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Conservation and management of water resources for sustainable development in mountain ecosystem: a case study of Dewal Block, Uttarakhand, India

Conservação e gestão de recursos hídricos para o desenvolvimento sustentável em ecossistema montanhoso: um estudo de caso em Dewal Block, Uttarakhand, Índia

Arvind Kumar[1], Bindhy Wasini Pandey[2], Abhay Shankar Prasad[2], Usha Pathak[3], Amit Kant Awasthi[4]

1 - University of Delhi, Delhi School of Economics, Department of Geography, Delhi-110007, India.

2 - University of Delhi, Dyal Singh College, Department of Geography, Delhi-110003, India.

3 - University of Delhi, Delhi, Kalindi College, Department of Geography, India.

4 - University of Delhi, Dyal Singh College, Environmental Science, Delhi, India.

* Corresponding Author: Abhay Shankar Prasad (abhaydse@hotmail.com). Department of Geography, Dyal Singh College, University of Delhi, Delhi-110003.

E-mail: arvindkumardse@gmail.com , bwpdsegeo@gmail.com, abhaydse@hotmail.com (corresponding author), ushakpathak@gmail.com, awasthiak2@gmail.com.

Abstract: **Introduction**. Human activities cause ongoing disruption to natural systems and affect the way rivers behave in mountain ecosystems. Growing population, depletion of resources, changes in consumption, economic expansion, and unsustainable farming practices put immense pressure on natural and water resources. **Objective**. This paper examines the impact of water resources on natural resources and the livelihood of local people using traditional and new scientific techniques adopted by the locals. **Methodology**. A Participatory Rural Appraisal (PRA) involved research in different villages to understand the actual conditions of natural resource management and the livelihood options of key stakeholders. **Results**. The Dewal Block, Uttarakhand, India, has abundant natural resources that can meet the daily needs of local people. While the area receives sufficient rainfall, water drains to foothills due to steep slopes, lack of vegetation, and inefficient use of modern technology. Local communities have developed innovative techniques that are culturally accepted, economically feasible, and highly efficient. These include the *chal-khal* system, pit technology, *guls/kuls*, among others. **Conclusion**. The techniques help to enhance the living standards of the locals by actively involving them in the water resource management process. This facilitates ecological restoration, stream rejuvenation, and sustainable livelihood generation.

Resumo: **Introdução**. As atividades humanas perturbam continuamente os sistemas naturais e afetam a forma como os rios se comportam nos ecossistemas montanhosos. Crescimento populacional, esgotamento de recursos, mudanças no consumo, expansão econômica e práticas agrícolas insustentáveis pressionam os recursos naturais e hídricos. **Objetivo**. Este artigo examina o impacto dos recursos hídricos nos recursos naturais e na subsistência da população local, utilizando técnicas científicas tradicionais e inovadoras adotadas pelos habitantes locais. **Metodologia**. A Avaliação Rural Participativa (ARP) envolveu investigação em diferentes aldeias para compreender as condições reais da gestão dos recursos naturais e as opções de subsistência das principais partes interessadas. **Resultados**. O Bloco Dewal, em Uttarakhand, Índia, possui recursos naturais abundantes que podem atender às necessidades diárias da população local. Embora a área receba chuvas suficientes, a água escoa para os sopés devido às encostas íngremes, à falta de vegetação e ao uso ineficiente da tecnologia moderna. As comunidades locais desenvolveram técnicas inovadoras, culturalmente aceitas, economicamente viáveis e altamente eficientes. Incluem o sistema *chal-khal*, tecnologia de poços, *guls/kuls*, dentre outros. **Conclusão**. As técnicas ajudam a melhorar o padrão de vida dos habitantes locais, envolvendo-os ativamente no processo de gestão dos recursos hídricos, o que facilita a restauração ecológica, o rejuvenescimento dos riachos e a geração de meios sustentáveis de subsistência.

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Introduction

The ecosystems of the mountains offer a range of benefits, including agriculture, medicine, food security, industry, spiritual and cultural significance, and recreational opportunities. However, human activities such as unscientific development, road construction, and agriculture extension can cause ecological challenges and hydrological imbalances. Water is one of the essential natural resources, alongside land, forests, and wildlife, that is crucial for sustainable livelihoods and food security (Saurabh et al., 2022). It is instrumental in increasing crop yield, promoting agriculture diversification, reducing rural poverty, and facilitating holistic regional development. *Dewal Block* is endowed with natural resources that can meet the basic needs of its inhabitants. The primary livelihood options include agriculture, livestock rearing, and forest products, which rely heavily on the availability and distribution of water (Singh, 2009). Water and forests are intimately connected, as forests play a crucial role in the natural recharge of water by regulating the hydrological cycle (Niti Aayog Report, 2017).

Water in the region mainly comes from precipitation and the melting of glaciers. During the monsoon months, most of the surface water comes from plentiful rainfall. Due to steep slopes, physiographic challenges, and poor management strategies, most of the water drains into the valley under the influence of gravity. These challenges are causing negative effects on the socio-economic condition of the region. The growing population, changing consumption patterns, and expanding economy are putting significant pressure on the available natural resources. Additionally, the overexploitation and mismanaged use of water in the irrigation and agricultural sectors are worsening the situation (Pandey & Anand, 2021). The volume of water changes seasonally, and deforestation and surface runoff pose significant threats to water in the region.

The reduction in water quality poses a threat to the availability of portable water and can lead to health hazards, particularly for vulnerable groups such as women, children, the elderly, and those living in poverty. Water-borne diseases such as cholera, typhoid, and malaria are more prevalent in such conditions. The region is prone to cloud bursts and heavy rainfall, which often results in flash floods that cause environmental degradation. Soil pollution is mainly caused by soil erosion, including sheet and gulley erosion, and sewage, which negatively impacts soil fertility and water quality. The decreasing soil fertility affects agricultural productivity, limiting livelihood opportunities in the area. To combat erosion, the local community has adopted terrace farming, which has helped to some extent. However, they continue to face challenges (Mirana, et al., 2017).

Water quality can be negatively affected by both natural and human activities. Natural causes, such as cloud bursts, heavy rain, and surface runoff from flash floods, can increase the velocity and volume of water, carrying hazardous materials and debris into the water. This pollution makes the water unsuitable for use, particularly in low-lying areas during the monsoon season. Anthropogenic causes, such as road construction and deforestation, also contribute to water pollution and increase the risks and hazards in the region. Water pollution can lead to water scarcity, which is a serious concern (Bahadur, 2000).

The local communities are facing a significant challenge due to water scarcity. The limited water supply is insufficient for agricultural production and to reduce rural poverty in the region. The lack of modern technological knowledge prevents people from using natural resources to their full potential, hindering the growth of various economic sectors. Poor water management is a significant obstacle to the holistic development of Dewal Block, Uttarakhand. The region experiences erratic rainfall patterns, causing uneven distribution of water and flash floods. During dry months, crops are at risk due to a lack of soil moisture, making timely sowing and harvesting difficult. Natural vegetation, agricultural production, and horticulture are significantly affected by this situation, with crop failure being a common phenomenon that adds to the plight of marginal and small farmers.

The local water spring is a vital source of water for the village's daily needs. However, over the past few decades, there has been a noticeable decrease in the availability of water from springs and other sources. This situation poses a significant challenge for the villagers and raises concerns about future water scarcity. Therefore, it's essential to manage rainwater and natural springs sustainably, with a focus on environmental, economic, and social sustainability (Rawat et al., 1997). The growing population and water scarcity demand efficient water management to meet the needs of the community. In light of current consumption patterns and freshwater supply, water scarcity is expected to increase over the coming years (Ali and Jain, 2007). It is crucial

to prioritize sustainable water management to meet future generations' demands, as outlined in Goal 6 (clean water and sanitation for all) of the Sustainable Development Goals.

Ensuring the sustainable use of water is crucial for the overall development of the region. Unfortunately, there are growing imbalances between the demand and supply of water, high surface runoff, and a decrease in the quality of surface water. These issues have brought water concerns to the forefront (Bera and Das, 2021). People have been using this resource without any restrictions, and the lack of care in conservation has resulted in serious depletion. This is causing water to become a scarce resource, even with abundant rainfall. The shortage is measured in terms of the amount of water available for economic and social purposes (Tiwari and Joshi, 2012). The current demand and supply of water are insufficient to meet the growing population's needs. It is vital to establish a new equilibrium that promotes the efficient use of water through modern tools and techniques while considering local culture, geo-environmental conditions, and institutions (Bandooni et al., 2017). The region is blessed with abundant water resources, receiving an average of 100cm to 200cm of rainfall during the monsoon months. The winter season experiences cool temperatures and receives 20cm to 30cm of rainfall and snowfall, which nourishes glaciers, natural lakes, springs, and rivers, ultimately enhancing the region's natural beauty. However, water scarcity is becoming a growing concern within the region due to steep gradients, deforestation, barren lands, and anthropogenic interference that rapidly changes land use and land cover. This has resulted in high surface runoff, leading to soil erosion and decreased vegetative cover in some parts of the area. Consequently, springs and rivers are experiencing a decrease in their water flow, even though a large volume of water drains into valleys and plains without being utilized locally (Das, 2015, Pandey et al., 2017).

In today's world, it is crucial to conserve water and other related resources sustainably. The sixth goal of the SDGs emphasizes the efficient management and conservation of water. Sustainable water management relies heavily on the participation of local communities. The central principle of sustainable development is to promote development without causing destruction. It aims to establish a balance between society, the environment, and the economy by implementing maintenance and development mechanisms that meet human needs. This must be achieved without exceeding the carrying capacity of the ecosystem. The primary objective is to ensure long-term benefits from the resources available locally, which can be used to foster holistic rural development (Hussain et al., 2014). Moreover, it plays a critical role in reducing rural poverty and halting out-migration by promoting the sustainable utilization of natural resources, particularly water resources.

The Study Area

The study area chosen was the *Dewal*, Uttarakhand, India which is part of the Chamoli District in the Garhwal division of Uttarakhand. The block is located 57 km south of the district headquarters, Gopeshwar, and 182 km west of the state capital, Dehradun (Fig. 1). It is bordered by Tharali block to

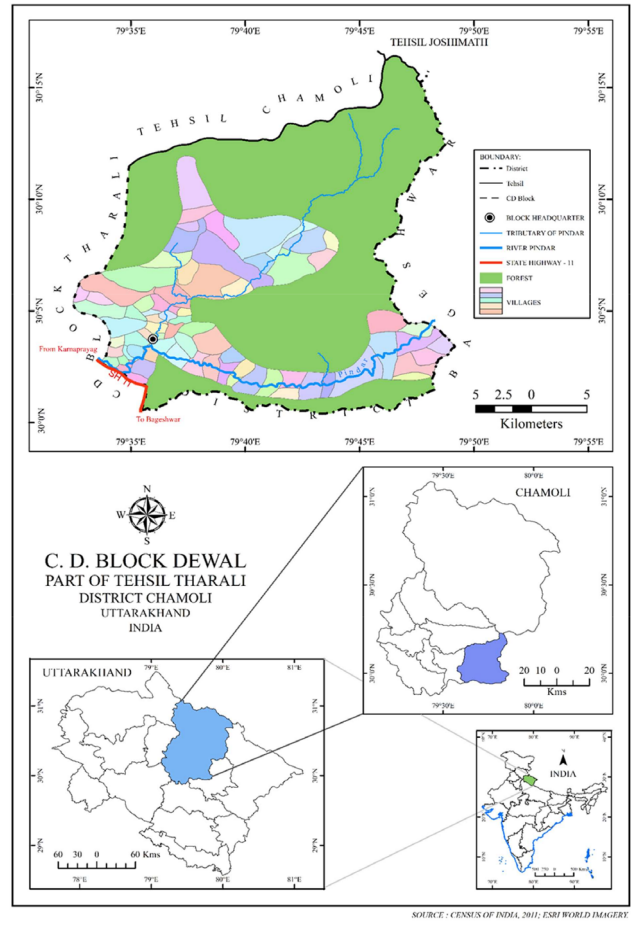

Figure 1. The Study Area, Dewal Block, Uttarakhand, India. Source: Census of India (2011)

the west, Garur block to the south, and Ghat block to the north, while also sharing a boundary with the Bageshwar district to the east. The region is geologically active and consists of foundational rocks such as gneiss, granite, and schist.

Dewal's drainage pattern is a component of the Pinder catchment sub-basin, and as a result, it boasts an abundance of flora and fauna. However, illegal poaching has become a prevalent issue in the area, leading to the extinction of various species. The excessive exploitation of resources and forest degradation has also diminished the forests' ability to regenerate, resulting in long-term negative impacts on the environment, society, and economy.

Database and Research Methodology

Both qualitative and quantitative methods have been used in the study and was conducted through a household survey using a random sampling method. Four villages, two at higher altitudes and two at lower altitudes were randomly selected out of the 72 villages in Dewal Block. Data was collected from respondents based on their personal narratives, beliefs, and experiences, and analysed using individual responses. The data collection process involved questionnaires, observations, group discussions, and face-to-face interviews. Quantitative data was obtained through direct observation, focus group discussions, and in-depth interviews with the community.

The questions included in it focused on the perception of people, level of awareness about the water resource, livelihood security through water conservation utilization, and government policies and schemes regarding water conservation and management. Secondary data used in the study include the census handbook of Chamoli District, villages, and town directory (2011), a socio-economic review of various years along with a statistical handbook/magazine provided by the Uttarakhand Government through its various official websites, etc. Subsequently, Participatory Rural Appraisal (PRA) at different villages was conducted to understand the actual conditions of natural resource management, water resources and the livelihood options of key stakeholders.

Results

Water is a vital natural resource, alongside land, forests, and wildlife. It plays a crucial role in increasing crop yields and reducing rural poverty, making it essential for sustainable development. The region is blessed with natural sources of water, including precipitation, glaciers, and surface water. However, groundwater is scarce and challenging to harness. Fortunately, most households are located near canals or rivulets, and local communities have used surface water for daily consumption for centuries. When selecting water sources, distance from settlements, water quality, and associated risks are all considered. Living close to the water source makes it easier to carry out daily activities and feed livestock, especially in undulating topography where collecting water can be a challenge.

In mountainous areas, modern technology has made it possible for people to live far from the water source by supplying water through pipelines. However, the location of settlements is still largely determined by the availability of water. Most households are situated near canals and rivulets, as surface water has been the primary source of daily consumption for centuries. Accessibility to water is crucial as it is collected directly from the source and used for domestic purposes such as drinking, cooking, washing clothes, and feeding livestock. Not all sources of surface water are safe for use, prompting people to collect water from alternative sources.

During the monsoon season, the region benefits from an increased water supply that not only satisfies human needs but also replenishes soil moisture. Forest uses monsoon water directly. It is reviving time for various types of flora in the forest. Trees require water for their growth and development provided by precipitation (Srivastav et al., 2021). Generally, high rainfall provides sufficient water supply at least seasonally and feeds surface water and groundwater. Rivers in the area flow rapidly from high mountains, which naturally purifies the water through mechanical and oxidation processes. All rivers are fed by snowmelt and are perennial, while small seasonal rivulets and *"gadera"* provide relief to locals (Singh, 1997). Although some of this water may not be safe for drinking and cooking, it can be used for washing clothes and animal rearing.

Dewal is a farm that prioritizes using organic methods to produce their crops. They utilize indigenous seeds, green manure, and organic matter to cultivate their crops. Instead of using chemical fertilizers, farmers use organic matter such as cattle dung, crop residuals, and forest by-

products as manure. They also opt for indigenous seeds that require less water and can thrive in varying climatic conditions. The use of natural organic substances not only enhances the nutritional value of the crops but also reduces health risks (Singh, 2004). As the demand for chemical-free products has increased, people are willing to pay a higher price for products that support sustainable livelihood and strengthen the local economy.

The forest is an important natural resource for rural residents, in addition to agriculture. It provides essential resources such as livestock fodder, fuelwood for cooking, organic farming green manure, and timber for building houses. These resources are vital for the household economy and their absence would significantly reduce the household income. The local population in the forest fringe areas rely on forest products for survival and additional income. Forests also provide a large amount of organic matter, which is used as fertilizer to produce crops. The forest and water systems are closely linked, creating a distinct ecosystem that reduces the risk of water-related hazards, such as landslides, flash floods, and drought. It maintains the hydrological cycle and influences water quality and availability by rejuvenating streams in the region.

Successful agricultural production and food security rely heavily on irrigation, which requires a sufficient amount of water. To support the increasing population, we must cultivate fallow land and implement efficient irrigation facilities. To irrigate their crops, farmers utilize topography and gravity to direct water flow and dig canals called *Guls or kuls* along the contour of the fields. Agricultural practices are part of a larger system that includes crops, livestock, forests, and other natural resources in the region. The agriculture and horticulture sectors employ over 80 per cent of the rural workforce.

Livestock rearing is an important source of income apart from agriculture. Water is an important ingredient needed for sustaining the life of livestock (Prasad et al., 2021). Water scarcity is causing a decrease in pastureland and forest which is the ultimate source of fodder for the animals. As a result, it negatively affects the livestock number. Natural recharge interference caused primarily by deforestation resulted in the drying up of many springs which were the ultimate source of water for people.

Discussion

Water and Health

The quality of water has a significant impact on the health and well-being of individuals. Adequate access to clean water and sanitation facilities plays a crucial role in enhancing work efficiency, education, life expectancy, and social development. Water is an essential resource that we use throughout the day, from morning to night, and life without it is unimaginable. Drinking, washing clothes, and cooking are just a few examples of daily chores that revolve around water. The impact of water quality is even more significant among elderly people and children who are more vulnerable to water-borne diseases. Infants and young children are particularly susceptible to health problems caused by unsafe drinking water, malnutrition, and living in unsanitary conditions.

Livelihood security options and sustainability

The connection between land and water is crucial for sustainable agriculture. Water is essential for maintaining soil moisture and keeping soil healthy, which is necessary for plant growth. Crop failure can occur due to water scarcity, while excess water can cause soil erosion. Local farmers practice terrace farming to reduce soil loss and utilize water more efficiently, leading to increased productivity (Sharma et al., 2001).

Historically, a significant amount of soil has been washed away due to sheet and gully erosion, resulting in a loss of organic matter and essential micro-nutrients needed for crop growth. To ensure sustainable agriculture, a soil conservation and fertility management mechanism is essential (Pandey et al., 2017). Indigenous practices and organic farming can achieve this goal. Dewal, a complete organic block in the Chamoli district of Uttarakhand, embraces organic farming, which emphasizes development without destruction, at the core of sustainable agriculture (Fig 2a). Farmers use organic matter like cattle dung, residuals of crops, and forest by-products as manure instead of chemical fertilizers. They also use indigenous seeds that require less water and can withstand various climatic conditions. Naturally occurring organic substances enhance the nutritional value of crops and reduce health risks (Singh, 2006). Due to the chemical-free nature of organic products,

Figure 2. (A). Sustainable agricultural field. Source: Primary survey, 2020; (B). Livestock and environmental conditions. Source: Primary survey, 2019; (C). Forest areas in Dewal Block, Chamoli. Source: Primary survey, 2019; (D). Local indigenous techniques for water conservation, Source: Primary survey, 2019

the demand for them has increased tremendously, leading to sustainable livelihood generation and strengthening of the local economy.

Irrigation is critical for successful agricultural production and food security. The availability of a sufficient amount of water is vital for crop growth. Cultivation of crops requires varying amounts of water, and with an increasing population, more food is needed to sustain them. Efficient irrigation facilities and wise resource use can increase production despite limited land-carrying capacity (Singh, 2009). Bringing fallow land under cultivation and efficient irrigation facilities can support the increasing population. Excess rainwater harvesting and management techniques can bring more than 60 percent of the area under cultivation through efficient irrigation. Farmers use topography and the flow of water under the influence of gravity for irrigation, digging canals along the contour of the fields to maintain water flow. The farming situation varies within regions with different physiographical and microclimate conditions. Agricultural practices are not seen in isolation but in the totality of crops, livestock, and forest along with the other natural resources of the region. The agriculture and horticulture sectors engage over 80 per cent of the rural workforce (Sati, 2008). Improved accessibility of water to the fields promotes high crop yield and reduces vulnerability against natural calamities like floods and droughts. The expansion of irrigation boosts food security, diversification of crops, and provides environmental sustainability (Khawas, 2004).

The types of crops grown in the area are determined by the traditional knowledge and practices of the indigenous people. These practices include crop rotation, crop diversity, and mixed farming, which help to maintain soil fertility and minimize risks. Farmers rely on indigenous traditional seeds instead of HYV seeds as they are more resilient to variable climatic conditions and heavy rains (Kumar and Rai, 2018). Indigenous crop species, such as Madua, wheat, and ragi, are considered superfoods in the region (Mishra and Rai, 2013) and require less water for growth compared to other crops.

Dewal is an entirely organic area where crops are grown using indigenous seeds, green manure, and organic matter. Forests provide a significant amount of organic matter that is used as fertilizer for crop production. The forest and water regimes are closely linked and create a unique ecosystem that reduces the risk of water-related hazards like landslides, flash floods, and drought. This ecosystem also maintains the hydrological cycle and influences water quality and availability by rejuvenating streams in the region. Apart from agriculture, the forest is a vital natural source of livelihood for rural residents and provides critical resources such as fodder for livestock, fuelwood for cooking, green manure for

organic farming, and timber for building houses. The absence of these resources would significantly reduce household income. The local population living in the fringe areas relies on forest products for survival and sometimes sells them for additional income.

Water resource and their impact on livestock

Livestock rearing is an important source of income apart from agriculture. Animals provide enough organic manure and at the same time, a by-product of crops acts as fodder for animals. Livestock rearing and agriculture support each other. Farmers hardly need chemical fertilizers for their crops. Water is an important ingredient needed for sustaining the life of livestock (Prasad et al., 2021). The consumption of water by livestock depends upon the environmental conditions, body size, pregnancy as well as age and lactation period of animals. In the summer months, animals consume double the amount of water as compared to the winter months. In addition, diet also affects the additional water intake. Large animals like buffalos and cows require more water than goats, sheep, and dogs. The animal that feeds on lush green pasture and grasses requires a little amount of water as compared to that fed on hay or dry leaves (Fig. 2b).

The health and productivity of animals are determined by the amount of quality water they drink. Poor quality of water is not acceptable by the animals and it adversely affects the food intake and subsequently affects the milk production as well as the working capacity of the animals. Water scarcity causes a decrease in pastureland and forest which is the ultimate source of fodder for the animals. As a result, it negatively affects the livestock number. Natural recharge interference caused primarily by deforestation resulted in the drying up of many springs which were the ultimate source of water for people.

Intrinsic relation between water and forest

The forest and water are intrinsically linked with each other. They make a distinct ecosystem that reduces the risk of water-related hazards like a landslide, local floods, and drought; maintains the hydrological cycle, and influences water quality and availability in the region. They also maintain the hydrological cycle and influence water quality and availability in the region. The trees in the landscape adapt to specific soil and water conditions and rely on specific water regimes to survive (Fanteso & Yessoufou, 2022). They also provide resistance to torrential rains, flash floods, and strong currents of water. Endemic species not only support biodiversity but also help nurture, moderate, and maintain river flow while providing food, fodder, and fencing material for communities.

Plants and trees in the forest play a vital role in circulating water, carbon dioxide, and chemicals between the ground and air. They also help maintain the weather pattern of the region. Changes in the forest have caused erratic precipitation, leading to flash floods and drought. The forest-water linkages don't stop there. They also help mitigate the adverse impact of natural hazards like mudflow, landslide, debris-flow, and fight climate change (Fig. 2c).

Forests act as natural purifiers of water and help rejuvenate streams, canals, and Gaderas by improving the natural recharge system of the region. They bring rain through evapotranspiration and cloud formation. The frequency and amount of precipitation determine the type of flora and fauna in the forest. The roots of trees bind the soil, protecting it from erosion and retaining soil moisture. They also bind the rock and protect it from landslides, debris flow, and mud flow. Land use and land cover changes have greatly influenced soil's ability to hold moisture and the overall health of vegetation.

Local indigenous and scientific methods for water conservation

In the study areas, the water harvesting method is used to ensure a consistent supply of water. This is crucial for achieving food security, expanding agriculture through improved irrigation, and creating more livelihood options for the local community (Bandooni, 2004, Acharya, 2011). By producing more grains, vegetables, fruits, and milk, there is better food availability with sufficient nutritional value, which benefits the overall health of the community, especially women who no longer have to travel far to collect water. This provides extra time for family and child care. Additionally, this fosters community participation and cooperation, which is crucial for natural resource management. By balancing resource use and population, the growing demand for resources from an increasing population with changing consumption patterns and modern lifestyles can be met sustainably with minimal environmental impact (Noor & Rai, 2014,

Kumar, 2012). To achieve this, scientific techniques must be combined with traditional knowledge (Joshi, 2016, Mishra et al., 2020). This approach not only boosts productivity, the economy, and livelihood opportunities but also improves the socio-economic condition of the local community and ultimately boosts the economy of Dewal Block. By implementing efficient water harvesting structures, many socio-economic (out-migration, poverty, social inequality) and environmental problems of the region can be solved in one go.

The *Chaal-khal* system is the simplest and most commonly used water conservation method by the locals in the study area. These ponds are usually rectangular or oval in shape and are built on the slopes of mountains. They do not require much effort or skill to construct and are used for livestock rearing and providing water for wild animals. Often, wild animals come to drink water from these reservoirs or *Chaal-khal* system (Fig. 2d). People also create small ponds with various kinds of grasses and trees grown around them to maintain soil moisture for the smooth growth of vegetation. These trees and grassroots prevent soil erosion and protect the pond from filling with eroded soil, mud, or gravel. They also support the local ecosystem and promote mutual existence. In recent years, rectangular cemented ponds have been constructed for rainwater harvesting and storage with the help of government initiatives and local community support (Sultana, 2009). The stored water is used for connected water supply pipelines in each household. However, the high altitude of these structures means that water flows downward under the force of gravity. This sometimes leads to a dirty water supply or an acute shortage of water during dry months. The stored water may also get dirty, making it unsuitable for drinking, as it may contain twigs or leaves along with it in the supply of water (Gulati and Rai, 2015). Water brings twigs or leaves along with it in the supply of water.

KUL/GULS as a Local Technique for Water Conservation Methods

In order to irrigate fields, small canals called Guhls or Kuls are constructed by diverting river or Gaderas water using gravity (Lant, 2020). These canals are built to follow the natural flow of the river and ensure efficient water usage while minimizing soil erosion. Most of the *Guhls* are constructed by the local community by collecting money and local collective effort which are managed by the local people themselves (Rawat & Reeteshsah, 2009, Davis, 1993).

Scientific methods are used to determine the best slope and volume of water to divert, and temporary check dams are built to redirect the water. Mostly these structures are constructed on perennial rivers to get the maximum benefits and use the perennial flow of the rivers (Saxena, 2017). The water is diverted in *Guhls* by building temporary check dams in the stream of the river. Since the high intensity of rainfall is very common with high kinetic energy causing huge surface runoff and damaging the check dams. However, these structures face challenges including the presence of rocks and gravel in the soil, technical issues with the Guhl's head position, and maintenance difficulties (Arora et.al.,2022). They also face the problem of its maintenance. Additionally, conveyance losses and improper field channels can result in high water losses during irrigation. Despite these challenges, Guhls are an effective way to utilize perennial river flow and provide water for agriculture.

Pit technology as a traditional technique of water harvesting

Water harvesting through pit technology is a simple and traditional technique. The process involves digging pits to collect rainwater, which can then be used for various purposes. To prevent soil erosion and maintain storage capacity, grasses are often grown around the pits. The size of the pits depends on the slope gradient of the region, with smaller pits on steep slopes and larger pits on gentle slopes. This technique not only conserves water but also helps retain soil moisture and create a healthy microclimate for the growth of indigenous flora. As a result, the region becomes greener with various trees and grasses growing. The roots of these plants hold water, allowing gradual seepage downslope under the action of gravity. This water can be collected at the valley bottom and used for daily needs (Wang et al., 2022).

Most of these pits are found in village forests with dense vegetative growth. During the rainy season, the water stored in the pits gradually seeps into the ground, recharging the Gadera and small rivulets of the region. The Phaldia village is a prime example, where people still collect water from Gadera/rivulets.

The pit technology, along with traditional water conservation methods, has contributed significantly to the rejuvenation of the Dhara and springs in the area. Respondents from Phaldia have reported that pit-making has made a significant contribution to the rejuvenation of the Dhara and springs, and they no longer have to travel long distances to fetch water. Many seasonal streams have become perennial, solving the problem of daily life (Joshi, 2018, Ramappa et al., 2014). In the past, many of these water sources had dried up, and water was only available seasonally. However, in recent years, they have been rejuvenating at a fast pace, which is a good sign for the prosperity of the region. It would facilitate agricultural development and green grasses for livestock.

Conclusion

The people of Dewal Block, located in Uttarakhand, have always lived in harmony with nature. They rely on natural resources like land, water, forest, and biodiversity for their survival and have deep roots in nature, with their traditions, culture, and way of life closely intertwined with it. The Dewal Block is a higher altitude area of the Himalayas that was initially inaccessible due to geophysical constraints. However, with technological innovation, scientific interventions, and transport development, humans have been able to penetrate the higher altitudes and exploit natural resources such as land, water, and forests for subsistence agriculture.

Water is a crucial natural resource for mountainous people's survival, and women and young girls often have to travel 1.5 to 2 kilometers to fetch water for domestic use, adversely affecting their health and well-being. Most of the people in Dewal Block, Uttarakhand rely on subsistence agriculture and forest products, using natural resources such as water, forest, and land. Subsistence agriculture is characterized by small landholding, limited production, and low productivity, but it is the dominant contributor to the economy and engages the maximum workforce. *Mandua*, wheat, rice, and *chaulai* are the major crops, and vegetables and fruits such as potatoes, Malta, Lemon, and peach are also grown on a large scale. Farmers use traditional inputs like indigenous seeds, green manures, and organic matter, believing in production without destruction of the environment. Organic farming is an emerging agricultural sector that aims to achieve sustainability.

The local community has adopted various traditional and neo-scientific methods to harvest rainwater, such as the *Chal-khal* system, pit technology, and gulls, along with the plantation of broad-leaved trees and oak forests. These techniques are famous in Uttarakhand and have been used for many years. The *Chal-khal* system is rectangular or oval and is primarily constructed for livestock rearing. The pit technology has revolutionized the effective water conservation and management method, along with ecological restoration and rejuvenation of springs and *Gaderas. Guls* are the irrigation canals made by diverting the perennial water source, which has solved the plight of farmers to some extent. Broad-leaved trees and oak forests have played an instrumental role in retaining soil moisture capacity, ecological restoration, and rejuvenating the springs and rivulets. The future of these conservation methods lies in their potential for value addition in economic and ecological terms, addressing the various issues faced by rural people. The overall benefits can be manifested through the increase in forest cover and ecological restoration, along with the rejuvenation of many water sources across the Himalayan landscape. These methods are now being implemented worldwide in the mountainous regions to address the plight of rural people in Uttarakhand, India.

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