



Social, economic and environmental trade-offs of hydropower mega-dams in the Eastern Himalaya: Community perceptions from the Teesta River basin, Sikkim

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Abstract

Mega-dams are typically promoted for hydropower generation, flood control, and regional development; however, they frequently impose significant social, economic, and environmental costs on surrounding populations. This study examines the externalities of a Mega-Dam Project on the Teesta River basin in Sikkim, with particular focus on public perceptions across diverse socio-demographic groups. Using a structured questionnaire survey of 123 respondents, data were analyzed through SPSS (v.26). Descriptive statistics (mean $\pm$ standard deviation) were employed to summarize item-wise responses and to rank questionnaire statements based on mean Likert scores. Normality, correlation, and chi-square tests were conducted where appropriate. The internal consistency of the questionnaire was assessed using Cronbach's alpha ($\alpha = 0.851$), indicating high reliability. Results revealed that 47% of respondents perceived negative social impacts, especially displacement and the disruption of community networks. Environmental concerns were more pronounced, with 64% identifying biodiversity loss, ecosystem degradation, and water pollution as the most serious issues. Younger respondents showed heightened concern for environmental degradation, while older participants emphasized economic benefits. Overall, the findings underscore inequities in the distribution of costs and benefits, reflecting limited community consultation and inadequate safeguards. The study highlights the urgent need for participatory decision-making, inclusive policies, transparent benefit-sharing, and credible environmental protection measures to ensure that hydropower development in the Teesta basin follows a more equitable, sustainable, and community-centered trajectory.

Keywords: Mega-Dam Project, Teesta River Basin, Social-Economic-Environmental (SEE) Impacts, Livelihood Disruption, Public Perception

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1 Introduction

Considered as 'mega' projects, the construction of vast dams can reshape the future of a region while implementing great changes to the landscape of the region. Still, they also touch people's lives in very personal ways, uprooting communities, altering livelihoods, and changing the environment that people depend on (Ziolkowski, 2024). Built to tame rivers and deliver cleaner power, flood protection, irrigation, and easier transport, their benefits can be real and transformative for many communities (Molle, 2009). At the same time, these structures often trigger complex social and ecological shifts that spark debate and hardship for

those who live downstream or lose land and culture (Biswas, 1999). When a project drifts from its original goals, what began as hope can turn into harm for people and ecosystems. Some of the major concerns regarding the building of mega dams are mostly influenced by the geographical location, network access, and the local resident's individual or community experiences (Ziolkowski, 2024). These mega projects can have either positive or negative impacts and contributions to the surrounding local areas (Kim, 2025). Relocation of the people and the community for building such mega dams mostly have a negative impact on the local region where the dam is being built (Alla and Liu, 2021).

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The displacement of large groups of people in the contemporary world impacts their social cohesion, networks, livelihoods, and culture practices in ways in which they may not have the resources to adapt (McCartney, 2009). These people have been documented in the literature as the ‘displaced people.’ Supporters argue that their relocation is beneficial; however, critics have documented numerous cases where the relocation leads to social isolation and impoverishment (Scudder, 2012). The social fabric of affected communities can be permanently altered, with long term implications for social cohesion and cultural identity (Bergkamp et al., 2000). Mega dams are often praised for their dimensions as well as the human promises they uphold: the generation of long-term jobs for community members, the provision of dependable energy for home and industrial use, irrigation expansion and impact on crop production for subsistence farming, and transformation of farming livelihoods (Biswas, 1999). For numerous populations, a dam signifies economic potential, and further energy autonomy, providing massive quantities of stable, renewable energy which enhances energy independence and facilitates the reduction of fossil fuel reliance (Shi et al., 2019).

Mega dams promise big economic gains, new jobs, energy production, and boosts to agriculture, but those gains are contested because the up-front costs are huge and projects can saddle governments with long-term debt and cost overruns, calling the financial wisdom of some schemes into question (Ansar et al., 2014). The benefits rarely fall evenly: while some people find new opportunities, others, particularly those who are displaced, face lasting economic hardship and loss of livelihoods (Ansar et al., 2014).

Environmentally, these projects produce mixed outcomes. They supply renewable energy and can reduce flood risk in some places, yet trapping and storing river water alters natural flows in ways that can damage ecosystems; extreme storage or mismanagement has caused catastrophic floods, mass displacement, and habitat destruction in the past (Ansar et al., 2014; Baxter, 1977). Interrupted flows harm fish migration and reduce aquatic biodiversity (Kingsford, 2000). Large reservoirs drown land, destroy terrestrial habitats, and release methane from decaying vegetation, adding another climate concern (Prairie et al., 2018). Downstream sediment starvation changes riverbank and floodplain fertility, undermining ecosystems and agricultural land alike (Alikhani and Karbin, 2019).

Similar concerns have been raised regarding the construction of such mega dams in the eastern-Himalayan regions to fulfil the ever-growing need for energy. These mega projects may impact the region’s rich biodiversity, ethnic cultures and its people (Dukpa et al., 2019). However, these developments have not been without controversy, sparking resistance from local communities and raising concerns about their environmental and social impacts. Previous studies have also provided a comprehensive overview of the challenges and conflicts associated with hydropower development in the region (Bomzon et al., 2023; Dukpa et al., 2019; Grumbine and Pandit, 2013; Menon et al., 2003; Pandit and Grumbine, 2012; Rai and Khawas, 2021).

These studies bring human stories to the center of development debates, showing how traditional governance

systems matter for fair decision-making, how biodiversity stands at real risk, and how communities can be uprooted unless development becomes more inclusive and sustainable (Baruah, 2017). Such previous studies on the development debates on building mega dams gives us the guidance on respecting the ecological limits of the region and the social responsibilities for the local communities instead of focusing only on the economic growth (Jabeen et al., 2024). That tension is especially visible in the Himalayan hydropower push: projects in places like Sikkim, India, provoke intense scrutiny because their impacts touch fragile mountain ecosystems, local livelihoods, and indigenous rights in complex and often contested ways (Dukpa et al., 2019). These projects and their activities have brought serious environmental harm, loss of biodiversity, and impacts on local livelihoods such as decreased agriculture, potential risks on health, and human health detriments (Huber and Joshi, 2015). Uneven access to jobs, growing calamities, and loss of culture have been added as impacts of mega Dam projects (Lepcha, 2017). Therefore, it is due to the above-mentioned detrimental impacts that the local activists along with the indigenous people are now demanding sustainable approaches to be infused during the constructions of such mega projects especially in the Himalayan regions.

Other work on the issue has outlined the conflicts and challenges of hydropower development in the region in significant detail (Arora, 2009; Baviskar, 2019; Kukreja, 2023; Wu et al., 2019). These studies underscore the importance of considering traditional knowledge, environmental sustainability, and the well-being of local communities in hydropower planning and implementation. The research emphasizes the legal guidelines for public participation, the benefits of local community engagement, and the complexities of anti-dam politics in the changing political landscape. Therefore, it is interesting to note that the construction of mega dam projects is not only influenced by the engineering scale but also by the geographical region, local people, culture and the communications between the two parties i.e., the constructing party and the affected party (Gergan, 2020). Public opinion can be highly polarized, with some viewing mega dams as essential for development and others as symbols of environmental destruction and social injustice (Baruah, 2017).

Hence, the two main objectives were first to evaluate the social, economic, and environmental (SEE) consequences of the Mega-Dam Project along the Teesta River basin. Second, the study sought to understand how various demographic factors, such as age, gender, occupation, education level, and place of residence, impact the perception of the SEE consequences.

2 Methodology

2.1 Study area

The research was conducted in the Indian northeastern state of Sikkim. Sikkim’s mountain beauty is a defining element of her people’s daily lives. The glacial peaks, alpine meadows, and rich biodiversity of Sikkim define how people live, work, and engage with one another and the land. The Teesta River, born of North Sikkim’s glacial ice and

carved by deep valleys as it flows to southern West Bengal, is the heart of the region's ecology, local economies, and hydropower ambitions. Consequently, changes to the river impact communities, fields, and forests. The research localized to four sites and capture the varied Sikkimese human realities and interactions with their environment. These sites and coordinates are: Singtam (27.23467°N, 88.50168°E), a busy riverside township, with the transport, trade, and riverside livelihoods making her people particularly attuned to changes in the river, dynamics and Rangpo (27.1761°N, 88.5287°E), a cross-border commercial hub and infrastructure; Rorathang (27.1954°N, 88.6115°E), an industrially developing, job drawing area with growing environmental clash and Rothak (27.1725°N, 88.294°E), a rural community with traditional land uses and many derelict fields. The research was localized to four sites to capture diverse Sikkimese socio-environmental settings and community interactions with the riverine landscape. Each site offers new and diverse perspectives regarding the impact of the dam and attendant activities being constructed in Sikkim.

2.2 Data Collection

A purposive–convenience sampling strategy was adopted to target respondents residing in communities located along and downstream of the Teesta River, where direct and indirect impacts of the mega-dam project were most likely to be experienced. Approximately four major settlements—Singtam, Rangpo, Rorathang, and Rothak—were covered during the survey, with respondents drawn from multiple neighbourhoods and surrounding villages within each location. The survey was conducted on a voluntary basis and included 123 respondents approached from river-adjacent communities. To gather the required data, questionnaires were implemented using a hybrid approach integrating both online surveys and face-to-face interviews, accommodating varying levels of accessibility and respondent preference. The face-to-face interviews were conducted primarily through door-to-door visits. The questionnaire was administered in English and local languages (Nepali and Hindi), depending on respondent preference, to ensure comprehension and accurate responses. For respondents with limited literacy, questions were read aloud and explained verbally to facilitate informed and reliable participation. Prior to participation, all respondents were informed about the objectives of the study, the voluntary nature of participation, and the confidentiality of their responses, and verbal informed consent was obtained. Eligibility criteria included respondents aged 16 years and above who had resided in the study area for a minimum of one year, ensuring adequate familiarity with local environmental and socio-economic conditions. No personal identifiers were collected, and all responses were anonymised to maintain ethical standards and protect participant privacy.

2.3 Data Analysis

The data were arranged in Excel sheets and analyzed using SPSS version 26. To summarize the dataset, we calculated descriptive statistics like means, standard deviations, and confidence intervals. We checked whether the data fol-

lowed a normal distribution using the Kolmogorov-Smirnov and Shapiro-Wilk tests, and tested questionnaire consistency with Cronbach's alpha; to explore relationships between variables we used Pearson correlation matrices, while mean-rank comparisons revealed which impacts respondents judged most important, and chi-square tests examined differences in responses across demographic groups (local, resettled, displaced); findings were presented in tables and figures and interpreted against the existing literature to situate the Mega-Dam Project's broader effects on community wellbeing and local environments.

3 Results

3.1 Study area

The study area encompasses the Teesta River basin in Sikkim, a region characterised by steep Himalayan terrain, dynamic river systems, and extensive hydropower development. The basin includes both upstream and downstream zones that experience varying degrees of environmental, social, and economic influence from mega-dam construction. Within this broader context, data were collected from four key locations—Singtam, Rangpo, Rorathang, and Rothak—selected for their proximity to the Mega-Dam Project and their representation of both directly and indirectly affected communities. These sites reflect diverse settlement types and livelihood settings within the Teesta basin. The geographical distribution of the study sites is illustrated in Fig. 1, which provides a visual representation of the study area. Additionally, Fig. 2 presents photographic documentation of field interactions, including participant interviews and regions along the Teesta River that were severely affected by the Glacial Lake Outburst Flood (GLOF) on 4 October 2023, offering visual context to the study.

3.2 Normality test

The results of the normality test of the questionnaire variables are shown in Table 1A and B. The Kolmogorov-Smirnov test shows non-significant ($p > 0.05$) results of 0.200. Hence, we accepted the null hypothesis and concluded that the present data is normally distributed. Similarly, the Shapiro-Wilk test produced a statistic of 0.981 with a significance level of 0.086, again indicating no significant departure from normality, as this value is also greater than 0.05.

The descriptive statistics give a clear, relatable picture of how people felt about the mega-dam: the average response sat at 104.57 with a 95% confidence interval from 101.39 to 107.75, and responses clustered tightly around the median of 104, suggesting many respondents shared similar views. Variation was moderate (variance 318.02; standard deviation 17.83; standard error 1.61), with scores ranging from a low of 59 to a high of 151, a span of 92 points that captures the more extreme views. Together with the Kolmogorov-Smirnov and Shapiro-Wilk results, the roughly normal distribution supports the use of parametric methods in follow-up analyses. Fig. 3 presents the QQ plot and box plot for visual confirmation.

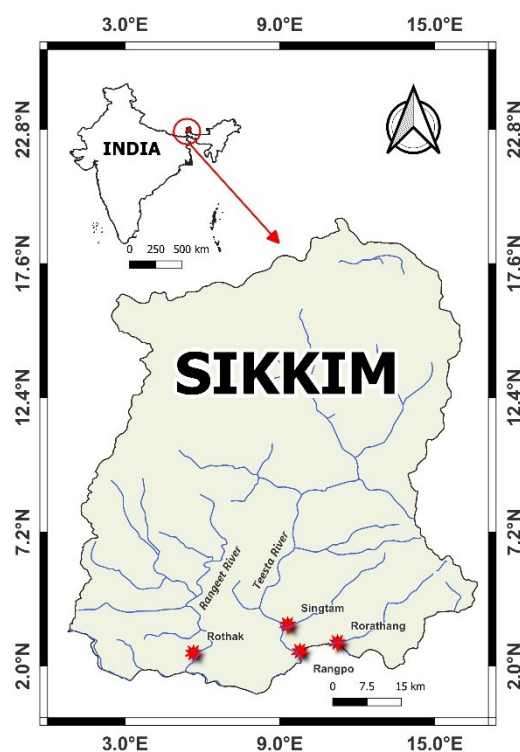


Fig. 1. Map of the study area.



Fig. 2. Teesta River basin (a) Teesta River, (b–c) Door-to-door survey, (d–e) Teesta River during monsoon season, and (f–h) Affected areas during Glacial Lake Outburst Flood (GLOF) by Teesta River on 4th October 2023.

3.3 Demographic details

The results of the descriptive analysis of the demographic variables is shown in Table 2.

Age Distribution. The age groups were categorised into four groups i.e., under 18 years, 19–24 years, 25–34 years and 35 or older respectively. Out of the 123 respondents,

59.3% belonged to the 35 or older age group (highest), 21.1% belonged to the 25–34 age group, 13.0% belonged to the 19–24 age group and only 6.5% belong to the under 18 age group. The results shows that the majority of the respondents were young adults representing a mature demography.

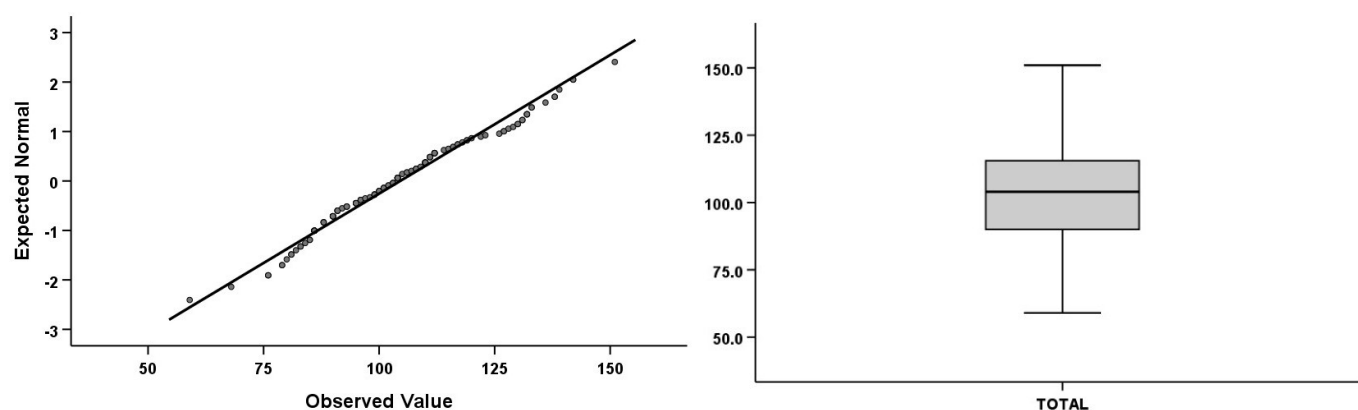


Fig. 3. Normality assessment of the total questionnaire score showing a Q–Q plot comparing observed versus expected normal values and a box plot illustrating the median, interquartile range, and distribution of responses. The linear alignment of points in the Q–Q plot and the absence of extreme outliers in the box plot indicate that the data are approximately normally distributed, supporting the use of parametric statistical analyses.

Table 1. Normality test.

(A)		Tests of Normality				
		Kolmogorov-Smirnov ^a			Shapiro-Wilk	
		Statistic	Df	Sig.	Statistic	df Sig.
TOTAL		0.070	123	0.200*	0.981	123 0.086
^a Lilliefors Significance Correction						
(B)		Descriptives			Statistic	Std. Error
	<i>Mean</i>				104.5691	1.60795
	<i>95% Confidence Interval for Mean</i>	<i>Lower Bound</i>			101.3860	
		<i>Upper Bound</i>			107.7522	
	<i>5% Trimmed Mean</i>				104.2692	
	<i>Median</i>				104.0000	
	<i>Variance</i>				318.018	
TOTAL	<i>Std. Deviation</i>				17.83305	
	<i>Minimum</i>				59.00	
	<i>Maximum</i>				151.00	
	<i>Range</i>				92.00	
	<i>Interquartile Range</i>				26.00	
	<i>Skewness</i>				0.298	0.218
	<i>Kurtosis</i>				-0.329	0.433

Gender Composition. Regarding gender, 56.1% of the total respondents were males whereas 43.9% were females. Most participants were married (69.1%, $n = 85$), with unmarried respondents making up 28.5% ($n = 35$) and a small minority (2.4%, $n = 3$) reporting divorced or other statuses, suggesting the study captures perspectives largely shaped by family responsibilities. In regard to education, 73.2% of the respondents belonged to the ‘high school or less’ group, 17.1% respondents had a ‘bachelor’s degree’ and the remaining 9.8% of the respondents selected ‘others’ group. Further, out of the total respondents, 91.9% respondents selected ‘local’ group for the community status, whereas 5.7% selected ‘resettled’ groups and only 2.4% of the respondents selected the ‘displaced’ groups.

3.4 Reliability Test

The results of the reliability test of the questionnaire variables is shown in Table 3. The Cronbach’s alpha value of 0.851 and the standardized alpha value of 0.844 reveals

that the data of the current survey is more than 80% reliable for further analysis and study. The details of the scale statistics and the summary item statistics is also given in the table.

Table 4A–C shows the results of the mean rank test for the Knowledge, Attitudes, and Practices (KAP) responses regarding the mega-dam project among the participants surveyed. This analysis looks at how respondents view the social, economic, and environmental impacts of the project.

Social impact perceptions. Respondents strongly perceive community displacement and disruption of social networks, with the highest mean score for the statement that the Mega-Dam Project has led to displacement and social disruption (mean = 3.57). Respondents report low levels of involvement in decision-making, with the lowest mean score for the statement that local communities feel adequately consulted (mean = 2.33).

Economic impact perceptions. The highest mean rank for the ‘ECO4’ questionnaire about the significant increase

Table 2. Descriptive analysis of demographic variables.

	Characteristics	Frequency	Percent	Valid Percent	Cumulative Percent
Age	<i>Under 18</i>	8	6.5	6.5	6.5
	<i>19-24</i>	16	13.0	13.0	19.5
	<i>25-34</i>	26	21.1	21.1	40.7
	<i>35 or older</i>	73	59.3	59.3	100.0
	Total	123	100	100	
Gender	<i>Male</i>	69	56.1	56.1	56.1
	<i>Female</i>	54	43.9	43.9	100.0
	Total	123	100	100	
Marital Status	<i>Married</i>	85	69.1	69.1	69.1
	<i>Unmarried</i>	35	28.5	28.5	97.6
	<i>Total</i>	3	2.4	2.4	100.0
	Total	123	100	100	
Education	<i>High school or less</i>	90	73.2	73.2	73.2
	<i>Bachelor's degree</i>	21	17.1	17.1	90.2
	<i>Others</i>	12	9.8	9.8	100.0
	Total	123	100	100	
Community status	<i>Local</i>	113	91.9	91.9	91.9
	<i>Resettled</i>	7	5.7	5.7	97.6
	<i>Displaced</i>	3	2.4	2.4	100.0
	Total	123	100	100	

Table 3. Reliability test of the variables.

Reliability Statistics	Cronbach's Alpha			Cronbach's Alpha Based on Standardized Items			N of Items	
	0.851			0.844			31	
Scale Statistics	Mean	Variance		Std. Deviation			N of Items	
	95.880	326.076		18.058			31	
	Variable	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Summary	Item Means	3.093	2.115	4.025	1.91	1.903	0.308	31
Item	Item Variances	1.854	1.074	2.566	1.492	2.389	0.151	31
Statistics	Inter-Item Covariances	0.289	-0.786	1.439	2.226	-1.83	0.134	31

of cost of living (mean = 4.02) shows that that the majority of the respondents are concerned with the topic. Whereas, the lowest mean rank for 'ECO6' (mean = 2.59) shows the respondents' disagreement with the benefits of farmers in regard to irrigation from the construction of the dam.

Environmental impact perceptions. Environmental concerns are pronounced, with strong agreement that the Mega-Dam Project has degraded water quality and aquatic ecosystems (mean = 4.02). Confidence in environmental oversight is low, with the lowest environmental-item mean for the transparency and effectiveness of monitoring and compliance (mean = 2.46).

Implications. The KAP mean-rank pattern highlights strong awareness of negative social and environmental impacts, paired with limited confidence in governance. Addressing these requires enhanced community participation, transparent benefit-sharing, and credible environmental monitoring.

The response percentage of the respondents for various questions regarding social, economic and environmental (SEE) impacts regarding the construction of mega dams is shown in Fig. 4A–C. The questionnaires based on the Likert-scale ranging from 'Strongly disagree' to 'Strongly agree' was framed and the response distribution for each of the questions belonging to three major social, economic and environmental (SEE) categories can be observed in the figures. For the social impact questionnaires, 'S3 and S6' ques-

tions were strongly agreed by the respondents (Fig. 4A). Regarding the economic impact questionnaires, 'ECO3 and ECO4' questions were strongly agreed by the respondents (Fig. 4B). Finally, for the environmental impact questionnaires, 'ENV3, ENV6 and ENV8' questions were strongly agreed by the respondents (Fig. 4C).

The results from the Pearson's correlation between social, economic and environmental (SEE) questionnaires is shown in Table 5. The results shows that the results of the questionnaires regarding SEE impacts on construction of mega dams are highly significant ($p < 0.01$) and correlated with one another.

The correlation pattern suggests that interventions improving social conditions are likely to influence economic sentiment, but environmental concerns will not automatically resolve with social or economic gains and therefore demand targeted attention. Project authorities should design integrated responses that leverage the social-economic linkage while implementing specific environmental measures and transparent communication to address ecological worries and build broader community support.

4 Chi-square analysis of Social-based questionnaire

Table 6 presents the Chi-square analysis results for the social impact-based questionnaire, examining how perceptions of social impacts from the mega-dam project vary according to demographic factors: age, gender, education, and community status.

Table 4. Mean rank test of the SEE response.

(A) Code	Social Impact-based questions	N	Mean	Std. Deviation	Rank
S1	The Mega-Dam Project has strengthened community cohesion and social bonds.	123	3.27	1.415	3
S2	The Mega-Dam Project has improved access to education and healthcare services for local communities.	123	3.20	1.389	4
S3	The Mega-Dam Project has led to the displacement of communities and disrupted social networks.	123	3.57	1.420	1
S4	Local residents feel adequately consulted and involved in decision-making processes related to the Mega-Dam Project.	123	2.33	1.371	9
S5	The Mega-Dam Project has enhanced cultural preservation and heritage conservation efforts in the region.	123	2.71	1.389	7
S6	The Mega-Dam Project has increased employment opportunities for local residents.	123	3.37	1.522	2
S7	Local communities feel a sense of ownership and pride in the Mega-Dam Project.	123	3.07	1.486	5
S8	The Mega-Dam Project has contributed to an increase in social conflicts and tensions within the community.	123	2.24	1.422	10
S9	The Mega-Dam Project has improved the overall quality of life for local residents.	123	2.87	1.476	6
S10	Local communities feel that their voices and concerns are being heard and addressed by project authorities.	123	2.34	1.372	8
(B) Code	Economic Impact-based questions	N	Mean	Std. Deviation	Rank
ECO1	The Mega-Dam Project has boosted economic growth and development in the region.	123	3.20	1.435	6
ECO2	Local businesses have experienced an increase in revenue and profitability due to the Mega-Dam Project.	123	3.21	1.369	5
ECO3	The Mega-Dam Project has created sustainable job opportunities for local residents.	123	3.52	1.601	3
ECO4	The cost of living has significantly increased in the region since the implementation of the Mega-Dam Project.	123	4.02	1.105	1
ECO5	The Mega-Dam Project has attracted foreign investments and stimulated economic diversification.	123	3.07	1.413	7
ECO6	Local farmers have benefited from improved irrigation and agricultural practices as a result of the Mega-Dam Project.	123	2.59	1.354	10
ECO7	The Mega-Dam Project has led to a rise in property values and real estate development in the area.	123	4.02	1.032	2
ECO8	Income disparities have widened among different socio-economic groups following the Mega-Dam Project.	123	3.42	1.079	4
ECO9	The Mega-Dam Project has facilitated infrastructure development and connectivity in the region.	123	2.91	1.466	9
ECO10	Local residents feel that the economic benefits of the Mega-Dam Project are equitably distributed among the community.	123	3.01	1.423	8
(C) Code	Environmental Impact-based questions	N	Mean	Std. Deviation	Rank
ENV1	The Mega-Dam Project has had a 5 impact on biodiversity conservation in the region.	123	2.60	1.464	8
ENV2	Local ecosystems have been adversely affected by the construction and operation of the Mega-Dam Project.	123	3.20	1.513	5
ENV3	The Mega-Dam Project has contributed to water scarcity and altered natural water flow patterns.	123	3.88	1.191	3
ENV4	Efforts to mitigate environmental damage caused by the Mega-Dam Project have been effective.	123	2.77	1.413	7
ENV5	The Mega-Dam Project has reduced the risk of natural disasters such as floods and droughts in the area.	123	2.86	1.439	6
ENV6	Local flora and fauna have experienced a decline in population and habitat loss due to the Mega-Dam Project.	123	3.91	1.261	2
ENV7	The Mega-Dam Project has promoted sustainable energy production and reduced reliance on fossil fuels.	123	3.69	1.181	4
ENV8	Environmental monitoring and compliance measures related to the Mega-Dam Project have been transparent and effective.	123	2.46	1.263	9
ENV9	The Mega-Dam Project has led to the degradation of water quality and aquatic ecosystems.	123	4.02	1.134	1
ENV10	Local communities feel that their environmental concerns and conservation efforts are being adequately addressed by project authorities.	123	2.11	1.073	10

Table 5. Pearson's correlation between SEE-level.

	Social	Economic	Environmental
Social	1		
Economic	.646**	1	
Environmental	.378**	.410**	1

** Correlation is significant at the 0.01 level (2-tailed).

Analysis by Age. The Chi-square tests showed a significant relationship ($p < 0.05$) between age and social impact statement namely S3 ($\chi^2 = 22.973$), S8 ($\chi^2 = 31.846$), S9 ($\chi^2 = 22.717$), and S10 ($\chi^2 = 37.689$). The results were non-significant for the remaining social impact statements

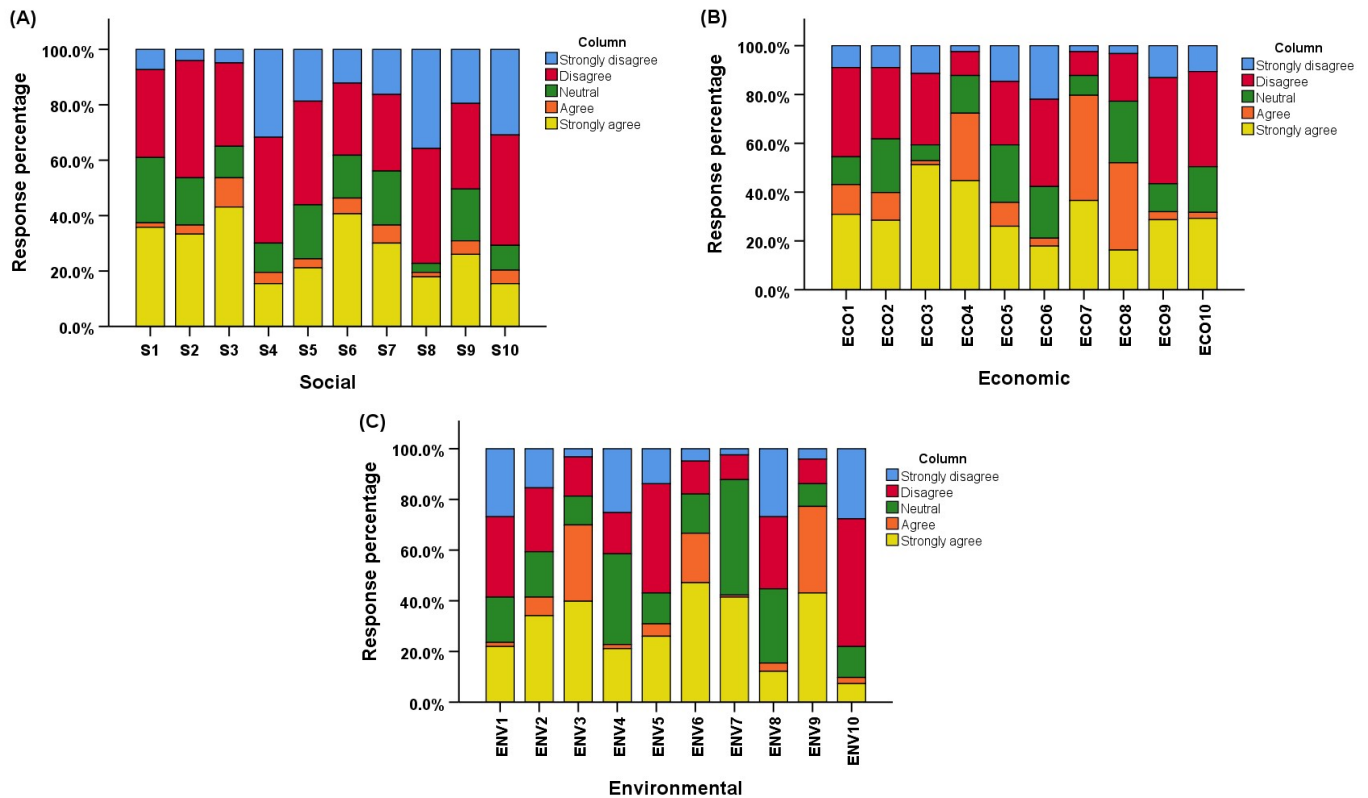


Fig. 4. Response percentage of Social, Economic and Environmental (SEE)-based questions on mega-dam construction. Likert-scale (Strongly disagree–Strongly agree) response distributions for social (A), economic (B), and environmental (C) impact questions on mega dam construction; strongest agreement was recorded for **S3 and S6 (A), ECO3 and ECO4 (B), and ENV3, ENV6 and ENV8 (C).**

according to age further suggesting that age does not significantly affect how respondents perceive social impacts related to the mega-dam project.

Analysis by Gender. The Chi-square tests showed a significant relationship ($p < 0.05$) between gender and social impact statement namely S1 ($\chi^2 = 10.998$), S5 ($\chi^2 = 16.335$), S6 ($\chi^2 = 11.605$), and S7 ($\chi^2 = 11.674$), whereas non-significant relationship with the remaining statements.

Analysis by Education. The Chi-square tests showed a significant relationship ($p < 0.05$) between education level and social impact statement i.e., S3 ($\chi^2 = 19.1$), S4 ($\chi^2 = 22.707$), S6 ($\chi^2 = 16.12$), S8 ($\chi^2 = 31.523$), S9 ($\chi^2 = 18.878$), and S10 ($\chi^2 = 29.231$) suggesting formal education does meaningfully differentiate how participants view the social consequences of the mega-dam project. The remaining statements (S1, S2, S5 and S7) had a non-significant relationship according to education level.

Analysis by Community Status. The Chi-square tests showed a significant relationship ($p < 0.05$) between community status and social impact statement with only S1 ($\chi^2 = 17.679$), and S9 ($\chi^2 = 16.079$). The results were non-significant for the remaining social impact statements according to community status further suggesting that community status does not significantly affect how respondents perceive social impacts related to the mega-dam project.

These insights can help project authorities create targeted communication and intervention strategies to address

the unique concerns of different demographic groups within the community.

5 Chi-square analysis of the economic-based questionnaire

Table 7 provides the Chi-square analysis results for the economic impact-based questionnaire, assessing how perceptions of economic impacts from the mega-dam project vary according to demographic factors: age, gender, education, and community status.

Analysis by Age. The Chi-square tests showed a significant relationship ($p < 0.05$) between age and the economic impact statement ECO1 ($\chi^2 = 23.164$), ECO5 ($\chi^2 = 22.175$), ECO6 ($\chi^2 = 38.94$), ECO7 ($\chi^2 = 21.383$), ECO9 ($\chi^2 = 21.328$) and ECO10 ($\chi^2 = 42.419$). The results were non-significant for the remaining economic impact statements in relation to age.

Analysis by Gender. The Chi-square analysis showed significant relationship ($p < 0.05$) between gender and the economic impact statement ECO2 ($\chi^2 = 11.71$), ECO3 ($\chi^2 = 12.218$), ECO7 ($\chi^2 = 9.862$), and ECO9 ($\chi^2 = 11.143$). The different responses from men and women show that perceptions of changes in local business performance vary by gender. Men and women do not assess business revenue and profitability impacts in the same way, which suggests gendered experiences, roles, or expectations influence how economic benefits are perceived. The result implies that eco-

Table 6. Chi-square analysis of a social impact-based questionnaire based on age, gender, education, and community status.

	Social Impact	Age	Gender	Education	Community Status
S1	<i>Chi-square</i>	18.287	10.998	10.516	17.679
	<i>df</i>	12	4	8	8
	<i>Sig.</i>	.107a,b	.027a,b,*	.231a,b	.024a,b,*
S2	<i>Chi-square</i>	17.129	1.337	8.029	4.529
	<i>df</i>	12	4	8	8
	<i>Sig.</i>	.145a,b	.855a	.431a,b	.806a,b
S3	<i>Chi-square</i>	22.973	5.965	19.1	12.54
	<i>df</i>	12	4	8	8
	<i>Sig.</i>	.028a,b,*	.202a	.014a,b,*	.129a,b
S4	<i>Chi-square</i>	19.683	6.942	22.707	11.568
	<i>df</i>	12	4	8	8
	<i>Sig.</i>	.073a,b	.139a	.004a,b,*	.172a,b
S5	<i>Chi-square</i>	15.641	16.335	9.744	9.408
	<i>df</i>	12	4	8	8
	<i>Sig.</i>	.208a,b	.003a,*	.283a,b	.309a,b
S6	<i>Chi-square</i>	20.796	11.605	16.12	5.504
	<i>df</i>	12	4	8	8
	<i>Sig.</i>	.053a,b	.021a,*	.041a,b,*	.703a,b
S7	<i>Chi-square</i>	14.992	11.674	10.335	3.989
	<i>df</i>	12	4	8	8
	<i>Sig.</i>	.242a,b	.020a,*	.242a,b	.858a,b
S8	<i>Chi-square</i>	31.846	3.354	31.523	7.717
	<i>df</i>	12	4	8	8
	<i>Sig.</i>	.001a,b,*	.500a,b	.000a,b,*	.462a,b
S9	<i>Chi-square</i>	22.717	1.819	18.878	16.079
	<i>df</i>	12	4	8	8
	<i>Sig.</i>	.030a,b,*	.769a	.016a,b,*	.041a,b,*
S10	<i>Chi-square</i>	37.689	6.526	29.231	6.944
	<i>df</i>	12	4	8	8
	<i>Sig.</i>	.000a,b,*	.163a	.000a,b,*	.543a,b

Results are based on nonempty rows and columns in each innermost subtable.

* The Chi-square statistic is significant at the .05 level.

More than 20% of cells in this subtable have expected cell counts less than 5. Chi-square results may be invalid.

b The minimum expected cell count in this subtable is less than one. Chi-square results may be invalid.

nomic outreach, support programs, and impact assessments should incorporate gender-sensitive approaches to capture and address these differing perspectives on local business outcomes. The remaining economic impact statements were non-significant in relation to gender.

Analysis by Education. The Chi-square test results for education levels showed significant relationship between educational levels the economic impact statement ECO4 ($\chi^2 = 16.156$), ECO5 ($\chi^2 = 23.874$), ECO6 ($\chi^2 = 26.119$), and ECO7 ($\chi^2 = 24.123$). The results were non-significant for the remaining economic impact statements in relation to educational levels.

Analysis by Community Status. The Chi-square analysis showed significant relationship ($p < 0.05$) between community status and the economic impact statement ECO2 ($\chi^2 = 22.469$), ECO3 ($\chi^2 = 19.78$), ECO7 ($\chi^2 = 25.369$), and ECO8 ($\chi^2 = 16.098$). These results suggest that the conditions of different community groups (local, resettled, displaced) have a significant influence on how the mega-dam project has affected the local economy. The results were

non-significant for the remaining economic impact statements in relation to community status.

These findings provide valuable insights for project stakeholders. They highlight the need to address economic impacts contextually, considering demographic variations to promote a more inclusive approach to community engagement and support.

The chi-square analysis revealed that perceptions of economic impacts varied significantly across several demographic dimensions (Table 7). Age emerged as an important factor influencing economic perceptions, with significant associations observed for statements related to regional economic growth (ECO1), rising cost of living (ECO5), agricultural benefits (ECO6), changes in property values (ECO7), infrastructure development (ECO9), and perceived equity in benefit distribution (ECO10). These results indicate that respondents from different age groups assess both benefits and economic risks of the mega-dam project differently. Gender-based differences were also evident, particularly in perceptions related to local business performance (ECO2), employment opportunities (ECO3), property value

Table 7. Chi-square analysis of the economic impact-based questionnaire based on age, gender, education, and community status.

Economic Impact		Age	Gender	Education	Community Status
ECO1	Chi-square	23.164	8.948	8.883	11.885
	df	12	4	8	8
	Sig.	.026*,b,c	.062b	.352b	.156b,c
ECO2	Chi-square	12.222	11.71	11.562	22.469
	df	12	4	8	8
	Sig.	.428b,c	.020*,b	.172b	.004*,b,c
ECO3	Chi-square	10.083	12.218	6.34	19.78
	df	12	4	8	8
	Sig.	.609b,c	.016*,b,c	.609b,c	.011*,b,c
ECO4	Chi-square	11.658	7.644	16.156	11.256
	df	12	4	8	8
	Sig.	.473b,c	.106b	.040*,b,c	.188b,c
ECO5	Chi-square	22.175	1.914	23.874	12.866
	df	12	4	8	8
	Sig.	.036*,b,c	.752b	.002*,b	.117b,c
ECO6	Chi-square	38.94	7.104	26.119	10.462
	df	12	4	8	8
	Sig.	.000*,b,c	.131b	.001*,b,c	.234b,c
ECO7	Chi-square	21.383	9.862	24.123	25.369
	df	12	4	8	8
	Sig.	.045*,b,c	.043*,b	.002*,b,c	.001*,b,c
ECO8	Chi-square	12.014	3.964	13.591	16.098
	df	12	4	8	8
	Sig.	.445b,c	.411b	.093b,c	.041*,b,c
ECO9	Chi-square	21.328	11.143	5.961	10.929
	df	12	4	8	8
	Sig.	.046*,b,c	.025*,b	.652b,c	.206b,c
ECO10	Chi-square	42.419	2.809	7.215	8.678
	df	12	4	8	8
	Sig.	.000*,b,c	.590b	.514b,c	.370b,c

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* The Chi-square statistic is significant at the .05 level.

b More than 20% of cells in this subtable have expected cell counts less than 5. Chi-square results may be invalid.

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changes (ECO7), and infrastructure development (ECO9). This suggests that men and women experience and interpret economic outcomes of the project through distinct social roles and livelihood expectations, highlighting the importance of gender-sensitive economic assessments. Education level significantly influenced perceptions of economic impacts associated with cost of living (ECO4), investment and diversification (ECO5), agricultural benefits (ECO6), and property value changes (ECO7), indicating that respondents with higher educational attainment were more critical or discerning in evaluating long-term economic consequences. Community status further shaped economic perceptions, with significant differences observed between local, resettled, and displaced respondents for statements related to business revenue (ECO2), employment opportunities (ECO3), property values (ECO7), and income inequality (ECO8). These findings underscore the uneven distribution of economic costs and benefits across community groups affected by the mega-dam project. Overall, the results highlight that economic impacts of the mega-dam project are not perceived uniformly but are strongly condi-

tioned by demographic characteristics, reinforcing the need for context-specific, inclusive economic planning and compensation strategies.

6 Chi-square analysis of the environmental-based questionnaire

Table 8 presents the Chi-square analysis of the environmental impact-based questionnaire, investigating how perceptions of environmental impacts from the mega-dam project vary according to demographic factors: age, gender, education, and community status.

Analysis by Age The Chi-square tests showed a significant relationship ($p < 0.05$) between age and the environmental impact statement ENV2 ($\chi^2 = 28.115$), ENV3 ($\chi^2 = 23.329$), ENV6 ($\chi^2 = 28.501$), ENV8 ($\chi^2 = 23.6$), ENV9 ($\chi^2 = 27.073$) and ENV10 ($\chi^2 = 25.522$) indicating younger respondents report stronger concerns about adverse effects on local ecosystems than older respondents. This pattern suggests generational differences in environmental awareness or exposure to information that shape how ecosystem

Table 8. Chi-square analysis of the environmental impact-based questionnaire based on age, gender, education, and community status.

Environmental Impact		Age	Gender	Education	Community Status
ENV1	<i>Chi-square</i>	19.389	2.647	17.091	5.894
	<i>df</i>	12	4	8	8
	<i>Sig.</i>	.080a,b	.619a,b	.029a,b,*	.659a,b
ENV2	<i>Chi-square</i>	28.115	2.081	28.808	8.019
	<i>df</i>	12	4	8	8
	<i>Sig.</i>	.005a,b,*	.721a	.000a,b,*	.432a,b
ENV3	<i>Chi-square</i>	23.329	6.18	18.96	4.266
	<i>df</i>	12	4	8	8
	<i>Sig.</i>	.025a,b,*	.186a	.015a,b,*	.832a,b
ENV4	<i>Chi-square</i>	15.655	4.277	29.364	4.511
	<i>df</i>	12	4	8	8
	<i>Sig.</i>	.208a,b	.370a,b	.000a,b,*	.808a,b
ENV5	<i>Chi-square</i>	15.514	4.016	27.046	16.827
	<i>df</i>	12	4	8	8
	<i>Sig.</i>	.215a,b	.404a	.001a,b,*	.032a,b,*
ENV6	<i>Chi-square</i>	28.501	2.464	6.946	9.794
	<i>df</i>	12	4	8	8
	<i>Sig.</i>	.005a,b,*	.651a	.543a,b	.280a,b
ENV7	<i>Chi-square</i>	9.203	3.374	21.608	12.87
	<i>df</i>	12	4	8	8
	<i>Sig.</i>	.686a,b	.497a,b	.006a,b,*	.116a,b
ENV8	<i>Chi-square</i>	23.6	7.519	19.375	12.534
	<i>df</i>	12	4	8	8
	<i>Sig.</i>	.023a,b,*	.111a	.013a,b,*	.129a,b
ENV9	<i>Chi-square</i>	27.073	2.526	10.089	6.909
	<i>df</i>	12	4	8	8
	<i>Sig.</i>	.008a,b,*	.640a	.259a,b	.546a,b
ENV10	<i>Chi-square</i>	25.522	4.815	21.951	8.304
	<i>df</i>	12	4	8	8
	<i>Sig.</i>	.013a,b,*	.307a	.005a,b,*	.404a,b

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* The Chi-square statistic is significant at the .05 level.

More than 20% of cells in this subtable have expected cell counts less than 5. Chi-square results may be invalid.

b The minimum expected cell count in this subtable is less than one. Chi-square results may be invalid.

harm is understood. The results were non-significant for the remaining environmental impact statements in relation to age.

Analysis by Gender. The Chi-square analysis showed non-significant relationship between gender and any of the environmental impact statements indicating there was no influence of gender in relation to environmental concern.

Analysis by Education. The Chi-square analysis showed a significant relationship ($p < 0.05$) between education level and the environmental impact statement ENV1 ($\chi^2 = 17.091$), ENV2 ($\chi^2 = 28.808$), ENV3 ($\chi^2 = 18.96$), ENV4 ($\chi^2 = 29.364$), ENV5 ($\chi^2 = 27.046$), ENV7 ($\chi^2 = 21.608$), ENV8 ($\chi^2 = 19.375$) and ENV10 ($\chi^2 = 21.951$) indicating that higher-educated respondents are more likely to recognize or report negative effects of dam on ecosystems. This suggests formal education increases awareness or the ability to interpret environmental change. The results were non-significant for the remaining environmental impact statements in relation to education level.

Analysis by Community status. The Chi-square analysis showed a significant relationship ($p < 0.05$) between community status and the environmental impact statement ENV5 ($\chi^2 = 16.827$), indicating that locals, resettled people, and displaced groups perceive ecological impacts differently depending on their lived experiences and stakes in local resources. The results were non-significant for the remaining environmental impact statements in relation to community status.

Age, gender, education, and community status all influence environmental perceptions of the mega-dam. Younger and more educated respondents show stronger concern about ecosystem harm, gender shapes views on water impacts, and community status frames how people judge biodiversity and ecosystem change. Stakeholders should pair targeted communication and education with participatory monitoring and tailored engagement—designing messages and mitigation plans that reflect generational, gendered, educational, and residency-specific perspectives to build trust and address locally felt environmental harms.

Table 9. Frequency of the overall perception questionnaire.

		Frequency	Percent	Valid Percent	Cumulative Percent
Overall, how positively or negatively do you perceive the social impacts of the mega-dam project on your community?	Very Negative	40	32.50	32.50	32.50
	Negative	18	14.60	14.60	47.20
	Neutral	36	29.30	29.30	76.40
	Positive	2	1.60	1.60	78.00
	Very Positive	27	22.00	22.00	100.00
	Total	123	100	100	

Table 10. Chi square analysis of the overall perception questionnaire based on age, gender, education, and community status.

Overall perception		Age	Gender	Education	Community status
Overall, how positively or negatively do you perceive the social impacts of the mega-dam project on your community?	Chi-square	26.396	1.858	11.789	8.982
	df	12	4	8	8
	Sig.	.009*,b,c	.762b,c	.161b,c	.344b,c

Results are based on nonempty rows and columns in each innermost subtable.

* The Chi-square statistic is significant at the .05 level.

b More than 20% of cells in this subtable have expected cell counts less than 5. Chi-square results may be invalid.

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7 Overall perception

The detailed report about the frequency of the overall perception questionnaire is given in Table 9. The results revealed that a significant number of respondents, specifically 32.50%, view the social impacts as “Very Negative.” Another 14.60% consider them “Negative,” making a total of over 47% dissatisfied with the mega dam projects. In contrast, 29.30% of participants took a “Neutral” stance, indicating some uncertainty about the project’s effects. Only a small number, 1.60%, reported a “Positive” perception, while 22.00% felt the impacts were “Very Positive.”

The overall percentages indicate that fewer than a quarter of respondents viewed the social impacts favourably. This highlights a general sense of scepticism or concern within the community. This high level of negative perception stresses the need to address community concerns and improve communication about the social benefits of the mega-dam project. Overall, the findings point to significant issues with how the project is seen socially. They also emphasize the need for proactive engagement and attention to community needs to build support and understanding.

Table 10 shows the results of the chi-square analysis for the overall perception questionnaire using demographic factors like age, gender, education, and community status. The analysis finds a significant relationship ($p < 0.05$) age ($\chi^2 = 26.396$), and the overall perception of the social impacts of the mega-dam project. This suggests that different age groups have varying views on the project’s social impacts, with younger and older respondents likely seeing the project’s effects in different ways. However, the results show non-significant relationship between gender, education, and community status vs the overall perception questionnaire.

The details of response percentage of overall perception by age is given in Fig. 5. Maximum number of respondents under the age group of ‘Under 18’ strongly agreed with the overall response statement of “Overall, how positively or negatively do you perceive the social impacts of the mega-dam project on your community?” whereas maximum number of respondents belonging to the ‘25–34, and 35 or older’ age groups strongly disagreed with the aforementioned statement. Moreover, the older age group re-

spondents show a broader range of opinions, including a significant number with a more positive view too. This underscores the need to engage with different age groups to address their specific concerns and perspectives about the construction of a mega dam project.

Overall, the results indicate that environmental concerns emerged as the most pronounced impact of the mega-dam project, with biodiversity loss, degradation of water quality, altered river flow, and habitat loss receiving the highest levels of agreement among respondents. Social impacts were also strongly perceived, particularly community displacement, disruption of social networks, limited public participation in decision-making, and reduced trust in project authorities. Economic perceptions were mixed, with respondents acknowledging infrastructure development and employment opportunities while simultaneously expressing concern over rising costs of living, unequal distribution of benefits, and limited gains for local farmers. Demographic analysis revealed that age and education were the most influential variables shaping perceptions. Younger and more educated respondents consistently reported stronger concern regarding environmental degradation, whereas older respondents were relatively more inclined to emphasise perceived economic benefits. Gender and community status influenced specific social and economic perceptions, particularly relating to employment, local business impacts, and quality of life. These patterns highlight the uneven distribution of perceived costs and benefits across social groups and underscore the importance of demographic context in understanding community responses to mega-dam development.

8 Discussion

8.1 Social Impacts

The construction of mega-dams has always been a controversial topic, mainly due to the forced relocation of people living in and around the area, the disruption of social networks, and the lack of community engagement. In this study, many respondents shared negative views, stressing the loss of cultural identity, weakening of traditional gov-

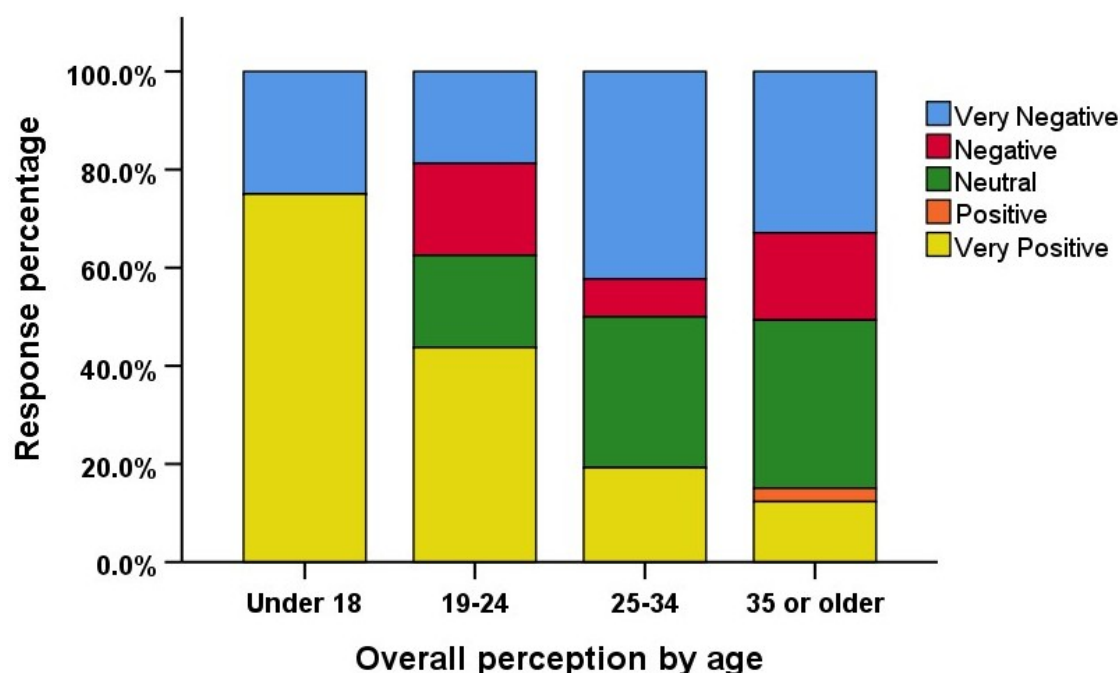


Fig. 5. Response percentage of overall perception by age.

ernance, and insufficient consultation from project authorities. These issues are consistent with earlier research (Scudler, 2012), which pointed out the long-term effects of displacement caused by dams. Resettled people often face loss of land, instability in their livelihoods, and social breakdown.

There was noticeable gender-based differences in perceptions between man and women. Women expressed more worries about disrupted social structures and economic dependence than the men. Gender-specific vulnerabilities were also noted, revealing that displaced women encounter greater economic and social challenges due to fewer job opportunities and disrupted caregiving roles. Furthermore, previous studies argued that large dams change the social dynamics of affected areas, often leading to weakened community ties and increased social conflicts (Bergkamp et al., 2000).

Additionally, this study also highlighted the limited involvement of the local people in decision-making processes. Most respondents were not happy with the lack of consultations with them. Earlier study had highlighted the importance of participatory governance, explaining that successful dam projects should include local knowledge, traditional leadership, and open communication (McCartney, 2009). The disputes over the Teesta River hydropower projects reported by earlier study (Arora, 2009) further support the idea that being left out of policy decisions creates social resistance and distrust. To address these issues, governments and hydropower developers should focus on dialogue, fair compensation, and strong relocation plans, as past studies suggest (Dukpa et al., 2019; Menon et al., 2003).

8.2 Economic Impacts

The study showed a disparity among the young and older respondents in terms of Economic views on the mega-

dam projects. it shows a divided perspective. Younger respondents were more optimistic about job creation and infrastructure development. In contrast, displaced individuals and older residents express doubt regarding the same. This finding supports previous research (Ansar et al., 2014), which criticized large dams for often failing to achieve economic goals, especially regarding lasting jobs and fair distribution of benefits.

Addressing the rising cost of living was an aspect of this study. Numerous respondents gave feedback stating they experienced adverse financial impacts after the dam was put into place. This concern was also acknowledged by the earlier study (Biswas, 1999), in which he pointed out that although dams contribute to economic development, they also tend to cause inflation, rising property prices, and hyper-competition for resources, especially affecting agrarian communities.

The study also highlighted the gaps in wealth and income inequality among different groups of people. Resettled populations experienced financial hardship, while local elites and urban investors gained significantly from the projects. This observation aligns with earlier research by (Flyvbjerg et al., 2003), which stated that hydropower projects often benefit politically connected groups at the expense of rural populations. Another study has also emphasized that economic gains usually concentrate in urban areas, while displaced rural communities suffer the most from economic drawbacks because of the mega dam projects (Kim, 2025).

In order to promote fair development, stakeholders need to implement targeted policies to help vulnerable groups. Earlier study has also suggested progressive tax systems, direct support for livelihoods, and incentives for community-led businesses to reduce economic gaps (Baruah, 2017). Additionally, other studies have called for clear compensation

plans and long-term job strategies for displaced communities (Kukreja, 2023).

8.3 Environmental Impacts

Among all the concerns related to the mega dam projects, the environmental concerns emerged as the most significant issue in this study. The concerns, such as Biodiversity loss, water degradation, and habitat destruction, ranked highest among respondents' worries. Out of the 123 respondents, a striking 64% of participants reported negative environmental views. This clearly reflects their concerns about changes in water flow, sedimentation rate, and greater vulnerability to extreme climate events. These worries are similar to those found in earlier studies (Pandit and Grumbine, 2012), which highlighted the risks of species extinction caused by hydropower in the Himalayas. Other studies have also shown similar concerns that large dams disrupt aquatic life cycles. Dams impede riverine processes critical to fish movements, oxygenation, sediment transport, and erosion (Baxter, 1977; Wu et al., 2019). For the Teesta River, respondents were concerned about the quality of river water, which corresponds with previous findings (Sikder and Elahi, 2013), which studied methane emissions from long-flooded reservoirs and associated them with long-term greenhouse gas retention.

The construction of dams with climate change impacts continues to be poorly addressed. Respondents noted that, after the dam construction, there were more landslides, erratic rainfall, and dry periods. Previous studies have described these phenomena as the result of poorly planned water management interventions made on the Himalayan region (Rai and Khawas, 2021). Unregulated mega dam construction, has further exacerbated the impacts of global warming (Sikder and Elahi, 2013). They described glacial retreat and subsequent alterations to river systems, phenomena that Sikkim is currently experiencing. Given these environmental risks, there is a need to incorporate sustainable practices into hydropower planning. Costa et al. (2016) suggested using Strategic Environmental Assessments (SEA) to ensure projects do not harm ecological balance. Del Bene et al. (2018) called for stronger measures to adapt to climate issues and prevent irreversible habitat loss in their earlier studies.

Recent developments in the Teesta basin further reinforce the environmental concerns identified in this study. Hydropower projects in the Eastern Himalaya continue to face political and public scrutiny, with increasing calls for updated Environmental Impact Assessments (EIAs), revised flood-risk evaluations, and renewed public consultation. These concerns intensified following a massive landslide on 20 August 2024 that severely damaged NHPC's Teesta V hydropower station at Balutar, Sikkim, highlighting the vulnerability of large infrastructure in fragile Himalayan terrain (Bera, 2025). Recent research has framed such events within the concept of "compound risk," where interacting hazards such as landslides, floods, and climate extremes jointly amplify ecological and infrastructural vulnerability. The Teesta V incident illustrates how slope instability, extreme rainfall, and altered river dynamics

can cascade into severe infrastructure failure, while post-GLOF siltation has emerged as a major downstream management challenge, prompting dredging and desilting efforts in parts of West Bengal as flood-mitigation measures (Bera, 2025). These developments provide important context for community perceptions observed in this study, particularly the heightened environmental concern among younger and more educated respondents. Growing exposure to compound hazards linked to rapid infrastructure expansion—roads, tunnels, and dams—appears to reinforce public scepticism regarding dam safety and environmental governance, strengthening demands for precautionary planning, adaptive risk assessment, and inclusive decision-making.

9 Future Perspectives

Future research should adopt longitudinal designs to track social, economic, and environmental impacts across project phases, enabling clearer assessment of harm, persistence of benefits, and effectiveness of mitigation measures. Policy and regulatory frameworks such as the Environmental Impact Assessment (EIA) Notification (2006), the National Disaster Management Plan (NDMP), the National Water Policy, and guidelines issued by the Central Electricity Authority (CEA) for hydropower development must be critically reviewed to identify accountability gaps and risk governance limitations. Strengthening alignment between these frameworks and local-level implementation is essential to ensure that affected communities gain recognition, redress, and meaningful participation in decision-making. At the same time, future studies should explore sustainable, people-centred solutions, including alternative energy options, ecological restoration strategies, and climate-resilient infrastructure design, consistent with national commitments under the National Action Plan on Climate Change (NAPCC). Integrating long-term monitoring, policy analysis, and applied research on sustainable technologies can provide planners with context-sensitive guidance that elevates community voices and supports more equitable trade-offs between development objectives and environmental health.

10 Conclusions

The study highlighted the various impacts of the mega-dam project, which includes the serious social, economic, and environmental challenges. Though some benefits exist, like job creation and infrastructure development, these benefits are overshadowed by issues such as the displacement of people, increasing costs, and ecological harm. The findings further demonstrate that demographic factors—particularly age, gender, education level, and community status—play a critical role in shaping perceptions, with younger and more educated respondents expressing stronger environmental concern, while older respondents and locally established groups were relatively more inclined to emphasize perceived economic benefits.

To mitigate these challenges more inclusive strategies for hydropower development are essential. More attention should be given to shared decision power whereby planning involves the say of the impacted people. Policy on

the economy affects the distribution of given resources. These should be aimed at displaced people and the economically and socially marginalized people. Environmental stewardship must be placed at the forefront of the agenda. High stewardship and societal sustainability will be attained when there are better reporting, monitoring, and adherence to protection of open ecosystems.

In the end, the successful execution of such projects depends on balancing development goals with social and ecological health. By promoting transparency, inclusive governance, and sustainable practices, authorities can work to reduce negative effects while maximizing benefits for all involved.

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Conflict of interest

The authors declare that they have no conflict of interest.

Data Availability Statement

In accordance with the ethical protocol framing this research and the consent form of the participants, data collected, processed and analysed have been anonymised and stored securely. Data are therefore not available for sharing to protect the safety of those who took part in the research.

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YT & SR: writing, methodology, data collection, **JDB & PP:** literature review, statistical analysis. **TB & AMT:** protocol development, project supervision, data interpretation, writing.

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