation, and solidarity, ensuring shared needs and purposes in life. Social resources are defined by relationships and networks among neighborhoods, groups, and families (Coleman, 1988). People use informal safety nets, based on these relationships, to maintain their livelihood plans during emergencies and challenging times (Kleih et al., 2003). The study revealed that 87.3% of respondents shared their socially held knowledge with societal members due to a strong network relationship (67.70%) among them (**Table 6**). Ahmed et al. (2021) reported that sharing socially held knowledge is 80%, which is lower than the results found in this study. About 12.90% of the respondents had clubs, playgrounds, and community centers for amusement as a social feature based on faith, which is lower than the value found (32.7%) in Akwa Ibom State, Nigeria (Udoh et al., 2017); 53.15% of the respondents were members of NGOs, union councils, and local institutes such as libraries, hospitals, schools, etc.; and 46.85% of them were not involved in any associations (**Table 6**). In another research it was found that households have 81.8% NGO membership in Nigeria (Udoh et al., 2017), which is higher than the finding of this research. The respondents' social capital findings align with previous research findings (Islam & Chuenpagdee, 2018; Ahmed et al., 2021). The social capital index of 0.55 is lower than the floating fishermen's index of 0.624 reported by Ahmed et al. (2021).

Table 6. Social capitals of respondent's households.

Indicators	Capital indicator's score			Capital's index		
	Jadukata River	Nawagang River	Average	Jadukata River	Nawagang River	Average
Knowledge dissemination (%)	85.40	89.20	87.30	0.52	0.58	0.55
Member of NGO, union council, local institute (%)	51.80	54.50	53.15			
Club, playground and community center for amusement (%)	10.80	15.00	12.90			
Good relations with neighbors (%)	60.20	75.20	67.70			

3.5. Financial Capital

The analysis of financial capital revealed that the average household income among respondents was approximately US$134.23 per month, translating to US$33.56 per capita per month (**Table 7**). This figure is significantly lower than the national per capita monthly income of US$94.69 (BBS, 2018). After covering household expenses, respondents were able to save an average of only US$7.59 per month—a figure typical of populations living just above the poverty line. Similar patterns of negligible savings have been reported among fishermen in Indonesia

(Hidajat, 2015) and farmers in the Meherpur district of Bangladesh (Rana et al., 2021). Respondents had limited access to formal or semi-formal loans due to a lack of collateral. On average, they secured US$39.38 annually in collateral-free loans from various NGOs (**Table 7**), a finding that closely aligns with Ahmed et al. (2021), who reported a similar figure of US$39.59. Many respondents refrained from taking financial loans, citing poor credit histories, lack of loan security, and a complex application process (Kuang et al., 2019; Johnson, 2012; Wichern et al., 2017). Consequently, only 14.3% were engaged in small business ventures, a rate much lower than the 83.6% reported by Udoh et al. (2017). In addition to NGO loans, respondents borrowed informally from financially better-off relatives, neighbors, or friends, averaging US$11.24 per year (**Table 7**). This is higher than the US$5.28 reported by Tikadar et al. (2022) for small-scale fishermen.

Table 7. Financial capitals of respondent's households.

Indicators	Capital indicator's score			Capital's index		
	Jadukata River	Nawagang River	Average	Jadukata River	Nawagang River	Average
Saving (US$/month)	6.97	8.20	7.59			
Job and Remittance (US$/year)	7.38	20.51	13.95			
Farming production (%)	81.32	87.90	84.61			
Wage jobs (%)	16.30	18.30	17.30			
Business (%)	12.30	16.30	14.30	0.184	0.212	0.198
Income (US$/month)	104.83	163.63	134.23			
Loan from NGO and other (US$/year)	40.20	38.56	39.38			
Loan from informal Institute (US$/year)	11.89	10.58	11.24			

Farming remains the primary source of income for the majority of respondents, with 84.61% involved in agriculture, poultry, dairy, or fish farming—higher than the 68.2% observed in Akwa Ibom State, Nigeria (Udoh et al., 2017). The overall financial capital index was calculated at 0.198, which exceeds the values reported by Tikadar et al. (2022) and Ahmed et al. (2021). These findings suggest that communities in impoverished regions generally lack adequate financial capital due to low income, restricted access to credit, and limited revenue-generating opportunities. Financial capital is a critical livelihood component, and its indicators, such as household income are influenced by factors like cultivable land, forest resources, education, access to loans, internet connectivity, and political engagement (Yang et al., 2020). Furthermore, age, training, and participation in NGO activities show a significant positive correlation with income levels (Tikadar et al., 2022). To compare income disparities between mining-affected and non-affected riverine inhabitants, box plots were utilized (**Figure 6**). The median lines for each group lie outside the interquartile boxes, indicating significant income variation. The box plot for the Nawagang River group was notably longer, suggesting greater income dispersion, while both the Jadukata and Nawagang groups exhibited outliers beyond the whiskers, indicating asymmetric distributions. On average, incomes among mining-affected communities were lower due to the substantial loss of fish and crop yields caused by AMD (Karar et al., 2017). Among all livelihood capitals assessed, financial capital scored the lowest with an index of 0.198 (**Table 7**), whereas physical capital scored the highest at 0.72 (**Table 4**). These results align with previous studies on small-scale and floating fishermen in the northeastern floodplains and river systems of Bangladesh (Tikadar et al., 2022; Mushfique et al., 2021), where riverine inhabitants receive modest improvements in transportation and income-generating opportunities.

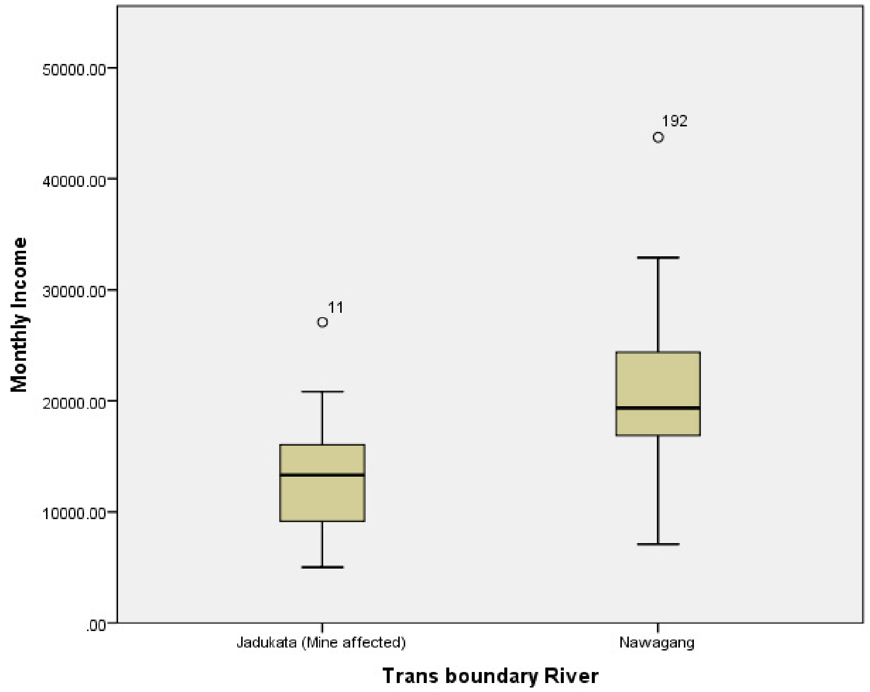

Figure 6. Box plot for two riverine habitant's monthly income.

The overall Livelihood Assessment Index (LAI) for transboundary riverine communities in northeastern Bangladesh was calculated at 0.487, based on the average of all five capital indices: human (0.61), physical (0.72), natural (0.36), social (0.55), and financial (0.198). This value aligns with findings from Tikadar et al. (2022) and exceeds the LAI of 0.316 reported by He and Ahmed (2022a). Despite this moderate score, the overall livelihood status of respondents remains low, consistent with studies from disaster-prone riverine islands. This low livelihood status reflects serious barriers in accessing both formal and informal loans, stemming from limited opportunities for income generation, employment, access to usable forest resources, safe water, healthcare, education, and land use rights. The spider diagram (**Figure 7**) visually represents the LAI for each form of capital, ranging from 0 (lowest) to 1 (highest), and clearly indicates that the livelihood index of mine-affected communities is lower than that of non-mine-affected groups.

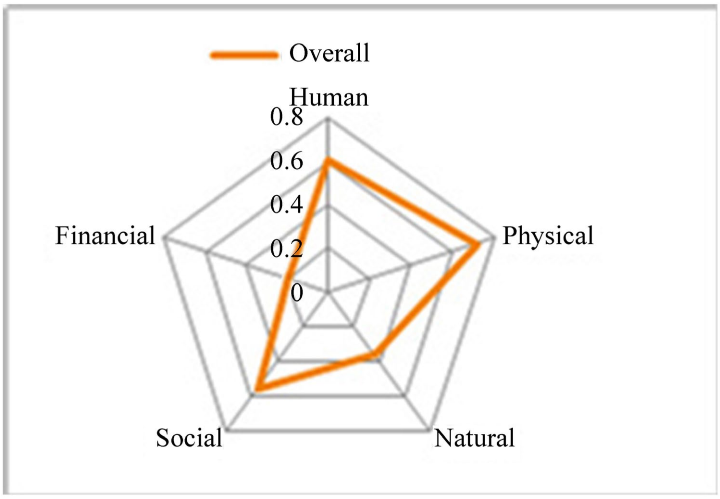

Figure 7. Index values of livelihood capitals of riverine inhabitants.

3.6. Livelihood Assessment Index Comparison for Mine-Affected and Non-Mine-Affected Riverine Inhabitants

Table 8 presents a comparative analysis of livelihood status based on different livelihood capitals namely human, physical, natural, social, and financial for both mine-affected and non-mine-affected riverine communities. The Livelihood Assessment Index (LAI) values for the Jadukata (mine-affected) riverine area were 0.57 (human), 0.67 (physical), 0.30 (natural), 0.52 (social), and 0.184 (financial), whereas for the Nawagang (non-mine-affected) riverine area, the values were 0.64, 0.76, 0.41, 0.58, and 0.212, respectively. Among these, significant differences were observed in physical, natural, and financial capital, while differences in human and social capital were statistically insignificant. Indicators such as soil erosion control, air quality, transportation infrastructure, healthcare facilities, and income levels were notably lower in the mine-affected Jadukata area. Although mining activities have not led to substantial changes in health service access or interpersonal relationships, they have contributed to an increase in waterborne and respiratory diseases, including tuberculosis, chronic cough, gastric issues, and eye infections (Hota & Behera, 2015). Environmental degradation from mining has also affected soil stability, waste management, water quality, and agricultural productivity, thereby intensifying food insecurity and disease prevalence.

Financial capital in the Jadukata region is particularly strained. Limited income sources and reduced access to productive assets such as livestock, small enterprises, and farming tools further hinder economic resilience. Similar findings were reported by Mishra and Pujari (2008), who noted that agricultural lands in the coalfield regions of Odisha had become infertile, severely impacting farming livelihoods. The overall LAI scores for mine-affected and non-mine-affected transboundary riverine communities in northeastern Bangladesh were 0.449 and

0.522, respectively, with the difference being statistically insignificant (Table 8; Figure 8). Nevertheless, the data suggest that the mine-affected Jadukata riverine communities are experiencing greater socio-economic challenges compared to their Nawagang counterparts.

Table 8. Comparison of livelihood assessment index among mine and non-mine affected riverine areas.

Livelihood capitals	Mine affected	Non-mine affected	Proportion test (Z-value) (Asymp. Sig. (2-sided))	Indicators	Mine affected	Non-mine affected	Proportion test (Z-value) (Asymp. Sig. (2-sided))
	Jadukata River	Nawagang River			Jadukata River	Nawagang River	
Human	0.57	0.64	NS	Physically and Mentally fit	0.770	0.840	NS
				Able to read, write and perform	0.663	0.720	NS
				Having labor force capacity	0.735	0.875	NS
				Having well behave and humanity	0.402	0.485	NS
				Leadership quality	0.269	0.285	NS
Physical	0.67	0.76	**	Transport facilities is sufficient	0.770	0.850	**
				Drinking water source is tube well	0.827	0.872	NS
				Having semi concrete house	0.314	0.362	NS
				Have clean and affordable electricity	0.982	0.991	NS
				Hospitality is available	0.371	0.688	**
				Sanitation facilities is available	0.754	0.813	NS
Natural	0.30	0.41	*	Water quality is good	0.155	0.215	NS
				Usable forest	0.104	0.128	NS
				Per capita land use (decimal)	0.19	0.22	NS
				Soil erosion protection is sufficient	0.531	0.885	***
				Air quality is good	0.529	0.585	*
Social	0.52	0.58	NS	Knowledge dissemination	0.854	0.892	NS
				Member of NGO, union council, local institute	0.518	0.545	NS
				Club, playground and community center for amusement	0.108	0.150	NS
				Good relations with neighbors	0.602	0.752	NS
Financial	0.184	0.212	NS	Saving (US$)	0.175	0.189	NS
				Job and Remittance (US$)	0.010	0.011	NS
				Farming production	0.53	0.58	NS
				Wage jobs	0.13	0.15	NS
				Business	0.14	0.163	NS
				Income (US$)	0.364	0.459	***
				Loan from NGO and others (US$)	0.093	0.086	NS
				Loan from informal institute (US$)	0.063	0.061	NS
Value of LAI					0.449	0.522	NS

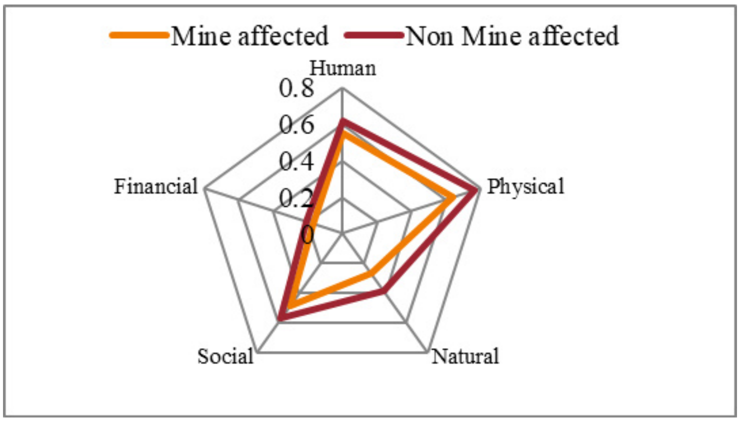

Figure 8. Index values comparison of livelihood capitals for mine and non-mine affected riverine inhabitants.

3.7. Livelihood Opportunities for Mine-Affected and Non-Mine-Affected Riverine Inhabitants

The all-up livelihood opportunities were measured by asking ten questions as shown in Table 9 and Table 10, where the mean scores of each statement are less than 2.5, 2.5 to 3.5, and greater than 3.5, indicating that the statement's contributions in all-up situations are positive, neutral, and negative roles, respectively. From the table, it was shown that improved environmental safety and increased modern technology use contribute positive, negative, and neutral rules in Jadukata riverine areas in all-up situations for livelihood opportunities at every cluster; and improved public health contributes the same result in both riverine areas also. Similarly, income generating and saving, increased waterborne diseases, increased fish and crop cultivation, and decreased public wealth are playing positive and neutral roles in the Jadukata and Nawagang riverine area's inhabitants for different clusters. In addition, improved housing aspects play positive and neutral roles in Jadukata riverine areas, and positive roles in Nawagang riverine areas for all clusters, but the roles of it make family life painful, which is completely alternate. On the other hand, improved environmental safety and increased modern technology use play positive and neutral roles in Nawagang riverine areas across all clusters. There were significant ($p < 0.001$) different to contribute in living opportunities among the clusters in all riverine areas for every statement except income generating and saving in the Jadukata riverine area. The statement that it makes family life painful and improved housing aspects were also insignificant ($p > 0.05$) difference to contribute in living opportunities among the clusters in the Jadukata and Nawagang riverine areas (Table 10).

Table 9. K-mean clustering or Non-hierarchical clustering for Jadukata and Nawagang riverine habitant's observation.

	Cluster for Jadukata river			Cluster for Nawagang river		
	1	2	3	1	2	3
Income generating and saving	2.79	2.95	2.17	2.97	1.83	2.58

Continued

Increased water borne diseases	2.09	2.70	2.74	1.94	2.61	2.82
Increased fish cultivation	2.62	2.26	3.26	1.84	2.74	2.24
Increased crop cultivation	1.53	1.30	3.09	1.44	2.70	1.24
Improved environmental safety	2.26	2.51	4.26	2.13	3.17	2.44
Increased modern technology use	2.00	2.86	4.35	2.00	3.19	2.67
Improved public health	3.85	1.33	3.26	3.75	3.48	1.36
Decreased public Wealth	1.06	3.44	1.91	1.19	1.57	3.24
It make family life Painful	1.59	2.07	1.91	2.38	2.78	2.98
Improved housing aspect	2.44	2.81	2.48	2.38	2.35	2.44

Table 10. ANOVA among the different cases of riverine habitants for different clusters.

	Significance for Jadukata river	Significance for Nawagang river
Income generating and saving	0.081	0.008
Increased water borne diseases	0.019	0.002
Increased fish cultivation	0.032	0.044
Increased crop cultivation	0.000	0.000
Improved environmental safety	0.000	0.000
Increased modern technology use	0.000	0.000
Improved public health	0.000	0.000
Decreased public Wealth	0.000	0.000
It make family life Painful	0.133	0.145
Improved housing aspect	0.432	0.948

4. Conclusion

The transboundary riverine inhabitants' livelihood status in acid mine-affected and non-mine-affected areas of the extreme northeastern part of Bangladesh basically depends on various river sources and surrounding productive farms. Their living statuses are affected by river pollutants coming from upstream areas of India, river-bank farming activities, and socio-environmental issues. The study evaluated the livelihood status of riverine households based on different capitals and compared their living status in acid mine-affected and non-mine-affected riverine areas. The all-up LAI (for both mining and non-mining) of human capital, physical capital, natural capital, social capital, and financial capital was found to be 0.61, 0.72, 0.36, 0.55, and 0.198, respectively. The all-up Livelihood Assessment Index (LAI) of 0.487 for transboundary riverine inhabitants in northeastern Bangladesh is indicating low livelihood status in both areas. The LAI Index for each capital was found to be 0.57, 0.67, 0.30, 0.52, and 0.184 in the Jadukata riverine areas; and 0.64, 0.76, 0.41, 0.58, and 0.212 in the Nawagang riverine areas, respectively. Among these capitals, no significant difference was found between the mine-affected and non-mine-affected riverine inhabitants' livelihood status with respect to human and social capital except for physical, natural, and financial capital. But the indicators such as soil erosion protection, air quality, transportation facilities, hospitality, and income in mine-affected and non-mine-affected areas for human, social, and financial capital were significantly different.

The overall LAI for mine-affected and non-mine-affected areas was estimated at 0.449 and 0.522, respectively, indicating an insignificant difference. However, the comparatively lower LAI in acid mine-affected areas suggests that communities along the Jadukata River are experiencing greater socio-economic hardships than those along the Nawagang River. To improve livelihood outcomes, alternative income-generating activities such as poultry and livestock rearing, handicrafts, tailoring, fish drying, and similar ventures could help mitigate the adverse effects of river pollution. The study further recommends river management interventions to maintain natural flow, reduce the impact of flash floods, and preserve local ecosystems through dredging. Additionally, support from government agencies and NGOs is essential to enhance healthcare, education, and financial stability in these vulnerable communities. The findings of this study may serve as a reference point for future national and international research on riverine livelihoods.

The East Khasi Hills of Meghalaya, India, are identified as the primary source of pollution in the two rivers connected to the Surma River, posing a serious threat to fish biodiversity. The continued degradation of these rivers could foreshadow similar ecological decline in other severely polluted waterways. To counter this, initiatives such as the establishment of Hazardous Waste Treatment Centres (HWTC), public awareness campaigns, and pollution control measures should be prioritized to safeguard biodiversity. A nationwide study would offer comprehensive insights into the livelihood dynamics of riverine communities and support the development of evidence-based policies. However, it is important to note that the variables used in this study may not be universally applicable to all riverine regions.

Ethical Statement

The authors followed the ethical standards to conduct the research.

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Conflicts of Interest

There is no conflict of interest in the research declared by the authors.

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