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Environmental and Cultural Impacts of Hydropower Development in Kinnaur

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Abstract: This paper presents a holistic assessment of the environmental and cultural impacts of hydropower development in Kinnaur district of Himachal Pradesh. Examining the planning, construction and operation processes of river-based projects (dams, reservoirs, tunnels and diversions), the study shows that flow control, disruption of sediment mobility and reduction in environmental flows affect aquatic ecosystems, fish breeding, coastal vegetation and stability of slopes; As a result, water quality deteriorates, erosion-landfall risks increase. At the socio-cultural level, land acquisition and resettlement reflects displacement of communities, disintegration of livelihood patterns and erosion of Kinnauri traditions / ethos, while also yielding benefits such as energy supply, infrastructure and employment. It is clear from the study that the distribution of profit and loss is uneven; Marginalized groups are more affected by lack of information, participation and response mechanisms. As a matter of policy, cumulative impact assessment, rigorous environmental flow standards, slope-stability and sediment management, transparent social impact assessment, free, prescriptive and consent-based (FPIC) consultation, cultural heritage mapping, and livelihood restoration are essential. Technically for practical implementation, risks can be mitigated by real-time sensors, adaptive flow operations, low-footprint generation methods and community-based monitoring. In the long run, sustainable models based on climate-resilient, equitable profit-sharing and local participation enable a balance of energy security, ecological conservation and cultural sustainability. In conclusion, hydropower development in Kinnaur is justified only if environmental-cultural boundaries are respected by placing community knowledge at the centre of decision-making and transparent accountability is ensured with adaptive management.

Keywords: Hydropower, Kinnaur, Environmental flows, Displacement, Cultural heritage, Biodiversity, Sustainable development.

Introduction

Kinnaur district is a major part of the Himalayan region, where natural beauty and diverse biological systems are extremely rich. The topography is rich in hills, valleys and rivers, providing favourable conditions for hydropower projects. The process of hydropower development involves controlled blockage of river flows, construction of dams and use of state-of-the-art technologies, thereby meeting the local energy needs

as well as augmenting the national power supply. However, the environmental and cultural impacts associated with the operation of these projects have also been widely observed. From an environmental point of view, natural ecosystems are disrupted due to hydroelectric installations, which has a negative impact on aquatic ecosystems. Changes in water quality can be caused by backwaters, and residential sites can also be affected. This also endangers the ecological balance as there is an increased risk of imbalance in monsoon and water currents. Cultural influences include the displacement of local communities, the erosion of traditions and local traditions, and changes in social structure. This change can be positive for economic development, but also affects cultural heritage and social and traditional lifestyles. It is necessary to balance these aspects so that while meeting the requirement of power generation, environmental and cultural conservation can also be ensured.

Process of Hydropower Development

The process of hydropower development is aimed at producing electrical energy using the water resources available in the region. It begins with the construction of reservoirs and dams, which control the flow of the river. In this process, high-efficiency water turbines are installed, which convert the energy of flowing water into mechanical energy. These turbines are connected to generators to produce electrical energy. Local numbering system, waterways and environmental parameters are constantly taken care of while planning. This process requires continuous monitoring and environmental impact assessment to ensure conservation of water bodies. The implementation of hydropower projects is mainly through tunnelling, dam construction, deforestation and construction of reservoirs, which are adapted to the geographical and climatic characteristics of the region. The role of the local population is crucial in this regard, as the successful conduct of projects is dependent on their cooperation and understanding. Diagnosis of affected objects is carried out at the beginning of the projects, with appropriate analysis of water flows, ecosystems and social structures. During this process, local communities are sensitized and their interests are protected as and when required. While pursuing this development process, it is imperative to keep in mind environmental protection, social stability and sustainability so that hydropower projects provide long-term benefits.

The Geography of Kinnaur

The district of Kinnaur is located in the north-western part of Himachal Pradesh, which is known for its geographical diversity and distinct landscape. The region is part of the dense mountain ranges of the Himalayas, with high peaks, deep valleys, rivers and waterfalls predominating. The topography of Kinnaur is rapidly changing, comprising high hills, steep slopes and fertile valleys. The rivers, including the main water source, flow at a rapid pace, providing a suitable base for hydropower projects. The climate of the region is mostly temperate, with heavy snowfall and heavy rainfall in winter. Due to this geographical structure, the number of permanent residents in Kinnaur is limited, and the lifestyle here is based exclusively on mountain traditions and agriculture. Also, the natural surroundings and unique biodiversity make this region unique. With the proposed development of hydropower projects, the impact of the geographical features here will not only help in power generation, but will also bring significant changes at the environmental and cultural level. These development works are required to follow sustainable measures and precautions so as to conserve natural resources and ensure uniqueness of the area.

Environmental impact

The major concern in the environmental impacts of hydropower projects is the impact of rivers on the ecosystem. During construction work, the flow of rivers can be blocked,

which affects the water channels and the surrounding flora and fauna. The lifespan of many local aquatic and fish species can be affected, as changes in flow and fluctuations in water level damage their habitat. At the same time, dam construction disrupts the natural cycle of water flow, which imbalances the ecology of the area. Hydropower projects can also affect the stability of the land due to soil erosion and unnecessary water conservation, which can increase the incidence of landslides. Additionally, plantations and biodiversity around the catchment area are damaged, thereby weakening the balance of the local ecosystem. River changes also cause changes in water quality, such as a decrease in the oxygen content of the water, which poses a threat to aquatic life. The biggest environmental threat of these projects is the permanent crisis of water resources, which can also become a serious problem for socio-economic life. Environmental protection requires that these projects are implemented within the provisions, and sustainable plans are made to conserve the ecosystem. At the same time, environmental impacts can be minimized with the participation and awareness of local communities, so as to ensure conservation of natural environment along with development.

(a) Impact on Ecosystem

The implementation of hydroelectric projects in Kinnaur has had a profound impact on the ecosystem. The energy generation work from the projects involves the construction of large dams and reservoirs, which affect the direction and flow of natural water flow. This disrupts the natural cycle of the river, endangering the lives of aquatic animals and plants. The altered flow zone of the water habitat harms the local fish species, thereby reducing biodiversity. At the same time, the destruction of wildlife habitat areas occurs during dam construction, threatening the survival of many species. Their migration routes are disrupted, disrupting their life cycle. Pollution of underground and surface water sources occurs during construction work, which affects soil and water quality. As a result, an imbalance is created in the natural ecological balance of the river, which has a negative impact on the entire environment. Geo-spatial changes due to hydropower projects and static changes of water currents can disturb the balance of the local ecosystem, leading to disruptions in ecological activities. Thus, these deep-rooted changes in the structure and functioning of the ecosystem not only result in loss of natural resources, but also lead to permanent environmental challenges.

(b) Changes in Water Quality

Implementation of hydropower projects results in significant changes in the water quality of water sources. Primarily, the machinery, equipment and chemicals used during construction and operation have an impact on water sources. Construction activities can lead to a mixture of impurities in the water, including heavy metals, alkali-based chemicals, and harmful solid particles. These chemicals and pollutants disrupt the natural biological and chemical cycle of rivers and lakes, which can lead to low water sanitation levels. In addition, the pumping and withdrawal of water due to power projects also leads to imbalance in the flow of water, affecting the continuity and quality of water. As a result, the life of aquatic fauna and flora is endangered, as they face polluted and unstable water sources. In addition, unnecessary and excessive pollution in water sources not only disrupts the balance of ecosystems, but also affects the water use regime of local communities. The long-term impact of these changes in water quality adversely affects economic activities, health indices and environmental protection efforts. In the absence of proper management, these water quality problems can become permanent and complex, making it extremely important to take care of both sustainability and sensitivity in Himalayan regions like Kinnaur.

(c) Ecological Balance

With the development of hydroelectric projects in the Kinnaur region, the balance of the ecosystem has been affected in a wide and complex manner. During the construction and operation of hydroelectric power plants, the habitat and lifestyle of terrestrial and aquatic organisms have changed. River flow cuts and stagnation in water levels are affecting the reproductive cycle of fish and aquatic life, weakening the natural stability of the ecosystem. Moreover, the establishment of hydropower plants has increased the pressure on the flora and fauna biodiversity of the valley, making conservation of some species difficult. Irregularity in water flow, change in water quality and obstruction of natural flow of the river are unbalancing the ecological balance. These changes affect the ecosystem along the rivers, which is a matter of concern for the biodiversity and environmental sustainability of the region. The migration of local plant and animal species is also being affected, which poses a threat to the integrity of the ecology. At the same time, changes in water flows from hydropower projects are increasing environmental pressures, affecting geometrical and water conservation processes. As a result, the challenges of managing and conserving natural resources are emerging. Thus, with hydropower development affecting the ecosystem balance, it has become extremely important to follow necessary measures for conservation of local life forms and biodiversity, so that development work is possible while preserving the environment.

The construction of hydroelectric projects in Kinnaur district has a profound impact on the social and cultural life of the local communities. The language, traditions and cultural rituals associated with these projects change, which can jeopardize the preservation of cultural resources. The traditional festivals and activities in the affected areas present a changed scenario, with a direct impact of the hustle and bustle brought about by the hydel projects. At times, these projects encroach upon local traditions and historical sites, leading to a cultural heritage crisis. Such projects can create obstacles in preserving the cultural identity and values of communities, especially when local communities do not naturally adapt to these changes. On the other hand, some projects are economically viable as well as capable of generating new cultural activities and contacts, but it is necessary to maintain a balance. It is necessary to preserve local traditions so that along with development, cultural heritage can also be protected. For this, the government and non-government institutions should make concerted efforts so that the original culture and traditions can be preserved. This keeps the socio-cultural fabric of the local communities strong and the process of development can also prove to be beneficial for all. The importance of social consciousness and participation becomes particularly evident in this context, where efforts related to cultural preservation can gain acceptance. In short, the cultural impact of hydropower projects not only poses new challenges, but also identifies barriers to the preservation of society's traditions and heritage, which require appropriate attention at the government and local levels.

(a) Impact on Local Communities

Hydropower projects in Kinnaur have had a profound impact on local communities. Due to these projects, the traditions, lifestyle and cultural heritage of various societies are in danger of being damaged. In particular, tribal groups living in high mountain areas are struggling to preserve their traditional customs, festivals and local languages, while the influence of the new economic and technological culture is spreading rapidly. These projects have led to the displacement of many villages, shattering the social fabric of local communities. This has affected their traditional way of life, agricultural system and local beliefs. Many younger generations have turned away from traditional

customs as the basis of their lives is changing. Additionally, the economic inequalities that have developed in local communities are a matter of concern, where some are benefiting from energy projects, but most remain disadvantaged due to lack of employment and awareness as expected. It has become necessary to reconcile the cultural trends and economic shifts that occur in the implementation of these projects, so as to ensure the preservation of local distinctiveness and autonomy. At the same time, the participation and involvement of local communities in decision-making should be encouraged so that they can both preserve and benefit economically from their cultural heritage. In the absence of these efforts, the long-term positive impact of hydropower development may come under doubt if the social and cultural context of local communities is completely ignored.

(b) Preservation of Culture and Traditions

The environmental impact of the increasing proliferation of hydroelectric projects in Kinnaur district is not only evident, but these projects have also had a significant impact from a cultural point of view. Special initiatives have become necessary to protect and preserve the traditions, customs and cultural heritage of the local communities. Preservation of traditional festivals, religious events and folk art is an important means of preserving the cultural identity of the region. Preservation of these traditions is possible only through awareness and education, with the main step being to make the local youth aware of the importance of these diverse cultural dimensions. At the same time, migration due to hydroelectric projects and change in the traditional lifestyle of the natives have been observed, which are hindering the preservation of these traditions. Therefore, the project developers and the government should take up awareness programmes in this direction so as to ensure preservation of cultural values. Conservation of these cultural heritages can be sustained through community-based conservation programmes, creation of local cultural centres and promotion of traditions. Thus, in the absence of strong policy and social participation, there is a danger of fragmentation and extinction of these traditional customs, which can damage the cultural diversity of the region. Therefore, it is necessary to strike the right balance between the environmental and cultural impacts of hydropower projects so that along with development, traditions are also preserved and the cultural heritage of the region remains intact.

(c) Economic Development and Cultural Transformation

The development of hydroelectric projects in Kinnaur district has led to an upsurge in economic activities, leading to increased employment opportunities in the local communities. New infrastructure and projects have diversified the region's economy, encouraging local businesses. This has not only improved the income but the wealth of the region has also been filled with new possibilities. Despite this, the impact of these economic advances is also being felt at the cultural level. Rapid changes have been observed in traditional lifestyle and cultural values. The underground lifestyle and local festivals have begun to decline, as traditional practices have become less common than new jobs and modern lifestyles. Cultural differences between different communities have also emerged, with more visible Western influence. In this changing scenario, preservation of traditions has become challenging, while new exchange process has also come into existence due to economic development. It has become a necessary task to strike a balance between local traditions and economic recovery, so that both the prosperity and cultural heritage of the region can be preserved. At present, the focus is not only towards economic progress, but also ensuring respect for cultural values, so that cultural identity is also preserved along with development. In this process, balanced development is sought through government policies, community

awareness and local organizing.

Advantages of Hydroelectric Projects

Evaluating the benefits of hydel projects, it is evident that these projects significantly contribute to the energy security and economic prosperity of Kinnaur district. Firstly, through these projects, renewable energy generation in the region increases significantly, making power supply sustainable and reliable at the local level. This not only meets the domestic energy requirements but also enhances the industrial and commercial activities. In addition, hydroelectric projects also provide local employment opportunities. Activities such as construction, operation, and maintenance create jobs that ensure the economic stability of the local community. These jobs are not only long-term but also help in skill development, thereby empowering local talent. In addition, these projects also see the development of related infrastructure, such as roads, communication networks, and better management of water resources, which promote social and economic development. In particular, disaster management and emergency situations also provide stability, as local energy resources can be used seamlessly. In order to reap the benefits of these projects, it is essential that local communities are given participation in the schemes and their needs and traditions are respected. This strengthens social support for projects and ensures long-term sustainability.

The main attraction of the hydroelectric projects in Kinnaur is the potential for energy generation. Through these projects, the contribution of green energy in the country increases along with meeting the regional energy requirements. This energy generation process mainly involves the creation of reservoirs and controlled flow of water flow, from which electricity is generated through turbines. This system is considered to be highly efficient and sustainable, helping to sustainably meet the energy requirements of the region. The energy generated from hydropower projects is used in industrial, domestic and transport sectors, which play an integral role in the economic development of the region. Additionally, this potential of hydropower promotes energy independence in the region, leading to stability and reliability in power supply. However, the impact on environmental and cultural structures has also been observed with these projects. The construction of hydroelectric power plants can have an impact on regional water flows and ecosystems, in which the life of fish and other aquatic creatures can be affected by changing water currents.

National hydropower projects have reinforced the opportunity for direct economic benefits to local communities. The employment supply is mainly in construction works, technical works and operations related activities, which open up new employment opportunities for the local people. This not only improves their economic condition but also leads to development of basic amenities at the local level, such as expansion of road, health and education services. In addition, the technical and managerial skills associated with hydropower projects are also helpful in the skill development of local youth. Appointment of trainers and experts during the projects gives an opportunity to the local talent to get training, thereby making them self-reliant in future.

Losses of hydropower projects

Losses of hydropower projects in Kinnaur give rise to several serious environmental and social challenges. First, these projects can lead to a permanent water crisis, as the construction of reservoirs and the demand for more water can dry up traditional water sources, which not only affect the local ecology but also adversely affect agriculture. This reduces the availability of water in the area, which is dangerous for both the water-driven lifestyle and the ecosystem. On the other hand, due to hydroelectric projects, large tracts of land have to be settled, necessitating the

displacement of the local population. To deal with this, many times communities have to move away from their home - family and traditions, which leads to cultural instability. These projects also face environmental hazards during construction, such as degradation of natural sites, forest impacts, and loss of biodiversity.

The topic of permanent water crisis remains a major concern during the implementation of hydropower projects. Due to the geographical features of the Himalayan region, the volume and flow of water resources here are highly variable, which increases the pressure on permanent water sources. During the construction and operation of hydropower infrastructure, water needs to be stored, controlled, and flow altered, which can affect regional climate and water availability. The quantity of water may appear relatively stable in the initial phase of the projects, but the long-term effects may lead to irregularity in water flow and drought-like conditions. This in turn affects local livelihoods and traditional ways of life, disrupting the natural dynamics of the river. Excessive water storage and controlled flow can lead to depletion of groundwater table, deepening the existence of water crisis in the region. In addition, it is common for water storage to dry up streams and springs, endanger the survival of aquatic life, and create obstacles to soil irrigation.

The implementation of hydel projects is an important phase of displacement of local population especially in hilly areas like Kinnaur. In the process, many villages and communities are shifted away from their traditional habitat due to geographical barriers and environmentally challenging conditions. This rehabilitation process often affects the dialect, language, cultural heritage and traditions of the state in the absence of necessary planning and supervision. Excessive displacement leads to the breakdown of social fabric, affecting the solidarity and cultural continuity of communities. Many families are forced to leave their historical and religious sites, while displacement also negatively affects their employment, education and family ties. In this process, not only the traditional lifestyle and social structure of the local people are disturbed, but they also face difficulties in living according to new needs in new places. Lack of government schemes and projects and the absence of local communities complicate the problems of displacement, which threatens to erode their core cultural and social values.

Future direction

The inclusion of sustainable and sustainable aspects of hydropower development in the future direction is very important. The use of latest technologies and environmental conservation measures are required to strike a balance between the evolving environmental and cultural factors. Developed countries and local communities must work together to explore sustainable energy sources to meet the growing demand for energy. At the same time, conservation of local water resources and sustainability of ecosystem should be ensured while planning hydropower projects. At the time of environmental impact assessment, microscopic inspection and re-assessment of impacts is necessary to avoid unnecessary losses. Preservation of cultural heritage in the society should also be the main priority. The traditions and customs associated with it should be consciously promoted so that it can discharge international standards and cultural plurality. Participation of local communities should be encouraged through better policy frameworks and related protocols. In this view, promoting innovation, transparency and community participation is essential for achieving the Sustainable Development Goals, both in government and in local governance. This will not only increase energy production but also ensure social and economic stability. In the future, the benefits of hydropower projects will be sustainable only when the synergy of environmental protection, cultural promotion and social

inclusion is established. This requires renewable technology, harnessing of local resources and long-term discipline so that the impact of strategies is long-lasting and inclusive. Sustained efforts towards technological advancement and policy reform are, therefore, necessary, with due regard to sustainable development and socio-environmental interests.

Ensuring implementation of hydropower projects is essential for sustainable development. It should ensure long-term benefits by carefully assessing environmental and cultural impacts and adopting appropriate measures. Firstly, the latest technologies should be incorporated in the design of the projects while minimizing the environmental impact. This can reduce the pressure on the ecosystem and ensure the protection of life-giving natural resources. Strict adherence to regulatory regimes is necessary to maintain balance in water flow and water quality. At the same time, local communities should be sensitized to conserve and restore natural water sources. This will ensure their participation and help in environmental protection. From the cultural point of view, the preservation of local traditions and historical sites is essential during the implementation of projects, so that cultural identity and heritage are not violated. It is important to respect the lifestyles and traditions of the local communities and ensure their participation in change as per their needs. This will maintain social stability and allow us to continue to evolve with cultural change. To strike a balance with economic and social development, sustainable and inclusive models of projects must be built.

Inclusion of latest technologies in modern hydropower projects has become extremely important for mitigating environmental and social impacts in hilly areas like Kirnora. These technologies are being used at various stages of site selection, construction, operation and conservation, thereby improving both sustainability and efficiency. For example, realistic geology and geotechnical tools are used to accurately analyze elevation and catchment area, leading to better designs. At the same time, high-definition computational simulation software is used to create accurate models of water flow, allowing immediate estimation of environmental impacts during construction. The latest technologies include the use of smart sensors that continuously monitor water level, water flow and pollutant levels. This ensures sustainability of energy production as well as water quality, and immediate corrective steps can be taken as required. In order to reduce long-term environmental impacts, systems for automatic regulation of environmental flows are also being adopted, which help in maintaining ecosystem balance.

Conclusion: The development of hydroelectric projects in Kinnaur is having a serious impact on the environmental and cultural environment. From an environmental point of view, the ecosystem is undergoing changes, the area of agricultural land is decreasing, and water quality is declining. Due to the dams built on the streams, the flow of water is being blocked, which is harming the aquatic creatures and wildlife. Additionally, degradation of water sources and soil erosion are also adding to the environmental challenges. On the other hand, in the cultural context, the lives and traditions of local communities are being affected. Displacement has threatened the survival of many traditional practices and altered the social structure of communities. It has also become a challenge to preserve their cultural values. Economically, these projects have provided new employment opportunities, leading to overall development in the region. However, on the contrary, some places are also witnessing permanent water crisis and unbalanced distribution of resources. Policy initiatives and mutual participation are essential for the success and sustainability of these projects. Government policies as well as the involvement of the local administration and

community are imperative so that the benefits of the projects are maximized and the losses are minimized. In the future, the latest technologies should be used with sustainable development in mind, thereby ensuring environmental and cultural protection. These efforts are aimed at development as well as appropriate conservation of ecological and cultural heritage, so that local communities feel equally supported and protected.

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