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Joint Determination of Perceived Favorable and Adverse Environmental Impacts of Mega-Dam by Residents: The Case of Merowe Dam, Sudan

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Abstract

Background: Although mega-dams play a significant role in development, providing electricity, irrigation, and flood control, perceptions of their contribution remain mixed, particularly regarding the environmental impacts. **Methods**: This study jointly determines perceived favorable and adverse environmental impacts of mega-dams by affected residents using a bivariate Tobit model on a clustered random sample of 300 households surveyed from (a) upstream, (b) upstream-relocated, and (c) downstream communities of the Merowe Dam in Sudan. Model diagnostic reveals that the perception of favorable and adverse environmental impacts is significantly and positively correlated, implying that univariate analyses of such perceptions are biased, thereby justifying the use of a bivariate approach. Such joint perception analysis using a bivariate Tobit model confirms that affected residents are well aware of both the positive and negative impacts of the dam, not commonly seen in the literature. **Results**: Results reveal significant differences in perception among communities on individual indicators of favorable and adverse environmental impacts of the dam. Education, income from farming, and relocation significantly decrease the likelihood of perceiving adverse environmental impacts whereas farmers of all farm types increase it. Selected farming categories and gain in land size after dam's construction significantly increases the likelihood of scoring high on favorable environmental impacts whereas income from fishing significantly reduces it. **Conclusions**: Perception towards the favorable and adverse environmental impacts are not independent, rather significantly and positively correlated, confirming that affected residents are aware of both types of impacts of the Merowe Dam. Upstream-relocated residents are less likely to report the significant adverse environmental impacts of the dam, whereas both upstream and upstream-relocated residents are less likely to report significant favorable impacts of the dam. **Policy implications**: Include establishing educational institutions, allocation of agricultural land, and mitigating adverse environmental impacts by setting up community environmental monitoring programs in affected areas to boost community perception of the favorable environmental impacts of mega-dams.

Keywords: environmental impact; mega-dam infrastructure; people's perception; bivariate Tobit model

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1. Introduction

Population growth has led to a massive need for constructing large-scale infrastructure such as cities, roads, bridges, and dams to accommodate the growing demand for energy, housing, and other essential needs. Technological advancement has accelerated the development of such infrastructure, which in turn has caused imbalances in ecosystems and a loss of ecological stability (Huesemann & Huesemann, 2011). Mega-dams, in particular, play an important role in energy generation and water management, especially in developing economies (Agrawala et al., 2003). These large-scale projects are often justified by their contributions to hydroelectric power, irrigation, and flood control. However, despite their advantages, mega-dams remain highly contested due to their complex ecological and environmental consequences (Verhoeven, 2015). It has been observed that developing countries are increasingly dependent on dams to meet the rising demand for energy and water across industrial, domestic, and agricultural sectors (Boulange et al., 2021). Hydropower is perceived as a clean source of energy, generating electricity with minimal emissions and limited contributions to global warming (Bai et al., 2020). Nevertheless, mega-dam projects face substantial environmental challenges (Yah et al., 2017). As Boulange et al. (2021) note, reservoirs and dams exert complex local, regional, and global influences on the environment and climate. The creation of reservoirs and hydropower systems can alter local and regional climates and significantly affect the availability and accessibility of water resources Boulange et al. (2021). These environmental and climatic shifts may, in some cases, instigate resource-based conflicts amongst and between governments and local communities (Agrawala et al., 2003). Furthermore, environmental concerns often intensify political negotiations and power struggles among local, regional, and global stakeholders, each motivated by expectations of shared benefits (Verhoeven, 2015).

Environmentalists continue to raise concerns about the social and ecological consequences of dam construction, including population displacement and biodiversity change. Conversely, proponents of hydropower view these projects as vital sources of renewable energy (Basson, 2004). Mega-dams generate a range of adverse environmental effects—during construction, after completion, and throughout the operational phase, which often extends for decades. The potential impacts of dams extend across physical and biological environments, affecting construction sites, reservoir areas, and both upstream and downstream regions. Despite these widely recognized negative effects, investment in mega-dams continues to grow (Alexander, 2015). However, questions surrounding their ideological foundations, financing mechanisms, and implementation strategies have intensified in light of their environmental implications (Verhoeven, 2015).

In Sudan, despite economic challenges and environmental concerns, the government has pursued multiple mega-dam projects to stimulate industrial and agricultural growth (Verhoeven, 2015). The **Merowe Dam**, in particular, was promoted as a catalyst for economic transformation and socioeconomic improvement. However, scholars and practitioners have argued that its construction has had substantial social and environmental consequences in the region (Askouri, 2007). The project has also been associated with negative outcomes, such as forced displacement and the disruption of traditional livelihoods (K. McDonald et al., 2009).

Community perceptions play a critical role in shaping the long-term environmental impacts of mega-dams. While some groups benefit from improved infrastructure and employment opportunities, others experience displacement, livelihood loss, and environmental degradation. Ecological concerns—such as biodiversity loss, altered river ecosystems, and declining water security—further fuel public debate. Existing research often overlooks the perspectives of affected communities, creating a gap in understanding their perceptions and lived experiences. This study addresses this gap by surveying 300 residents from three groups: (a) upstream residents who refused relocation, (b) upstream-relocated communities, and (c) downstream residents affected by changes in water flow following the construction of the Merowe Dam in 2009. The study examines community perceptions of both favorable and adverse environmental impacts associated with the Merowe Dam across its project lifecycle. Specifically, the objectives of this study are to: (a) assess the perceived favorable and adverse environmental impacts of the Merowe Dam by affected residents, and (b) identify the range of socio-economic factors shaping these perceptions. The contribution of our study to the existing literature are as follows: (a) by centering the voices of affected residents, this research offers a micro-level perspective that complements conventional macro-level analyses largely focusing on the costs and benefits of mega-dams; (b) conducted a joint perception analyses by using a bivariate Tobit model to investigate whether perceptions on the favorable and adverse environmental impacts of the mega-dam by affected residents are independent or not, i.e., whether residents are aware of both types of impacts; and (c) it contributes to ongoing debates by highlighting the lived experiences behind the complex environmental consequences of mega-dams—dimensions that are rarely captured in the existing literature.

2. Literature Review

Community perceptions of mega-dams' environmental impacts are shaped by various factors, including the spread of waterborne diseases, waterlogging, salinization, erosion, sedimentation, impacts on wildlife and forestation, water supply and flow, flooding, and social consequences (Barbarossa et al., 2020). These dimensions have been extensively discussed in the academic literature, with scholars noting both the positive and negative effects of large-scale dam projects. Research on environmental impacts has grown, particularly alongside the rise of emerging economies such as Brazil and China (Yah et al., 2017). However, limited attention has been given to the factors influencing local perceptions, despite their critical importance for sustainable development (Jackson & Sleigh, 2000).

Most studies have analyzed and evaluated the broader impacts of mega-dams at the national or regional level, often focusing on contributions to GDP and large-scale environmental consequences (Flyvbjerg, 2009; Ansar et al., 2014; Everard, 2013). Fewer studies have explored the perspectives and lived experiences of affected communities—the primary stakeholders in such projects. Understanding these micro-level perceptions is essential, as communities embody diverse expectations and experiences—some realized, others unfulfilled—throughout the lifecycle of mega-dam development.

Increasing global awareness of environmental issues has progressively shaped how displaced and local communities perceive mega-dams (Ziolkowski, 2024). Environmental concerns such as biodiversity loss, altered water flow, and climate change have become central to public discourse and activism (Ziolkowski, 2024). Everard (2013) and Isaacman and Isaacman (2013) observe that non-governmental organizations (NGOs) and communities dependent on agriculture, fishing, and water resources are among the most vocal opponents of mega-dam construction. This heightened awareness often fuels local resistance and demands for more sustainable and socially just alternatives (Ziolkowski, 2024).

Several scholars have also questioned the characterization of dams as clean or renewable energy sources, citing emissions and environmental degradation associated with erosion, deforestation, and sedimentation (Ziolkowski, 2024). Conversely, other scholars contend that dams in arid and semi-arid regions, particularly small structures known as check dams, provide several benefits but these are often ignored (Agoramoorthy et al., 2016). These dams remain crucial for irrigation, flood control, and effective water management (Abdullah et al., 2020).

Studies also highlight negative environmental impacts such as siltation and evapotranspiration, which can intensify land and water conflicts (Verhoeven, 2015). Gleick (2014) argues that mega-dams represent a shift from traditional, community-based water management toward centralized systems aimed at modernization, while ignoring the warnings of ecological risks exemplified by projects such as the Three Gorges Dam in China. From a critical standpoint, mega-dams symbolize technological dominance that disrupts both ecosystems and societies (Goodman & Chant, 1999).

The growing body of literature examines the environmental dimensions of dams, particularly the complex relationship between climate change and dam systems. Scholars have investigated the interactions between hydrological variability, infrastructure resilience, and environmental feedback mechanisms (Barbarossa et al., 2020). Many studies have established a connection between climate change and dams from multiple perspectives. Some focus on projected climate scenarios and their implications for dam performance, safety, and water management efficiency (Loza & Fidélis, 2025). These studies highlight that increased temperatures, shifting precipitation patterns, and extreme weather events can significantly alter reservoir inflows, sedimentation rates, and flood risks—posing serious challenges to long-term operational sustainability (Barbarossa et al., 2020). Other scholars examine the role of dams and reservoirs as sources of greenhouse gas emissions, released through the decomposition of organic matter in flooded zones. Such emissions have been linked to the worsening of global climate change, challenging the traditional perception of hydropower as an entirely clean or renewable energy source (Loza & Fidélis, 2025). These two perspectives underscore the need for integrated environmental assessments that consider both the impacts of climate change on dam systems and the contribution of dam operations to global warming.

In addition, issues of environmental justice arise in relation to who benefits from the dam and who bears the costs with little or no benefit (Ribeiro & Morato, 2020; Sharma & Sharma, 2025). Mega-dams are also situated within an intensive political and global debate regarding their economic, social, and environmental implications. These impacts, particularly their environmental consequences, have been widely documented in the political ecology literature (Kumar, 2024).

Despite these debates, other scholars recognize that in some developing countries, dams have contributed significantly to regional social and economic development. Many have been constructed with the objectives of ensuring water security, providing energy supply, and improving flood protection (Barbarossa et al., 2020). Nonetheless, these benefits are counterbalanced by substantial adverse effects on river ecosystems and habitats, altered flow regimes, degraded water quality, and greenhouse gas emissions from reservoirs. Despite the controversies and negative associations surrounding the environmental impacts of dams, they continue to be designed and constructed worldwide. According to the ICOLD General Synthesis (2020), there are approximately 58,700 large dams globally, with a projected collective storage capacity ranging between 7000 and 8300 km^3 (Mulligan et al., 2020). Some scholars offer a more balanced perspective; Agrawala et al. (2003) suggest that dams can function as carbon-neutral energy sources within broader climate change frameworks. Williams and Samset (2010) similarly note that, despite ideological divides, most stakeholders share a common goal of enhancing human well-being. Nonetheless, the divide persists, often rooted in epistemological differences—supporters tend to adopt a utilitarian stance, while critics emphasize empirical evidence and community-based experiences.

In summary, the literature reveals an evolving debate surrounding mega-dams, environmental impacts, and community perceptions. Numerous factors shape how communities perceive such projects, yet much of the existing research remains focused on macro-level analyses of environmental assessment and economic performance. Less attention has been paid to micro-level perspectives, particularly those of directly affected communities, whose favorable and/or adverse perceptions provide essential insights into the sustainable development discourse surrounding mega-dam projects.

3. Methodology

3.1. The Study Area

The Merowe region in northern Sudan is marked by distinct social, economic, and cultural characteristics (Rigg, 2007). The region covers more than 100 villages and remote islands with rudimentary transport systems, e.g., mule carts, boats, and a limited number of vehicles/cars (Askouri, 2007). Amri and Hamdab encompass islands along the Nile between Dar el-Arab and Et-Tereif, near the Northern-Nile State border. The area is 150 km^2 and remote with rough tracks, high temperatures in the summer (up to 46 °C), and harsh desert terrain (DIU, 2007). Merowe Dam lies 25 km downstream, connected by a new road to Merowe city.

Agricultural operations are limited in this Fourth Cataract region, transitioning into a desert with steep riverbanks. Seasonal migration to central Sudan is common, and residents rely on self-sufficient farming, growing primarily beans, millet, and vegetables for trade and consumption (Barbour, 1966). The main source of income is date palms grown in fertile river silt, and access to infrastructures and services (e.g., schools, hospitals, etc.) is limited (Barbour, 1966). Traditional farming practices, especially among the Manasir and Shagiah tribes, are intertwined with social customs, whereas date palms symbolize pride, identity, and status (Haberlah, 2012).

The Merowe area captures the environmental shift driven by dam construction (Rigg, 2007). Case study research, as advocated by Yin (2003), positions Merowe as a model for examining environmental perceptions of dam-induced change. According to Welzel et al. (2003), such shifts affect livelihoods, social structures, and human development in both upstream and downstream communities. Merowe exemplifies how mega-dams shape economic, political, and environmental transformations (Becker & Murphy, 2009), reflecting broader historical and geopolitical dynamics. Mega-dam projects such as Aswan and Merowe dams continue to invoke painful memories of huge displacement among affected populations (Power et al., 1996) as well as unanticipated environmental impacts.

3.2. Data Collection and Sampling Strategy

The second author conducted fieldwork in the Merowe region from April to September 2017. The study utilized a multi-stage cluster sampling method. In the first stage, the study area was divided into three localities in northern Sudan: (a) upstream-relocated communities; (b) upstream-resident communities near the reservoir, who refused to relocate; and (c) downstream communities affected by water flow changes but not direct displacement. In the second stage, villages in each cluster were chosen to represent different levels of closeness and most likely exposure to the impacts of the dam. The selected villages are: Amri Two and Amri Three from upstream-relocated areas; Al-Kab and Omdwima from upstream-resident communities near the reservoir; and Hamdab West, Al-Degawit, and Nouri from downstream communities, respectively. In the third stage, households in the selected villages were chosen using simple random sampling based on household lists obtained from the local government authority records. Where the list was inaccessible, systematic random sampling was employed by selecting every nth household (e.g., 1–3, 3–6) after a random starting point. This technique ensured that household selection remained random and reduced sampling bias. And later in the analysis, we used cluster-robust standard errors in the estimation procedure to further reduce/eliminate any sampling bias.

A total of 300 households were surveyed from a population of 30,000 using multistage cluster random sampling (100 households per locality). The sample size was calculated using Becker and Murphy's (2009) formula, which produced a minimum optimal number of 264 households, which was then extended to 300 to accommodate non-responses. Cluster sampling was used to minimize geographic and social bias (David & Sutto, 2004). In the two upstream areas, 50 households were randomly selected across four locations. For downstream settlements, 33 households were selected from two villages and 34 households from one village. The survey questionnaire covered demographic information (e.g., family size, occupation, education), land ownership and perception of the Merowe Dam's environmental impacts. The researcher, assisted by four field staff, distributed the questionnaires over two months.

It is important to note that although the data for this study were collected in 2017, the timing of data collection is not critical and unlikely to influence perception, as we have applied advanced econometric models to determine the underlying structural factors influencing perception of three categories of residents of the Merowe dam region. What is more important is to consider whether we have evaluated the perceived impacts of the dam too early, from its inception in 2009. This is because investigation on the perceived impacts of such a large-scale infrastructure project should be conducted after sufficient time has elapsed, i.e., 10 years after the construction of the dam, so that residents are able to experience both the positive and negative aspects of this mega-dam over this extended period. Also, the key issues related to the environmental impacts of the dam remained largely unchanged. Furthermore, an attempt to update the data failed due to political unrest that started in 2019 and escalated even further in 2022.

3.3. Theoretical Framework

Analysis of the awareness and/or perception towards infrastructure and services provided by a facility, such as the Merowe Dam, is rooted in the principle of utility maximization (Rahman, 2003). While the actual utility function—reflecting ranks of individual preferences—is unobservable, what can be observed is a set of socio-economic characteristics that influence perceived utility, shaping respondents' perceptions of the dam's environmental impacts. We posit that demographic, socio-economic and locational factors influence how affected individuals perceive the Merowe Dam's environmental impacts, which are likely to be shaped by personal lived experiences and livelihood changes resulting from its establishment. This is because a resident's perception of the favorable and/or adverse environmental impacts of the dam is likely to be determined by the opportunities and challenges exerted by such a mega-infrastructure project after sufficient time has elapsed from its inception.

3.4. The Econometric Model

Factors influencing respondents' perceptions are best analyzed using limited dependent variable models. This is because the dependent variables, i.e., rank scores of the perception of the environmental impact, are bounded between 1 and 5. The Tobit model is particularly suitable, as it incorporates both censored observations at the limit—typically zero (e.g., no awareness of any environmental impacts arising due to the establishment of the Merowe Dam)—and uncensored observations above the limit (e.g., awareness of the environmental impacts exerted by the Merowe Dam), to estimate a regression line (J. F. McDonald & Moffitt, 1980). The model is expressed as follows (J. F. McDonald & Moffitt, 1980):

$$y_i = X_i\beta + u_i \; if \; X_i\beta + u_i > 0$$
$$= 0 \; if X_i\beta + u_i \leq 0,$$
$$i = 1,\, 2, \ldots\ldots n, \tag{1}$$

where n is the number of observations, y_i is the dependent variable (respondents' awareness of environmental impacts of Merowe Dam), X_i is a vector of independent variables representing attributes of the household and respondent-specific socio-economic characteristics, β is a vector of parameters to be estimated, and u_i is an independently distributed error term with zero mean and constant variance σ^2. The model assumes that there is an underlying stochastic index equal to ($X_i\beta + u_i$), which is observed when it is positive and hence qualifies as an unobserved latent variable. The advantage of the Tobit model, as in Equation (1), is that it captures awareness of the impact as well as the intensity of perception of the environmental impacts, whereas a probit model will provide only information on the awareness of the impact. The relationship between the expected value of all observations E_y and the expected conditional value above the limit $E_y{}^*$ is given by:

$$E_y = F(z)\, E_y{}^*$$

where F(z) is the cumulative density normal distribution function and $z = X\beta/\sigma$.

Extending this proposition further, we postulate that mega-dams do not universally exert only adverse environmental impacts as appears in the literature but that there could also be favorable environmental impacts due to mega-dams. We further assume that perception of the adverse and favorable environmental impacts of mega-dams is not independent, i.e., the same respondent can be aware of both types of impacts of mega-dams. In fact, evidence from data suggests that respondents of all communities are aware of both the favorable and adverse impacts of the Merowe Dam. Therefore, in order to incorporate such dynamics of perception on the environmental impacts of mega-dams, we postulate a bivariate Tobit model:

$$y_{1i} = X_{1i}\beta_1 + u_{1i} \; if \; X_{1i}\beta_1 + u_{1i} > 0$$
$$= 0 \; if X_{1i}\beta_1 + u_{1i} \leq 0, (the\ usual\ tobit\ specification\ as\ in\ 1)$$
$$y_{2i} = X_{2i}\beta_2 + u_{2i} \; if \; X_{2i}\beta_2 + u_{2i} > 0$$
$$= 0 \; if X_{2i}\beta_2 + u_{2i} \leq 0, (the\ usual\ tobit\ specification\ as\ in\ 1) \tag{2}$$
$$i = 1, 2, \ldots\ldots n,$$
$$\mu_{1i},\ \mu_{2i} \approx N\left[0, 0, \sigma_1^2,\ \sigma_2^2,\ \rho\right],\ covariance\ is\ \sigma_{12} = \rho\sigma_1\sigma_1$$

where y_{1i} denotes respondents who are aware of the adverse environmental impacts of mega-dams; y_{2i} denotes respondents who are aware of the favorable environmental impacts of mega-dams; and ρ is the correlation between the error terms μ_{1i} and μ_{2i}. The distributions are independent if and only if $\rho = 0$. The full maximum likelihood estimation procedure is utilized using NLOGIT4 software (Renfro, 2004).

3.5. The Empirical Model

The estimated empirical model includes a set of attributes of respondent-specific socio-economic characteristics and locational characteristics as explanatory variables that are assumed to influence respondents' awareness of the environmental impacts of the Merowe Dam. Table 1 presents the description, measure, and summary statistics of the variables used in the econometric models.

Table 1. Descriptive statistics of the variables used in the econometric model.

Variables	Definition and Measure	Mean	Standard Deviation
Dependent variables			
Adverse Environmental Impact Index	Composite index of all adverse environmental indicators, number	2.076	0.897
Favorable Environmental Impact Index	Composite index of all favorable environmental indicators, number	2.318	1.022
Demographic characteristics			
Age of the respondent	Years	37.500	11.539
Gender of the respondent	Male = 1, Female = 0	0.707	
Primary level education	Yes = 1, 0 = otherwise	0.057	
Secondary level education	Yes = 1, 0 = otherwise	0.030	
High school completed	Yes = 1, 0 = otherwise	0.329	
University-level education	Yes = 1, 0 = otherwise	0.560	
Family size	Number of persons in the family	5.826	2.737
Farming type			
Date palm trees	Date palm = 1, 0 = otherwise	0.534	
Vegetable farming	Vegetable farming = 1, 0 = otherwise	0.046	
Arable crop farming	Arable farming = 1, 0 = otherwise	0.232	
Livestock farming	Livestock farming = 1, 0 = otherwise	0.010	
Socio-economic characteristics			
Proportion of income derived from farming	Percentage	0.483	0.324
Proportion of income derived from fishing	Percentage	0.019	0.088
Proportion of income derived from trade/sales	Percentage	0.079	0.186
Change in land size after the Merowe dam	Percentage	0.196	0.772
Location of respondents			
Upstream resident	Upstream = 1, 0 = otherwise	0.332	
Upstream relocated	Relocated = 1, 0 = otherwise	0.335	
Number of usable observations		298	

Dependent Variable: Respondents' Environmental Impact Awareness Indices

Respondents were asked about a total of 12 indicators related to the environmental impacts of the Merowe Dam. These indicators were derived from reviews of previous studies on mega-dams, soliciting expert opinions prior to the data collection, and the Sudanese economic context. The authors later classified each indicator into favorable and adverse impacts, which effectively avoided bias in responses if residents were asked to rank favorable and adverse impacts of the dam upfront. A set of five indicators representing adverse environmental impact and seven indicators representing favorable environmental impact were constructed to evaluate the impacts of the Merowe Dam. As mentioned earlier, analyzing the perception of the environmental impacts after a number of years following the establishment of the dam in 2009 is more appropriate because residents are now able to reflect on the long-term effects and changes in the lived experiences exerted by the dam.

Box 1 summarizes the construction procedure of the respondents' awareness indices of the impacts of the Merowe Dam. Respondents were first read out the list of indicators and then asked to reveal their opinion on each impact indicator on a five-point Likert scale (R). A score of 1 is assigned for 'strongly disagree' and 5 for 'strongly agree' responses. Then the overall awareness index of the jth impact (AAI_{ij}) for each respondent is computed by summing up the scores of each impact indicator and then dividing them by the total number of indicators used for the jth impact (OAI_{ij}).

Box 1. Construction of the composite indices of favorable and adverse environmental impacts.

Rank of the importance of kth indicator of the jth impact on a five-point scale (R_{jk})	**1**	**2**	**3**	**4**	**5**
Rank interpretation	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Aggregate awareness index of the ith respondent on the jth impact (AAI_{ij})	$\sum\sum_{j=1}^{2}\sum_{k=1}^{7} R_{jk}, \forall j = 1, 2, ; k = 1, \ldots, 7$ (3)				
Overall awareness index of the ith respondent on the jth impact (OAI_{ij})	$\frac{AAI_{ij}}{N}$, *where N = total number of indicators for jth impact.* (4)				

4. Results

Although the core objectives of the Merowe Dam were to promote socioeconomic development through electricity generation, agricultural modernization (e.g., irrigation system electrification) and infrastructure improvements (e.g., educational and health facilities, paved roads, bridges, and communication networks), its establishment also exerted some environmental impacts, not necessarily only adverse impacts.

4.1. Favorable and Adverse Environmental Impacts of the Merowe Dam

Table 2 highlights statistically significant differences in all but one environmental perception indicator across regions. Starting with the adverse environmental impact scores, it is clear that downstream residents are more critical of the negative impacts, with a rank score of 2.34, followed by 2.08 and 1.81 for upstream and relocated residents, respectively. However, participants from upstream and relocated communities expressed different or more moderate views regarding the impacts of mega-dams. The implication is that relocated residents are least critical of the adverse environmental impacts of the Merowe Dam.

In contrast, perception of the favorable environmental impacts of the dam is highest for downstream residents (rank score 2.82), followed by upstream (rank score 2.28) and relocated residents (rank score 1.86), respectively. 'Reduced flooding' due to the establishment of the Merowe Dam recorded the highest scores for all communities, which was regarded as one of the strongest favorable environmental impacts of the dam. Overall, the Merowe Dam is seen as having moderate environmental benefits and limited negative impacts across all regions.

The bottom row of Table 2 presents the Spearman Rank correlation results for the perceived favorable and adverse environmental impacts across the three regions. The statistically significant and positive correlations across all community types indicate that participants share similar views on both the favorable and adverse environmental impacts of the Merowe Dam, although the intensity of such a perception varies. While the Merowe Dam's environmental impact remains debated in the literature, it is clear that study participants acknowledged both its benefits and challenges. Overall, the participants' views reflect the broader debate within the literature, indicating that there is no clear consensus on whether dams are environmentally good or bad.

Table 2. Favorable and adverse environmental impacts of Merowe Dam as perceived by the residents of different regions.

Sl. No	Environmental Impact Indicators	Responses								
		Downstream		Upstream-Resident		Upstream-Relocated		All Region		Differences in Rank Scores
		Score	Std	Score	Std	Score	Std	Score	Std	Kruskal–Wallis
1	Spread of waterborne diseases	1.90	1.17	1.94	1.34	1.97	1.20	1.94	1.23	0.379
2	Increased waterlogging	2.42	1.40	1.94	1.30	1.78	1.04	2.05	1.28	13.241 ***
3	Increased salinization	2.43	1.31	1.92	1.25	1.80	1.00	2.05	1.22	15.160 ***
4	Increased erosion	2.48	1.29	2.10	1.28	1.73	0.89	2.10	1.20	18.463 ***
5	Increased sedimentation	2.46	1.10	2.51	1.58	1.77	0.89	2.24	1.27	18.758 ***
	Overall adverse environmental impacts	2.34	0.97	2.08	0.93	1.81	0.72	2.08	0.90	21.854 ***
1	Habitat communities along the riverbank	3.03	1.49	1.70	1.04	2.05	1.23	2.26	1.38	42.167 ***
2	Diversity of wildlife	2.57	1.27	1.75	1.04	2.06	1.16	2.12	1.20	22.892 ***
3	Forest ecosystem	2.34	1.27	1.86	1.12	1.75	0.92	1.98	1.14	13.412 ***
4	Increase in water supply	2.53	1.23	2.57	1.52	1.83	1.04	2.31	1.32	17.874 ***
5	Increase in water flow	2.83	1.25	2.55	1.48	1.73	1.00	2.37	1.34	34.737 ***
6	Distance to the riverbank reduced	2.88	1.31	2.62	1.44	1.74	1.03	2.41	1.36	38.071 ***
7	Reduced flooding	3.61	1.52	2.90	1.70	1.84	1.22	2.78	1.65	52.089 ***
	Overall favorable environmental impacts	2.82	1.02	2.28	1.00	1.86	0.79	2.32	1.02	52.380 ***
	Spearman rank correlations between favorable and adverse environmental impacts	0.5344 ***		0.6977 ***		0.6339 ***		0.7011 ***		

Note: *** = significant at 1% level ($p < 0.01$).

4.2. Determinants of the Environmental Impacts of the Merowe Dam

Before discussing the econometric results, we present the key characteristics of the sample respondents (Table 1). The average age is 37.5 years, dominated by male respondents, which is in line with the cultural norm in Sudan where approaching female members is somewhat restricted. Respondents have an average of 13.5 years of education, which is unusually high and a household size of 5.82 members. Date-palm farming is the primary economic activity for 53.5% of respondents, followed by arable crop farming at 23.2%. Although income sources are diverse, farming contributes the largest share (48.2%). On average, household agricultural landholding increased by 19.6% after the construction of the Merowe Dam—a positive outcome given the continuing reliance on agriculture.

The result of the full information maximum likelihood estimation of the bivariate Tobit model is presented in Table 3. The lower panel of Table 3 presents model diagnostic test results. Globally, 41% of the estimated coefficients were significantly different from zero at 10% level, at least indicating that inclusion of these variables was correctly justified in explaining the favorable and adverse environmental impacts of the Merowe Dam. Cluster robust standard errors were used in order to control for the effect of cluster sampling of residents. The F-stat results further indicate statistically that these variables contribute significantly as a group to the explanation of the joint determinants of the favorable and adverse environmental impacts of the Merowe Dam. The key hypothesis of "correlation of the disturbance term between the two equations "*favorable environmental impact*" and "*adverse environmental impact*" is zero {i.e., ρ(*favorable*, *adverse*) = 0}" is strongly rejected at the 1% level of significance, implying that the use of a bivariate Tobit model to determine residents' perception of the environmental impacts is justified. This result also confirms that univariate analysis of such perception will lead to biased results. Furthermore, both sigma values were significantly different from zero at the 1% level. Such joint perception analysis using a bivariate Tobit model confirms that perceptions towards the favorable and adverse environmental impacts are not independent, implying that residents are aware of both types of impacts.

Among the demographic variables, age, gender and family size (used as a proxy for dependency pressure) show no significant effect on the perceptions of the dam's environmental impacts. However, respondents with primary and high school levels of education are significantly less likely to agree on the adverse environmental impacts of the Merowe Dam, which implies that education helps shape perception with careful evaluation of the effects the dam has on their lives.

Farmers of all types, i.e., date-palm, arable crop, vegetables, and livestock farmers, are significantly more likely to agree on the adverse environmental impacts. However, at the same time, arable crop and livestock farmers are significantly more likely to agree on the favorable environmental impacts of the Merowe Dam as well. Such results clearly demonstrate that residents from all communities are aware of both the positive and negative environmental impacts arising from the dam.

With respect to income sources, residents deriving income from farming are significantly less likely to agree on the adverse environmental impacts of the Merowe Dam, whereas residents deriving income from fishing are significantly less likely to agree on the favorable environmental impacts of the dam. An increase in agricultural land size arising post-construction of the dam is significantly more likely to have agreement on the favorable environmental impacts, as expected.

Respondents from the upstream-relocated area are significantly less likely to agree on the adverse environmental impacts of the dam, whereas both upstream and upstream-relocated residents are significantly less likely to agree on the favorable environmental impacts of the dam.

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Table 3. Joint determinants of perceived favorable and adverse environmental impacts of Merowe Dam by residents.

Variables	**Adverse Environmental Impact**		**Favorable Environmental Impact**	
	Coefficient	**z-Statistic**	**Coefficient**	**z-Statistic**
Constant	2.20897 ***	3.53	2.46947 ***	2.78
Demographic characteristics				
Age of the respondent	−0.00107	−0.09	0.00504	0.48
Gender of the respondent	0.09341	1.25	−0.00868	−0.04
Primary level education	−0.48114 ***	−2.59	−0.18763	−0.37
Secondary level education	−0.13476	−0.65	−0.00217	0
High school completed	−0.32461 *	−1.69	−0.05199	−0.09
University-level education	−0.11822	−0.86	0.11304	0.18
Family size	−0.00807	−0.18	−0.05305	−0.81
Farming type				
Date palm trees	0.49882 **	2.27	0.56442	1.61
Vegetable farming	0.84641 *	1.75	0.37963	0.59
Arable crop farming	0.55555 *	1.71	0.52142 *	1.69
Livestock farming	1.75834 ***	3.36	1.18003 ***	3.83
Socio-economic characteristics				
Proportion of income derived from farming	−0.29075 ***	−4.65	−0.14445	−1.3
Proportion of income derived from fishing	−1.09015	−1.41	−1.19111 *	−1.9
Proportion of income derived from trade/sales	−0.20756	−0.71	−0.48256	−1.09
Change in land size after Merowe dam	0.05309	1.09	0.07053 **	2.05
Location of respondents				
Upstream resident	−0.12845	−0.62	−0.35307 *	−1.94
Upstream relocated	−0.47438 ***	−3.07	−0.85322 ***	−5.76
Model diagnostic				
F statistic	678.7632 ***			
Correlation between the error terms ϱ (favorable and adverse impacts)	0.69238 ***			
σ_1	0.85916 ***			
σ_2			0.92290 ***	
Non-limit observations	291		291	
Number of observations	298		298	

Note: *** = significant at 1% level ($p < 0.01$); ** = significant at 5% level ($p < 0.05$); * = significant at 10% level ($p < 0.10$).

4.3. Discussion

This paper draws on perspectives from environmental justice, risk perception, and political ecology to understand how communities view and respond to impacts from mega-dam projects. While environmental justice emphasizes fairness and the distribution of benefits and costs, risk perception focuses on how communities understand environmental change. Political ecology provides a broader perspective by situating these perceptions within power relations, economic structures, and development policies (Kumar, 2024). Examining community perceptions of both the favorable and adverse environmental impacts of the Merowe Dam provides a deeper understanding of how large infrastructure projects shape environmental governance, local livelihoods, and perceptions of communities in relation to mega-project development.

Environmental justice is reflected in the perceptions of communities that benefited from the dam, e.g., through farming, irrigation, fishing, etc. However, many communities also perceive mega-dams as having adverse environmental impacts, including erosion, waterborne diseases, and exclusion of the affected communities from decision-making processes (Ribeiro & Morato, 2020). In the case of the Merowe Dam, the notion of environmental justice is relevant because such big infrastructure projects frequently produce uneven outcomes for local communities. Although the dam has created national benefits such as electricity generation, irrigation and economic development, many local communities experienced displacement, loss of livelihoods, ecological disruption, and social change (Sharma & Sharma, 2025). This demonstrates the dual nature of environmental justice, where some people benefit while others bear the costs (Ribeiro & Morato, 2020). For example, the more critical view of the downstream residents (upper panel of Table 2) aligns with critics such as Ziolkowski (2024), who highlights that the environmental impacts of mega-dams—such as biodiversity loss, changed water flow, and climate change effects—have become essential to public discussion and environmental activism. On the other hand, the moderate view of the upstream and relocated communities (upper panel of Table 2) aligns with the other side of the debate, as some scholars offer a more balanced interpretation, believing that mega-dams provide several environmental benefits (Agoramoorthy et al., 2016).

It is also important to explore how local communities perceive, interpret, and evaluate environmental risks related to the Merowe Dam. Community perceptions are formed by their experiences, knowledge, and socio-cultural context, influencing whether they view the dam favorably or unfavorably based on its impact on their lives and the environment (Abdullah & Rahman, 2021). In mega-dam projects, community perceptions of risk often vary from the assessments made by planners and policymakers. Local communities may perceive risks related to environmental degradation, changes in water systems, loss of agricultural land, and long-term ecological costs, although they may also recognize benefits such as improved infrastructure and energy availability (Abdullah & Rahman, 2021; Sharma & Sharma, 2025). As reflected in Table 2, the Merowe Dam has been perceived to have a moderate level of environmental benefits and limited adverse impacts across all three regions. These perceptions reflect the broader debate; as critics such as McCully (2001) warn of ecosystem degradation due to altered flows, limited evidence of severe harm—particularly regarding water flow—partially contradicts such claims. The low scores from upstream communities indicate unclear or minimal perceived impact (Table 2), aligning more closely with the literature suggesting that well-designed dams can offer environmental benefits in the context of climate resilience (Agrawala et al., 2003). The significant and positive correlation of perceived favorable and adverse environmental impacts of the Merowe Dam across all three regions (bottom panel of Table 2) indicates that there is no clear consensus on whether mega-dams are environmentally good or bad. As suggested by Abdullah et al. (2020), in some areas, dams can play a vital role in providing much-needed water and other benefits for various purposes, despite other perspectives highlighting their negative environmental impacts (Ziolkowski, 2024).

Apart from environmental justice and risk perceptions, political ecology also plays an important role in the dynamics of power, governance institutions, and economic interests of different actors that shape environmental outcomes (Abdullah & Rahman, 2021; Fam, 2017). In many developing economies, mega-dam projects are influenced by national development agendas, international funding, and political priorities, which can disregard local communities' voices in decision-making processes. Political ecology helps explain how state-led development strategies and infrastructure investments interact with local environmental and social realities (Kumar, 2024). In the case of the Merowe Dam, the decision to construct the dam was driven by the national agenda to generate electricity for the nation, improve irrigation and other infrastructural facilities in the region, with little regard to the benefits or costs to the local communities affected by the construction of this mega-infrastructure.

Among the determinants of perceptions, the mixed responses of farmer types about the favorable and adverse environmental impacts (mid-panel of Table 3) support studies by Scudder (2012) and Mayeda and Boyd (2020), who found that attitudes toward mega-dams vary based on socioeconomic backgrounds and lived experiences. Those who gain from the establishment of the dam are more likely to perceive environmental impacts favorably, for example, the arable and livestock farmers in our sample, who gained easy access to water resources through the establishment of the irrigation facilities (mid-panel of Table 3).

Our results on the influence of the education variables on the perception of environmental impacts (top panel of Table 3) partially align with the existing literature, which emphasizes the role of education and economic reliance on natural resources in shaping perceptions (Mayeda & Boyd, 2020; Isaacman & Isaacman, 2013; Baviskar, 1999).

However, results on income sources (lower panel of Table 3) are partially in contrast with Sovacool et al. (2012), who noted that communities dependent on natural resources (e.g., farming or fishing) are more likely to perceive dam impacts negatively. The reason may be due to the adverse effects of the dam on fishery resources.

Location matters and significantly shapes perceptions about the environmental impacts exerted by mega-dams. For example, the mixed results by resident categories (bottom panel of Table 3) are consistent with the literature, including Marsden and Murdoch (1994), Abdullah and Rahman (2021), Scudder (2012), and Mahapatra (2003), who found that displacement and resettlement conditions critically shape negative community attitudes towards the establishment of mega-dams.

Overall, the results strongly align with previous studies on the determinants of mixed perceptions toward mega-dam impacts (e.g., Mayeda & Boyd, 2020). The analysis of the joint determination of favorable and adverse impacts suggests that community attitudes toward mega-dam projects are rarely entirely positive or negative.

5. Conclusions and Policy Implications

The present study jointly determines the perception towards the favorable and adverse environmental impacts of the Merowe Dam by affected communities, using survey data from 300 households across upstream, upstream-relocated, and downstream areas. Findings show that perceptions towards favorable and adverse environmental impacts are not independent, but rather significantly related, confirming that affected residents are aware of both types of impacts of the Merowe Dam. Significant and positive rank correlations across both the favorable and adverse environmental impacts suggest similarity in perception intensity, regardless of location. Although upstream-relocated residents are less likely to report the significant adverse environmental impacts of the dam, both upstream and upstream-relocated residents are less likely to report the significant favorable impacts of the dam. Primary-level and high-school-level educated residents are less likely to agree on the significant adverse environmental impacts. An increase in land size after the construction of the dam significantly increases the likelihood of perceiving the environmental impacts of the dam favorably. Farmers of all farm types perceive the environmental impacts of the Merowe Dam negatively, but selected farm types increase the likelihood of perceiving the environmental impacts of the dam positively.

A number of policy implications emerge from these findings. First, enhancing education levels in affected areas will help residents better appreciate the favorable environmental impacts of mega-dam projects. This can be achieved by establishing educational institutions ranging from primary and secondary to college levels, in the affected locations, by the government as well as non-governmental organizations (NGOs). Second, focusing on improvements in agricultural livelihoods—especially land allocation to affected communities—can strengthen support for mega-dam projects. At present, only relocated residents have gained from an increase in land size, but the quality and/or suitability of this new land is not ensured. Therefore, the government can introduce a Restoration of Livelihood Program, aimed at recovering the loss of agricultural land and traditional livelihoods, which many communities experienced. For this, targeted livelihood programs are needed, which are vital for communities to regain their livelihoods through programs, such as irrigation support for small and medium farmers, fisheries development projects in the reservoir area, etc. These types of programs may support a reduction in poverty and increase economic independence with long-term livelihood sustainability. Third, addressing adverse environmental concerns, e.g., waterborne diseases, sedimentation, waterlogging, and erosion, could mitigate negative perceptions of the environmental impacts of mega-dams. For this, a joint government and Community Environmental Monitoring Program can be initiated by authorities and environmental NGOs to establish a community-led environmental monitoring initiative in the Merowe region. Local communities can be trained in understanding key environmental aspects and simple measurements of relevant indicators to oversee any changes in areas such as soil erosion, water quality, fish population, and the spread of waterborne diseases. This participatory method would enhance environmental data gathering, improve transparency, and involve communities in the environmental management of the Merowe Dam. Furthermore, mitigation of environmental health risk, arising mainly from waterborne diseases, needs to be undertaken by the government and specialized NGOs, e.g., the World Health Organization. Such programs could conduct health screenings and disease monitoring; campaigns raising awareness on the environmental health risks; and contribute to the development of rural healthcare facilities in affected villages. These actions can decrease the health risks related to the environmental changes exerted by the dam and can reduce the adverse perception towards the Merowe Dam.

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References

Abdullah, A. N., & Rahman, S. (2021). Social impacts of a mega-dam project as perceived by local, resettled and displaced communities: A case study of Merowe Dam, Sudan. *Economies*, *9*(4), 140. [CrossRef]

Abdullah, A. N., Rahman, S., Essex, S., & Benhin, J. (2020). Economic contributions of mega-dam infrastructure as perceived by local and displaced communities: A case study of Merowe Dam, Sudan. *Agriculture*, *10*(6), 227. [CrossRef]

Agoramoorthy, G., Chaudhary, S., Chinnasamy, P., & Hsu, M. J. (2016). Harvesting river water through small dams promote positive environmental impact. *Environmental Monitoring and Assessment*, *188*(11), 645. [CrossRef]

Agrawala, S., Raksakulthai, V., van Aalst, M., Larsen, P., Smith, J., & Reynolds, J. (2003). *Development and climate change in Nepal: Focus on water resources and hydropower*. OECD.

Alexander, N. (2015). *The age of megaprojects*. Economic Governance at the Heinrich Boell Foundation. Available online: https://us.boell.org/en/2015/08/31/age-megaprojects (accessed on 24 March 2026).

Ansar, A., Flyvbjerg, B., Budzier, A., & Lunn, D. (2014). Should we build more large dams? The actual costs of hydropower megaproject development. *Energy Policy*, *69*, 43–56. [CrossRef]

Askouri, A. (2007). China's investment in Sudan: Displacing villages and destroying communities. In *African perspectives on China in Africa* (pp. 71–86). Fahamu—Networks for Social Justice.

Bai, X., Shi, C., Guo, H., & Shu, P. (2020). Effects of climate change and water conservancy projects on hydrological regime downstream of Danjiangkou Dam. *Advances in Science and Technology of Water Resources*, *40*(4), 1–7.

Barbarossa, V., Schmitt, R., Huijbregts, M., Zarfl, C., King, H., & Schipper, A. (2020). Impacts of current and future large dams on the geographic range connectivity of freshwater fish worldwide. *Proceedings of the National Academy of Sciences*, *117*(7), 3648–3655. [CrossRef] [PubMed]

Barbour, K. M. (1966). Population shifts and changes in Sudan since 1898. *Middle Eastern Studies*, *2*(2), 98–122. [CrossRef]

Basson, G. (2004, October 27–29). *Hydropower dams and fluvial morphological impacts—An African perspective*. United Nations Symposium on Hydropower and Sustainable Development (pp. 27–29), Beijing, China.

Baviskar, A. (1999). *In the belly of the river: Tribal conflicts over development in the Narmada valley*. Oxford University Press.

Becker, G. S., & Murphy, K. M. (2009). *Social economics: Market behavior in a social environment*. Harvard University Press.

Boulange, J., Hanasaki, N., Yamazaki, D., & Pokhrel, Y. (2021). Role of dams in reducing global flood exposure under climate change. *Nature Communications*, *12*(1), 417. [CrossRef]

David, M., & Sutto, C. D. (2004). *Social research: The basics*. Sage.

DIU. (2007). *Merowe Dam project, funding*. Dams Implementation Unit Website.

Everard, M. (2013). *The hydropolitics of dams: Engineering or ecosystems?* Bloomsbury Publishing.

Fam, S. D. (2017). *The political ecology of the Bakun hydroelectric dam* [Doctoral dissertation, Australian National University].

Flyvbjerg, B. (2009). Survival of the unfittest: Why the worst infrastructure gets built—And what we can do about it. *Oxford Review of Economic Policy*, *25*(3), 344–367. [CrossRef]

Gleick, P. H. (2014). *The world's water volume 8. The biennial report on freshwater resources*. Island Press.

Goodman, D. C., & Chant, C. (Eds.). (1999). *European cities & technology: Industrial to post-industrial city*. Psychology Press.

Haberlah, D. (2012). Cultural landscape of Dar al-Manasir. In *Nihna nâs al-bahar—"We are the people of the river": Ethnographic research in the fourth Nile cataract region, Sudan* (pp. 49–74). Otto Harrassowitz Verlag.

Huesemann, M., & Huesemann, J. (2011). *Techno-fix: Why technology won't save us or the environment*. New Society Publishers.

ICOLD General Synthesis. (2020, April). Available online: https://www.icold-cigb.org/GB/world_register/general_synthesis.asp (accessed on 5 March 2026).

Isaacman, A. F., & Isaacman, B. S. (2013). *Dams, displacement, and the delusion of development: Cahora Bassa and its legacies in Mozambique, 1965–2007*. Ohio University Press.

Jackson, S., & Sleigh, A. (2000). Resettlement for China's three gorges dam: Socio-economic impact and institutional tensions. *Communist and Post-Communist Studies*, *33*(2), 223–241. [CrossRef]

Kumar, M. (2024). Violent transitions: Towards a political ecology of coal and hydropower in India. *Climate and Development*, *16*(9), 751–761.

Loza, A. R. A., & Fidélis, T. (2025). Integrating climate change into environmental impact assessments of dams: Insights from three case studies using an analytical model. *Impact Assessment and Project Appraisal*, *43*(1), 33–42. [CrossRef]

Mahapatra, S. K. (2003). Taming the waters: The political economy of large dams in India. *Indian Journal of Agricultural Economics*, *58*(4), 856.

Marsden, T., & Murdoch, J. (1994). *Reconstituting rurality. Class, community and power in the development process*. University College London.

Mayeda, A. M., & Boyd, A. D. (2020). Factors influencing public perceptions of hydropower projects: A systematic literature review. *Renewable and Sustainable Energy Reviews*, *121*, 109713. [CrossRef]

McCully, P. (2001). *Silenced rivers: The ecology and politics of large dams*. Zed Books.
McDonald, J. F., & Moffitt, R. A. (1980). The uses of Tobit analysis. In *The review of economics and statistics* (pp. 318–321). The MIT Press.
McDonald, K., Bosshard, P., & Brewer, N. (2009). Exporting dams: China's hydropower industry goes global. *Journal of Environmental Management*, *90*, S294–S302.
Mulligan, M., Van Soesbergen, A., & Sáenz, L. (2020). GOOD, a global dataset of more than 38,000 georeferenced dams. *Scientific Data*, *7*(1), 31. [CrossRef]
Power, M. E., Dietrich, W. E., & Finlay, J. C. (1996). Dams and downstream aquatic biodiversity: Potential food web consequences of hydrologic and geomorphic change. *Environmental Management*, *20*, 887–895. [CrossRef]
Rahman, S. (2003). Environmental impacts of modern agricultural technology diffusion in Bangladesh: An analysis of farmers' perceptions and their determinants. *Journal of Environmental Management*, *68*(2), 183–191. [CrossRef] [PubMed]
Renfro, C. G. (2004). Econometric software: The first fifty years in perspective. *Journal of Economic and Social Measurement*, *29*(1–3), 9–107. [CrossRef]
Ribeiro, H. M., & Morato, J. R. (2020). Social environmental injustices against indigenous peoples: The Belo Monte dam. *Disaster Prevention and Management: An International Journal*, *29*(6), 865–876. [CrossRef]
Rigg, J. (2007). *An everyday geography of the global south*. Routledge.
Scudder, T. T. (2012). *The future of large dams: Dealing with social, environmental, institutional and political costs*. Routledge.
Sharma, S. R., & Sharma, M. (2025). Environmental justice in hydropower development: Voices of the marginalized in Nepal. *Open Journal of Social Sciences*, *13*(5), 300–324. [CrossRef]
Sovacool, B. K., Valentine, S. V., Bambawale, M. J., Brown, M. A., Cardoso, T. d. F., Nurbek, S., Suleimenova, G., Li, J., Xu, Y., Jain, A., Alhajji, A., & Zubiri, A. (2012). Exploring propositions about perceptions of energy security: An international survey. *Environmental Science & Policy*, *16*, 44–64. [CrossRef]
Verhoeven, H. (2015). Water, civilisation and power in Sudan. In *Water, civilisation and power in Sudan: The political economy of military-islamist state building (African studies)* (pp. I–II). Cambridge University Press.
Welzel, C., Inglehart, R., & Kligemann, H. D. (2003). The theory of human development: A cross-cultural analysis. *European Journal of Political Research*, *42*(3), 341–379. [PubMed]
Williams, T., & Samset, K. (2010). Issues in front-end decision making on projects. *Project Management Journal*, *41*(2), 38–49. [CrossRef]
Yah, N. F., Oumer, A. N., & Idris, M. S. (2017). Small scale hydro-power as a source of renewable energy in Malaysia: A review. *Renewable and Sustainable Energy Reviews*, *72*, 228–239. [CrossRef]
Yin, R. K. (2003). *Case study research design and methods* (3rd ed.). [Applied social research methods series, 5]. Sage.
Ziolkowski, M. (2024). *Mega-dams in world literature: Literary responses to twentieth-century dam building*. University Press of Colorado.