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Prioritization of Socio-Ecological Indicators for Adaptation Action in Pauri District of Western Himalaya

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Abstract: Socio-ecological systems have increasingly faced climate-change impacts, which have adversely affected the lives and property of inhabitants. The present study aims to prioritize adaptation actions along an altitudinal gradient (<1200 m asl (Zone A), 1201–1800 m asl (Zone B), and >1801 m asl (Zone C)) in Pauri District, Uttarakhand. A cross-sectional survey research design was employed to prioritize adaptation action from 545 randomly selected households in 91 villages. A multi-disciplinary bottom-up indicator-based approach was applied to identify and normalize sectoral indicators, and PCA was used to prioritize sectoral indicators. Adaptation actions were designed with prioritized sectoral indicators along the altitude and stakeholder consultations. The prioritized indicators varied along the altitudinal gradient, and more than 50% of the indicators for the same sector were different along an altitudinal gradient. Sectoral adaptation planning along the altitude is pertinent in the mountain because they contribute to adaptation planning differently. Additionally, the mainstreaming of adaptation strategies with national and regional development measures is also required. Finally, cross-sectoral resource management that combines users, planners, scientists, and policymakers should be formulated along the altitude within the district. These findings contribute to minimizing the gap between policy/program fabrication and local requirements. The evidence-based valuable knowledge for decision-makers could enable Himalayan communities to adapt to the impacts of climate change effectively. Adaptation planning is also critical for designing adaptation projects for the Green Climate Fund, Adaptation Fund, and funds from multilateral and bilateral agencies. It will facilitate Nationally Determined Contributions, which aims to adapt better to climate change by enhancing investments in development programs in vulnerable sectors.

Keywords: climate change; adaptation; socio-ecological system; Western Himalaya

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1. Introduction

Several changes have been observed in the Himalayan climate [1]. The temperature in the Himalayan region is estimated to be increasing at a rate of 0.06 °C per year [2]. Other projections indicate that the average temperature in the Himalayan region will increase from 0.9 ± 0.6 to 2.6 ± 0.7 °C, a net increase of 1.7–2.2 °C, and there will be a 2–12% increment in rainfall intensity, by 2030 relative to 1970 [1]. The projected rise for parts of India is estimated to be above 3 °C by the 2080s [3]. These changes directly or indirectly affect socio-ecological system components [4]. The direct effects are physiological alterations and a reduction in ecosystem productivity through changes in climatic factors, i.e., temperature, rainfall, etc. [5]. The effect on factors associated with these is the indirect effect [6]. Climate-change impacts vis à vis mountainous specificity (fragility, marginality, and accessibility) pose a substantial risk to the sustenance of Himalayan communities [7,8].

Thus, sectoral vulnerability assessment and subsequent adaptation planning are pertinent, and it seems to be the effective approach to cope with climate-change impacts [9].

Adaptation refers to adjustments in the system to moderate the negative impacts and optimize the positive effects of climate change [10]. Adaptation can be an anticipatory and reactive adaptation, private and public adaptation, or autonomous and planned adaptation [11]. Strategies for adaptation vary with sectors and associated challenges [12]. At the same time, the multifactorial behavior of adaptation and its specificity to geographic location and the local mechanism has been discussed [13], with some emphasizing more improvements than adjustments [14]. Adaptation measures are fundamental to ensuring economic development and are not compromised by climate change [15]. These are sectoral practices, strategies or adjustments to overcome the negative impact of climate change, such as a shift in the production system or change in existing practices relevant to climate change and optimizing the positive effects of climate change.

Developing countries such as India are more vulnerable to climate-change impacts [16]. Implementing adaptation strategies is challenging due to the vast poor rural population, with lesser literacy levels and restricted development. There are several possible approaches to adapting the poor and marginalized communities to climate change. These are advancements in household characteristics (education, income, etc.) [17]; the diversification of agricultural and livelihood systems [18–20]; climate advice [21,22]; crop insurance [23,24]; the access to extension services [25,26]; the access to markets, credit services, farm assets and technologies [27], etc. Resource management (sustainable harvest; conservation; rejuvenation of degraded resources) and the allocation of assets (cash, credits, livestock, and poultry) could be another strategy [28]. This helps them strengthen their adaptive capacity and contribute to their social protection [29,30].

The efforts of the Indian government to combat climate-change impacts are reflected through the constitution of the 'Prime Minister's Council on Climate Change' in 2007 and the early implementation of adaptation policies and programs. India's principal adaptation policy framework is the NAPCC (2008) (eight national missions). It recognizes that effective and appropriate climate-change adaptation and mitigation planning would yield "co-benefits" that could further strengthen the country's overall development objectives [31]. The efforts for adaptation planning have gained new momentum with its inclusion in India's national development agenda. The twelfth five-year plan discussed climate change's adverse impact (2012–2017). Furthermore, the Indian government has also designed several adaptation strategies, such as the distribution of food grains at a highly subsidized rate (PDS); demand-driven employment by constructing productive, durable assets (MGNREGA); concrete dwelling (PMAY); the enhanced and subsidized access to farm inputs (HMNEH, PMKSY and RKVY-RAFTAR); health facilities (CGHS); the afforestation program (NAP and CAMPA); quantitative and qualitative improvement in livestock production systems (RPVY); equitable distribution, conservation, and minimizing the wastage of water (NWM); and many more.

Despite this great effort (policy, program, and strategies), adaptation opportunities are significantly limited in the Indian Himalayan region. Climate-change adaptation in the developmental program could be more effective in the Himalayan states. Adaptation at the local level is the most critical issue, as local factors are the ones that affect the severity of climate change [11]. Limited studies on the scale of climate change, the identification of vulnerable sectors, and the prioritization of adaptation strategies at a district level in Uttarakhand constrain the effective applicability of the adaptation program. Additionally, poor coordination and synergy among institutions; the limited awareness of schemes or programs; weak planning, field operations and appraisal activities; and poor mobility are unexplored co-factors. The inter-district or intra-state inequality in Uttarakhand in terms of development causes a disparity in income, access to resources, and livelihood opportunities. The scattered, small rain-fed agricultural land, poor package of practice, and higher dependency on natural support systems with bad resource management are sentient constraints for holistic mountainous development.

The traditional mountain adaptation practice needs to be improved by the pace of climate change and its impact.

The present study attempts to prioritize indicators from the socio-ecological system that lead to the vulnerability of the mountainous communities. The study identified the most common and determinable sectors, i.e., agriculture, forest, and water, to be considered as socio-ecological systems. Subsequently, actions for adaptation were identified, with the hypothesis that adaptation strategies contribute differently to vulnerability reduction along an altitudinal gradient. To our knowledge, no study has been carried out to investigate sectoral adaptation strategies as a direct response of stakeholders to climatic risks and therefore as means of climate-change adaptation. Many previous studies have focused on adoption as a way to achieve higher productivity, ignoring the need to adapt to new production conditions as dictated by ongoing climatic changes. Strengthening socio-ecological support systems is of prime importance for holistic mountainous development. The conservation of forests through afforestation and sustainable harvest would lead to improved forest health, reduced run-off, and increased percolation. It will ensure improved and long-term water availability. Sufficient water for households and agriculture would ensure food security and a good overall socioeconomic profile. This approach would improve understanding of how climate change affects the socio-ecological support system, what shapes their vulnerabilities, and what assets and facilities they require for adaptation. It enables local priorities to be identified and leads to the design of actions that contribute to adaptation in mountainous settings. We further highlight some gaps and limitations that should be designed before the planning process and that evade the downslides associated with secondary data [32].

Need for the Identification of Adaptation Actions

Sectoral vulnerability assessment is critical for adaptation planning. The assessment must emphasize past and current climate trends instead of prioritizing future climate models. Several Indian states have conducted vulnerability assessments as an essential component of the State Action Plan on Climate Change (SAPCC). The assessment approach and methodology were state-specific and thus were different. Moreover, vulnerability assessment and adaptation planning in IHR states focus on the future rather than the current climate vulnerability. The framework for sectoral adaptation strategies is not clearly outlined; the states planned actions without consulting stakeholders. These studies could not identify and extract the determinants of sectoral vulnerability.

The current vulnerability assessment assists in identifying and ranking the vulnerable sectors, helps to prioritize adaptation action, and highlights subsequent investments. Most importantly, the approach is comparable within the sectors and between the states. The comparable outcomes are helpful for policy/decision makers, implementers, and adaptation funding agencies, to have a common understanding of vulnerability and enable them to assess scales, causes, and actions for vulnerability. It will also help develop adaptation projects for the Climate Investment Funds, Green Climate Fund, Global Environment Facility, Adaptation Fund, and funds from multilateral and bilateral agencies.

The present approach gathers multi-sectoral data, making the assessment of region-specific sectoral indicators possible. The assessment also overcomes multilateral and bilateral agency challenges, such as a need for robust evidence across regions, sectors, and hazards in which data are scattered. It would also be helpful for design-out site-specific monitoring and evaluation mechanisms; further required is evidence to indicate that adaptation planning at the national level is stimulating adaptation planning at the subnational and local level, and information on future trends in national-level adaptation (its nature, scale, and the degree to which plans, strategies, frameworks or laws will be implemented) [33].

It will also facilitate Nationally Determined Contributions, which aim to adapt better to climate change through more investments in climate adaptation programs in vulnerable sectors (agriculture, water resources, health sector) and regions (Himalayan region, coastal regions, etc.). The vulnerability assessment contributes to reporting under the Paris Agreement, Article-9 through the assessment of climate-change impacts and vulnerability; the formulation and implementation of a National Adaptation Plan, including the monitoring and evaluation of adaptation plans, policies, and programs; and the development and implementation of resilience in socio-economic and ecological systems [34].

2. Material and Methods

2.1. Indicators: Selection and Definition

Indicators constitute information that is readily available or can be obtained easily and pragmatically. An indicator has been defined as a variable and measure of system behavior in terms of essential and perceptible attributes [35]. For the present research context, an indicator is a noticeable local variable or a piece of information selected based on its significance for livelihoods, the local economy, conservation, and resource management (availability, accessibility and usability). Initially, 119 indicators were selected for the assessment, but it was reduced to 90 after questionnaire testing and the first level of assessment, i.e., normalization. The indicators representing similar values for the selected altitudes were eliminated.

2.2. Study Area

The study was conducted in the Pauri district of Uttarakhand, India (29°20′–30°15′ N; 78°10′–79°20′ E) with an elevation range from 295 to 3116 m and a land area of 5230 km^2 (FSI, 2019). The district's population is 686,527, with a growth rate of −1.51%. The population density is 129 persons per km^2, and the sex ratio is 1103 females per 1000 males. The literacy rate in the district is 82.59% (males 93.18%, females 73.26%), compared with 74.04% nationally in India (males 82.14%, females 65.46%) (Census of India, 2011). The region has a sub-temperate to temperate climate, with a mean annual temperature of 25–30 °C (45 °C in June and 1.3 °C in January) and mean annual rainfall of 2180 mm, with over 90% of precipitation falling in the monsoon period (July–September) [36].

The topography of the district is mountainous. The cross-section of fluvial valleys displays a convex form, with steep valley sides, interlocking spurs descending towards the main channel and terraced agricultural fields on gentle slopes on the valley sides. Among the local people, known as Garhwali, most primarily engage in agriculture and have a high dependency on forest resources. Mountainous terrain, water scarcity, and highly labor-intensive work are significant agricultural constraints. The occurrence of diverse topographical and orographic features has resulted in remarkable regional biodiversity, with 61.72% of the area under forest cover [37]. The map of study area is presented below (Figure 1).

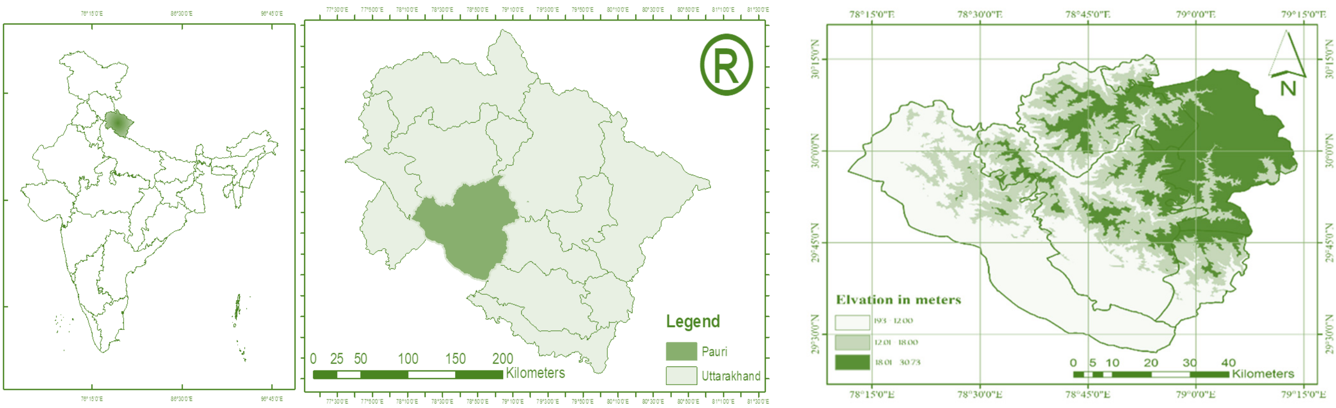

Figure 1. Digital elevation model of Pauri District in Uttarakhand, India, showing the location of the study site.

2.3. Sampling Strategies

Inter and intra-structural indicators of vulnerability and resilience assessment were compared in this study, especially the dynamics of natural-resource land utilization patterns. Lack of access to basic facilities such as schools, hospitals, and markets are other prominent causes of concern in the region [7]. The district was categorized into three zones: Zone A (<1200 m asl), Zone B (1201–1800 m asl), and Zone C (>1801 m asl) (Figure 1). Villages were selected based on three criteria: (a) dependency on forest (NTFP), (b) engagement in agriculture, and (c) utilizing natural water. Information was obtained through face-to-face interviews using a questionnaire, preferably with the head of households. The heterogeneity of villages was maintained by selecting more villages in each zone. Households in mountainous settings are sparsely distributed and generally engaged in their livelihood activity during the daytime, and thus it is difficult to obtain large samples. A total of 91 villages (30 in Zone A, 32 in Zone B, and 29 in Zone C) were surveyed in the study district. The villages were selected based on villagers' dependency on the forest. To avoid homogeneity in responses, a minimum of five and a maximum of ten respondents from each village were selected for interview. A total of 545 respondents from the three defined altitudinal zones (182 in Zone A, 187 in Zone B, and 176 in Zone C) were interviewed for data collection. The interviews were conducted in Hindi and the local language, with the support of one resident. The questionnaire covered issues and questions about all forms of livelihood capital integrated into the indices used here to determine vulnerability and adaptive capacity.

2.4. Analytical Framework

A bottom-up, indicator-based approach was applied [32]. This approach is helpful for decision-making and prioritizing interventions, as it allows characteristics to be compared [38]. It has been widely used for the assessment of vulnerability [32,39–42], adaptive capacity [43–48], and the fabrication of adaptation proxies [38]. Several prioritization approaches include simulation models, expert judgment, household and key-informant surveys, participatory appraisal, and hybrid methods [49–51]. However, these approaches are inept in providing site-specific action and intervention for adaptation.

The present approach applies the participatory assessment method, which includes a household survey, participatory rural appraisal, and focused group discussion. The information was converted into indicators, normalized, and assorted into components of socio-economic assessment and sectoral assessment (agriculture, water, and forest). Each of the components consists of a site-specific indicator. The indicators for all types of components were identified by the literature specific to the area or similar regions [7,8,52–56], preliminary field surveys and by expert consultation. Primary qualitative data and quantitative data were converted into indicators. The indicators were initially in different units or scales and were normalized based on their functional relationship, e.g., whether output increases with an increase in the value of the indicator (positive relationship; Equation (1)), or decreases with an increase in the value of the indicator (negative relationship; Equation (2)).

$$\text{Index}_{\text{sv\_pos}} = \frac{S_v - S_{\min}}{S_{\max} - S_{\min}} \quad (1)$$

$$\text{Index}_{\text{sv\_neg}} = \frac{S_{\max} - S_v}{S_{\max} - S_{\min}} \quad (2)$$

where S_V is the average value of the indicator at the village level, and $S_{\min}$ and $S_{\max}$ are the minimum and maximum values of the indicator.

The sectoral adaptation prioritization was carried out by identifying 90 socio-environment-specific indicators (Table S1). The indicators directly or indirectly related to climate change and posing impacts on selected sectors were also considered in the assessment. Afterward, the sectoral indicators were prioritized with principle component analysis (PCA) using statistical software, i.e., SPSS-22, with a belief in variables' redundancy. This means some of the variables were correlated with one another, possibly because they were measuring the same construct. PCA was used to analyze the interrelationships among a large number of variables and to explain these variables in terms of a smaller number of variables. It reduces high-dimensional data to a few dimensions. Thus, it could be examined visually.

After prioritization, the findings were shared with academicians, researchers, district-block-level staff, and villagers, and suggested actions were incorporated. A total of twelve (12) discussions, four (4) at each altitude, were organized to share finding with villagers. Three (3) seminars (one at each altitude) were arranged with Government officials, and a final discussion was organized with the Division Forest Officer and other forest department staff. Moreover, seven (7) regional experts (vulnerability and adaptation) were consulted virtually. The prioritized indicators were shared, and altitude-specific sectoral actions were noted. Lastly, the actions were finalized at the regional platform and organized with academicians, researchers, and district administration. A total of eighteen (18) experts (academicians (4), researchers (13), and district administration (1)) participated at a virtual regional platform (Figure 2). A set of sector-specific adaptation actions was finalized and is documented in the result section.

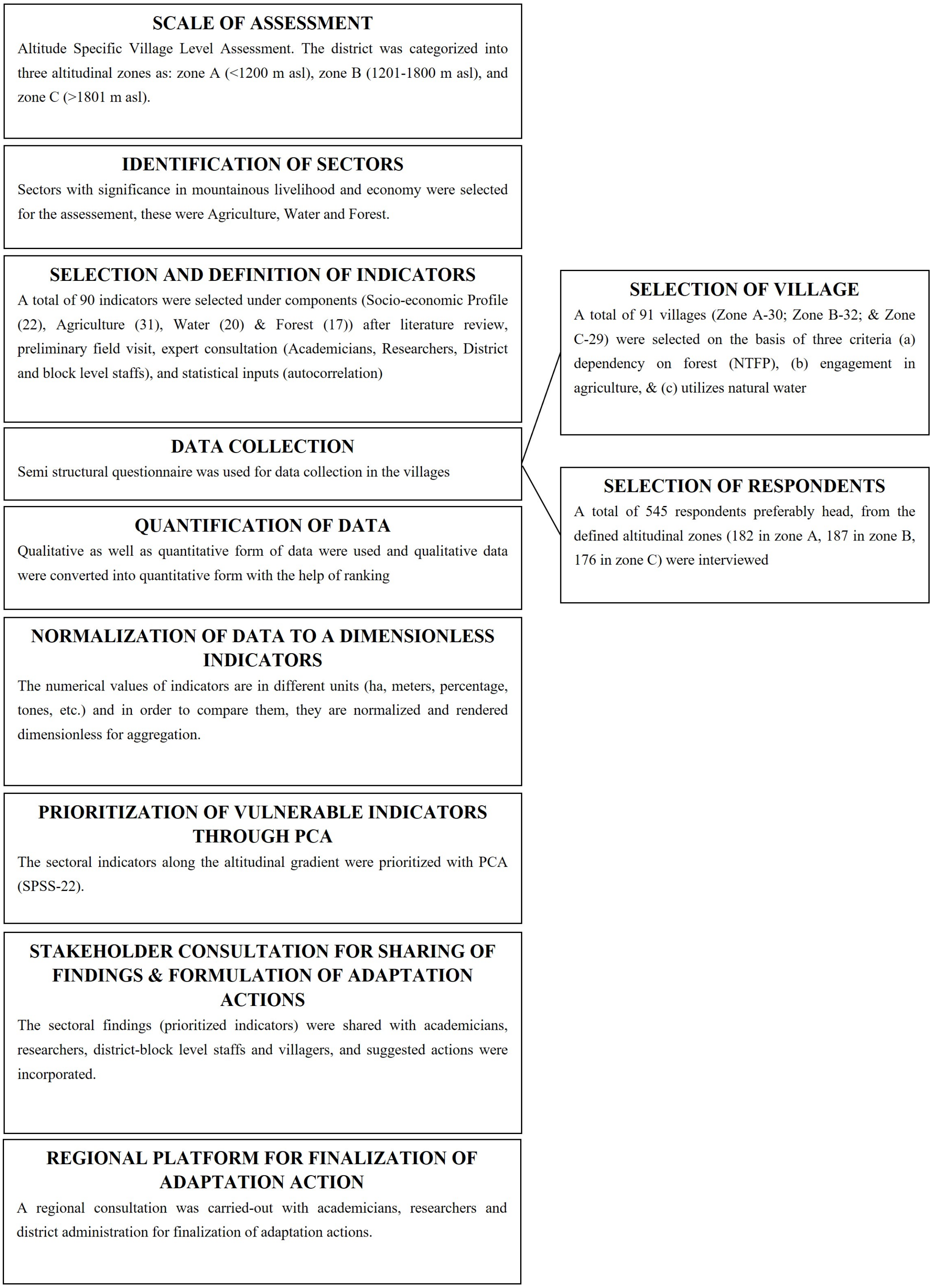

Figure 2. Approach adopted for prioritization of sectoral vulnerability indicators and adaptation actions along the altitudinal gradient.

3. Results

The sectoral adaptation actions along the altitudinal gradient in the Pauri district were designed considering the potential impact of climate change, the sensitivity of the selected sectors, and the capacity to withstand change. Local acceptance, feasibility, and maladaptation were also considered for the maximized yield of planned activity. PCA was used to prioritize drivers of vulnerability, and adaptation actions were finalized after stakeholder consultations. The resulting percentage variance with prioritized indicators is explained in Table 1. The results section is sub-divided into a socio-economic assessment and sectoral assessments. The details of prioritized indicators for socioeconomic, agriculture, water, and forest resources are presented in Tables 2–5.

Table 1. Percentage variance explained, and the number of variables (significant indicators contributing to vulnerability) shown in brackets at an altitudinal gradient of Pauri district.

S. No.	Components	Altitudinal Zones		
		Zone 'A'	Zone 'B'	Zone 'C'
A	Socio-economic Assessment	86% (9)	87% (9)	83% (8)
B	Sectoral Assessments			
B.1	Agriculture	88% (11)	88% (9)	85% (9)
B.2	Water Resources	77% (7)	78% (7)	79% (7)
B.3	Forest Resources	72% (4)	88% (4)	77% (6)

3.1. Socio-Economic Assessment

The Himalayas region faces multifaceted socio-economic challenges, characterized by high poverty and limited access to basic facilities such as healthcare, education, and clean drinking water. Moreover, inadequate infrastructure hinders economic growth and development opportunities. However, the Himalayas also hold great potential for holistic development such as tourism, a rich biodiversity, and a serene forest ecosystem, which can contribute to improving the socio-economic conditions of the region.

For the present assessment, a total of nine socio-economic indicators for Zones 'A' and 'B', and eight indicators for Zone 'C' explained 86%, 87%, and 83% of the variance, respectively. The prioritized indicators for the potential impact of climate change on the socio-economic condition were increased intensity, and the frequency of rainfall (Z A to C-I-1) and increased temperature (ZA-I-2). The exposure to climate change is almost similar for all three zones in the district, and it causes several direct and indirect impacts. Subsistence in the district is restricted by limited livelihood opportunities (ZB-I-5), which led to forced migration in Zones 'A' (ZA-I-3) and 'C' (ZC-I-4), and even skilled migration was reported in Zone 'B' (ZB-I-4) (Table 2). Diversified livelihood opportunity is required for adaptation actions in the district. It will likely reduce migration in the long run.

Access to school and primary health centers is a prioritized indicator for Zones 'A' (ZA-I-4 and 5) and 'C' (ZC-I-5 and 6), and improvements in these indicators are required for adaptation action. Furthermore, access to all-weather roads, markets, and daily information was also limited in Zone 'A' (ZA-I-6 and 7). Most of the area in Zone 'A' was within a radius of 20–40 Kilometer from the market and 60–70 kilometers from the district headquarter. Landslides restricted the access to markets, roads, and daily information. Therefore, landslide management techniques in infrastructure development, especially with roads, need to be integrated. Improved accessibility will strengthen small-market development in the district and should be supported by the government's special package.

Table 2. Prioritized indicators and adaptation actions at socio-economic level at an altitudinal gradient (A–C) in Pauri District.

Zone A	Zone B	Zone C
Prioritized Indicators		
1. Increased intensity and frequency of rainfall. 2. Increased temperature. 3. Migrated member per household. 4. Access to school. 5. Access to primary health center. 6. Access to information. 7. Access to all weather road and market. 8. Acquired help from social network. 9. Accessibility to development assistance (monetary).	1. Increased intensity and frequency of rainfall. 2. Uncertainty in monsoon rainfall. 3. Increased temperature. 4. Migration of skilled members. 5. Livelihood activity or profession of household. 6. Access to school. 7. Acquired help from social networks. 8. Loan repayments. 9. Accessibility to development assistance (monetary).	1. Increased intensity and frequency of rainfall. 2. Decision capability. 3. Dependents per household. 4. Migrated member per household. 5. Access to school. 6. Access to primary health center. 7. Acquired help from social networks. 8. Accessibility to development assistance (monetary).
Adaptation Actions		
1. Diversified livelihood opportunity. 2. Improvements in quality of education 3. Improvements in health sector and access to modern health facilities. 4. Integrate landslide management techniques in infrastructure development, especially with roads. 5. Instigate market development with special packages. 6. Mobilization of social network with involvement of GoU as a stakeholder. 7. Capacity building on policy and program of GoU.	1. Livelihood diversification and enhanced livelihood opportunities for skilled residents. 2. Improvements in quality of education. 3. Mobilization of social network with involvement of GoU as a stakeholder. 4. Sensitization on benefits of loan from banks and loan repayments. 5. Capacity building on policy and program of GoU.	1. Livelihood opportunity for skilled residents. 2. Improvements in quality of education. 3. Improvements in health sector and access to modern health facilities. 4. Mobilization of social network with involvement of GoU as a stakeholder. 5. Capacity building on policy and program of GoU.

The literate males with an age of more than 45 years possess better decision capabilities, and this indicator showed a high score in Zone 'C'. Weak decision capability (ZC-I-2); more dependents per household (ZC-I-3), and attaining help from a social network, i.e., relatives, neighbors, and friends (ZA-I-8; ZB-I-7 and ZC-I-7), were prioritized indicators in Zone 'C'. Mobilizing social networks with the involvement of GoU as a stakeholder is pertinent for long-term social cohesion in the district. Limited awareness and introverted behavior constrict households' access to development assistance in Zone 'A' to 'C' (ZA-I-9; ZB-I-9 and ZC-I-8); thus, the sensitization or building capacity towards existing policies and programs of the Government of Uttarakhand (GoU) is required for adaptation action in the district. The households' access to the bank, the procedure of attaining a loan, and loan-repayment benefits were limited in Zone 'B' (ZB-I-8) (Table 2).

3.2. Sectoral Assessment

Upon gaining a comprehensive understanding of the socio-economic context, the assessment process directs its attention towards sectors that hold significant importance for livelihood, economy, and conservation. By considering these sectors, the assessment aims to delve deeper into the implications of and potential for sectoral adaptation action. Understanding their role in supporting the livelihoods of individuals and communities, evaluating their contribution to the overall economy, and assessing their potential effects on conservation efforts allows for a more holistic understanding of their significance. This approach ensures that the assessment focuses on areas that have the greatest potential to drive positive change, addressing the interplay between economic growth, sustainable livelihoods, and environmental conservation.

3.2.1. Agriculture

A total of 11 indicators in Zone 'A' and 9 in Zone 'B' and Zone 'C' explained 88%, 88%, and 85% of the variance, respectively. The prioritized indicators of exposure to climate change in agriculture sectors were an increased intensity, the frequency of rainfall, and a decreased number of rainy days (ZA-I-1); an increased temperature and related extreme events, e.g., drought, forest fire, etc., (ZA-I-2; ZB-I-1); and an increased February–March temperature (rabi season) (ZA-I-3; ZC-I-1) (Table 3). Increasing temperature, especially during February–March, and intensified rainfall significantly affect the agricultural system in Zones 'A' (ZA-I-3) and 'C' (ZC-I-1). Mountainous fragility is directly proportional to altitude: the higher fragility, the greater the loss. Climate change and fragility augmented the loss and damage of agricultural land and were reported in Zones 'A' to 'C' (ZA-I-4; ZB-I-2 and ZC-I-3). The provision of compensation against the loss of agricultural land must be regularized for adaptation action. The landholdings in the district was as small and scattered, especially in Zones 'B' (ZB-I-3) and 'C' (ZC-I-4); a majority of the households had a small patch of agricultural land. The landholdings in Zone 'A' were comparatively more, with a larger patch of agricultural land, and small agricultural equipment or farm assets (hand tractor, power tiller, motor pump) were required in Zone 'A' (ZA-I-5); hence, improved agricultural equipment at a subsidized rate could be introduced (Table 3).

The possession of livestock is a traditional and integral part of the agricultural system. Most households in the selected zones possess indigenous livestock for economic needs. The households of Zone 'A' possess hybrid livestock (Sahiwal, Red-Sindhi, Tharparkar; tolerate heat stress up to 45–46 °C and yield > 12 litres/day milk), although possession of hybrid livestock and their management was limited in Zones 'B' (ZB-I-11) and 'C' (ZC-I-11). These are well known for their ability to withstand extreme climatic conditions, especially heat tolerance, and disease resistance. The preservation and adoption of these breeds with the following measures could be a viable option for long-term benefits from milk production. Therefore, introducing improved livestock and integrated fodder management is pertinent for adaptation action in Zones 'B' and 'C'. The proposed adaptation action would also reduce the dependency of local communities on forest for grazing and fodder collection.

The district's irrigation shortage was a common issue and was reported with higher priority in Zone 'A' (ZA-I-6). The shortage of irrigation was more pronounced during the rabi season. The irrigation shortage was attributed to the drying of perennial irrigation sources. Conversely, the percentage of area irrigated was a prioritized indicator for Zones 'B' (ZB-I-4) and 'C' (ZC-I-5) and was attributed to topographical constraints: small and scattered land and a lack of techniques to utilize available water (Table 3). This indicates that even with a restricted water source, the proportion of irrigated area is higher in Zone A, which was recorded during the field visit. Thus, the rejuvenation (traditional water sources)-focused adaptation action could be a window of opportunity in the state to harness and optimize irrigation opportunities.

Technological intervention for efficient water utilization is needed in Zones 'A' to 'C', and an improved irrigation system (drip, sprinkler, etc.) is required in Zones 'B' and 'C'. The availability of alternate strategies, such as requesting government support and implementing changes in crops or re-cultivation, was found to be limited in Zone A. Requesting government support, for instance, may have been constrained by complex processes, limited resources, or a lack of awareness about available assistance programs. Similarly, changing crops or engaging in re-cultivation practices might have been restricted due to factors such as soil suitability, market demands, or the availability of necessary resources and expertise. The limitations surrounding these alternate strategies underscore the need for a more nuanced and context-specific approach to address the challenges in the district. Therefore, a comprehensive assessment was undertaken to explore other viable options and to develop tailored solutions to overcome the existing barriers.

Table 3. Prioritized indicators and adaptation actions for agriculture at an altitudinal gradient (A–C) in Pauri District.

Zone A	Zone B	Zone C
Prioritized Indicators		
1. Increased intensity, frequency of rainfall and decreased number of rainy days 2. Increased temperature and related extreme events, e.g., drought, forest fire, etc. 3. Increased February–March temperature (rabi season) 4. Loss of agricultural land 5. Agricultural equipment such as tractors, power tillers, motor pumps 6. Problem in availing irrigation water 7. Alternatives or strategies after irrigation shortage (plant a smaller area, request for government support and changing crop) 8. Climate-resilient crop 9. Cropping intensity 10. Crop rotation and diversification 11. Production per hectare	1. Increased temperature and related extreme events, e.g., drought, forest fire, etc. 2. Loss of agricultural land 3. Scattered agricultural land. 4. Irrigated area (percentage of total) 5. Re-cultivation of crop after loss 6. Climate-resilient crop 7. Crop rotation and diversification 8. Production per hectare 9. Hybrid livestock	1. Increased February–March temperature (rabi season) 2. Accessibility and availability of pesticide/fertilizer 3. Loss of agricultural land 4. Scattered agricultural land 5. Irrigated area (percentage of total) 6. Dependent on agriculture for food 7. Insufficient food from farm, reduced production and crop loss 8. Re-cultivation of crop after loss 9. Hybrid livestock
Adaptation Actions		
1. Small and handy agricultural equipment at highly subsidized rate 2. Technological intervention for efficient water utilization and introduction of improved irrigation system, such as drip irrigation 3. Compensation for loss of agricultural land and weather index-based crop insurance 4. Climate-resilient crop, crop rotation and diversification	1. Technological intervention for efficient water utilization and introduction of improved irrigation system, such as drip irrigation 2. Compensation for loss of agricultural land and weather index-based crop insurance 3. Technical and input support after crop loss 4. Climate-resilient crop, crop rotation and diversification, high-yield livestock and mortality index-based livestock insurance	1. Technological intervention for efficient water utilization and introduction of improved irrigation system, such as drip irrigation 2. Improved access to agricultural inputs 3. Compensation for loss of agricultural land and weather index-based crop insurance 4. Improved access to agricultural inputs 5. High-yield livestock and mortality index-based livestock insurance

The prevalent crop loss due to drought was reported in the selected zones and prioritized in Zone 'A'. The introduction of climate-resilient crops and weather index-based crop insurance was required in this zone. Moreover, there was a high potentiality of increasing cropping intensity in Zone 'A' (ZA-1-9) through availing irrigation facilities and awareness. Crop rotation and diversity are required for agricultural production, and these activities are lacking in Zone 'A' (ZA-I-10) and 'B' (ZB-I-9) (Table 3). Capacity-building through field demonstration is required for adaptation action. Zone 'C's agricultural system is traditional, and households struggle for essential agricultural inputs. The dependency on agriculture was reported as higher in Zone 'C', and most households do not obtain sufficient food from agriculture (ZC-I-8 and 9).

Furthermore, Zone B (ZB-I-5) households generally refrain from re-cultivating or introducing new crops after a loss in the same season. Thus, in addition to agricultural insurance, technical and input support is required for adaptation action. Apart from uncertain climate conditions, the agricultural system of Zone 'C' is considerably constrained by the limited access to basic agricultural inputs (seed, fertilizer, pesticides, farm equipment, etc.) (ZC-I-2). Hence, its accessibility needs to be improved. The average agricultural production (food grains) in the selected zones (12–15 quintals/hectare) was lower than in the plain (20–25 quintals/hectare). It is further decreased due to climate-change impacts, wild-animal raiding, and limited agricultural inputs. This results in a limited income from agriculture, and mountainous communities are shifting from agricultural pursuits. Consequently, several patches of land are left uncultivated. Agricultural production was a prioritized indicator for Zones 'A' (ZA-I-11) and 'B' (ZB-I-8). Climate-smart agriculture practices along with the diversification of farming systems and cropping patterns could enhance the agricultural production in the mountain. Moreover, access to credit and agricultural inputs, capacity building, extension services, and value addition are equally important. These actions are tailored to the sectors and zones, highlighting the local needs of the district. The close collaboration between government agencies, research institutions, extension services, and farmers' organizations, is essential for the successful adoption and scaling up of these strategies.

3.2.2. Water Resources

A total of 77%, 78%, and 79% of the variance was explained by seven indicators in Zone 'A', 'B', and 'C', respectively. The prioritized indicators for Zone 'A' were uncertain, decreased, and intensified rainfall (ZA-I-1), an increased number of extreme climate events (ZA-I-2; ZB-I-1; ZC-I-1), and an increased temperature and drought incidence (ZB-I-2; ZC-I-2). It affects water availability and accessibility. Sufficient water availability was one of the critical challenges in the district, and it was further prevalent during the summer and monsoon seasons in Zones 'A' to 'C' (ZA-I-3; ZB-I-3 and ZC-I-3) (Table 4). Generally, Zone 'C' households receive water for 8–11 months from nearby sources (less than 0.25 KM). During the remaining months, households are forced to travel more than 0.25 to 0.50 KM and spend more time collecting water. Thus, the rejuvenation of traditional water sources and their maintenance is needed for adaptation in the district. The households do not receive sufficient water throughout the year, especially during the summer and monsoon seasons, due to inaccessible water sources in Zone 'B' (ZB-I-4) (Table 4). Moreover, households in Zone 'C' (ZC-I-4) were forced to travel >500 m for water collection during the water-scarce season (summer and monsoon seasons). Thus, conserving excess seasonal water or rainwater harvesting was required in the district for long-term water availability.

Water scarcity was also reported in Zone 'A', especially during summer, due to seasonal drying and perennial water sources (ZA-I-5). Dried water sources (ZA-I-4) were also reported in this zone with high priority. Springshed development with wider geographical distribution could be an effective opportunity to strengthen adaptation in the district. The pumping/lifting of water from distant sources together with extreme events, especially landslides, hinders the water supply, and sometimes also affects the water sources in Zones 'B' (ZB-I-5) and 'C' (ZC-I-5) (Table 4). It causes the regular breakage and blockage of pipelines and hinders water supply for household purposes in Zones 'A' (ZA-I-6) and 'C' (ZC-I-6). Thus, proper maintenance of the water-supply system and strategies for alternatives, such as tankers, handpump, water ATM, etc., must be regularized with special packages. The reduction in water quality was reported as a prioritized issue in Zone 'A' (ZA-I-7) and 'B' (ZB-I-7) (Table 4). Reduced water quality, scarcity, and limited hygiene led to water-borne diseases in Zone 'A' (ZA-I-7). Thus, the qualitative monitoring of the public water-supply system and the introduction of a locally accepted low-cost purification system in Zones 'A' and 'B' is needed. Moreover, the awareness of villagers and the establishment of a cadre of local youth could be an essential adaptation opportunity for constant water-quality monitoring (Table 4).

Table 4. Prioritized indicators and adaptation actions for water resources at Pauri district's altitudinal gradient (A–C).

Zone A	Zone B	Zone C
Prioritized Indicators		
1. Uncertain, decreased, and intensified rainfall. 2. Increased number of extreme climatic events. 3. Water scarcity. 4. Dried water source (10 years). 5. Sources of drinking water during summer. 6. Limited supply during extreme events. 7. Deterioration in water quality and water-borne disease.	1. Increased number of extreme climatic events. 2. Increased temperature and drought incidence. 3. Water scarcity. 4. Inaccessibility to sufficient water source. 5. Effect on water source due to extreme events. 6. Time required for water collection (minutes). 7. Deterioration in water quality and water-borne disease.	1. Increased number of extreme climatic events. 2. Increased temperature and drought incidence. 3. Water scarcity. 4. Drinking-water availability in proximity (<500 m). 5. Effect on water source due to extreme events. 6. Limited supply during extreme events. 7. Variation in water quality in last 10 years.
Adaptation Actions		
1. Rejuvenation and maintenance of traditional water source and spring shed development. 2. Conservation of seasonal excess water or rainwater harvesting. 3. Constant qualitative monitoring of supply water.	1. Constant qualitative monitoring and technological intervention for doorstep water supply. 2. Regular maintenance of traditional water sources. 3. Conservation of seasonal excess water or rainwater harvesting.	1. Technological intervention for doorstep water supply. 2. Regular maintenance of traditional water sources. 3. Conservation of seasonal excess water or rainwater harvesting.

3.2.3. Forest Resources

In total, 72%, 88%, and 77% of the variance were explained by four, four, and six indicators in Zone 'A', 'B', and 'C', respectively. The direct exposure of the forest ecosystem to climate change was a temperature rise, and the same was reported in Zones 'A' (ZA-I-1) and 'C' (ZC-I-1) (Table 5). Zone 'A' households depend on the forest for fodder and fuelwood (ZA-I-3). The households in this zone lack alternatives for fodder and strategies against fodder scarcity (ZA-I-4). The households of Zone 'B' also depend on the forest for fodder and fuelwood, and even after investing comparatively more time (ZB-I-3), they did not receive sufficient fodder or fuelwood (ZB-I-2). Contrastingly, the households of Zone 'C' receive sufficient fodder and fuelwood from the forest but invest more time (ZC-I-2) and travel a further distance (ZC-I-3). Thus, agroforestry practices and establishing a fodder bank were suggested in Zone 'A'. While a community center afforestation program with demand-oriented multipurpose tree species was recommended in Zone 'B' and 'C'. Additionally, alternatives to fodder were limited (ZC-I-6), and the unsustainable and unregulated harvest of NTFPs (especially MAPs) (ZC-I-5) was reported in Zone 'C'. Thus, the community must be trained for the sustainable and regulated harvest of NTFPs, and essential support (training, demonstration, inputs, market, etc.) needs to be provided from GoU for cultivation. A high anthropogenic pressure with substantial forest degradation was reported in the district. The limited regeneration (ZB-I-4) was reported in Zone 'B' due to the dominance of pine forests.

Table 5. Prioritized indicators and adaptation actions for forest resources at an altitudinal gradient (A–C) in Pauri district.

Zone A	Zone B	Zone C
Prioritized Indicators		
1. Increase in summer temperature. 2. Increased frequency of forest fire. 3. Fodder and fuel wood collection. 4. Alternative of fodder during fodder scarcity (cultivation of fodder, use previously stored fodder or use of more straw).	1. Increased forest-fire intensity. 2. Sufficient fodder and fuel-wood. 3. More time spent for collection of fodder and fuelwood. 4. Regeneration.	1. Increase in summer temperature. 2. More time spent for collection of fodder and fuelwood. 3. More distance travelled for collection of fodder and fuel-wood. 4. Dependent on natural water source. 5. NTFP collection. 6. Alternative of fodder during fodder scarcity (cultivation of fodder, use previously stored fodder or use of more straw).
Adaptation Actions		
1. Fire monitoring, warning, and management techniques. 2. Agroforestry practices with demand-oriented species. 3. Establishment of fodder bank on barren/uncultivated/panchayat land.	1. Fire monitoring, warning, and management techniques. 2. Community-centered afforestation program.	1. Community-centered afforestation program. 2. Orientation on sustainable harvest of NTFPs. 3. Strengthening of local institutions and market value chain. 4. Technical and initial support for cultivation of NTFPs.

Forest fire incidences were another prioritized issue in Zones 'A' (ZA-I-2) and 'B' (ZC-I-1). It was also noted that the majority of forest fires were intentional. The dominance of pines in Zones 'A' and 'B' also instigates forest fires. The acidic pine needles inhibit the production of grasses, and hence the villagers burn them. Therefore, fire-management techniques and innovative approaches for monitoring and warning must be required, and they should be included in the policy of GoU. The overall anthropogenic activities not only degrade forests but also deteriorate their services. The forest degradation and reduction in services, especially continuous water supply and purification, were reduced substantially in Zone 'C'. However, most of the households in Zone 'C' depend on natural water sources (ZC-I-4) (Table 5). The higher dependency on the deteriorating ecosystem also augments the vulnerability of households and forests.

4. Discussions

Adaptation or modification can reduce vulnerability to a certain extent. Identifying adaptation opportunities and the need to be more supportive of framing adaptation policies will be challenging. Thus, the identification of sectoral and site-specific adaptation opportunities is crucial. This needs to include adaptation or modifications in characteristics or behavior to better cope with existing or anticipated changes attributed to several direct and indirect factors. The inclusion of economic and social benefits, cultural acceptance and social feasibility, consistency with development objectives, and environmental impacts and spillover effects in adaptation measures were emphasized by Leary et al. [57]. At the same time, the need for strong governance in vulnerability reduction has been highlighted [58].

It is not necessarily the most exposed system that is the most vulnerable; highly sensitive systems and systems with lower adaptive capacity might be more vulnerable. The vulnerability depends on the system's capacity (internal and external) to modify its characteristics with change and/or the availability of adaptation opportunities [59]. Exposure to climate change is similar between all three zones in the district, but the sectoral responses to exposure are different. The major factors of climate exposure in the districts are temperature and rainfall. The climate variation in the district was identified by Jha et al. [60], who emphasized an overall increase in annual temperature (mean, maximum, and minimum) and decreasing trends in rainfall and the number of rainy days in the period of 1985–2015.

Climate change and mountainous fragility augment the damage caused by extreme events, especially landslides. Natural support systems are more vulnerable to climate change. Climate-change impacts are greater on forests; at the same time, forests are considered an adaptation tool for mountainous people [10]. The dependence of vulnerable people (poor and marginalized) on vulnerable ecosystems strains the district's livelihood.

4.1. Accessibility

Access to facilities, especially developmental and infrastructural, constricts the external capacity of people for adaptation. Access to education, health, road, information, and markets in Zone 'A'; access to schools in Zone 'B', and access to schools and health centers in Zone 'C' were the prioritized requirements for socio-economic development. These indicators contribute differently to the selected district's vulnerability and are collectively required in different combinations at an altitudinal gradient for adaptation. The improved access to facilities improves skill and capability levels and strengthens the local economy. The role of education is also of great importance in adaptation [61], and its limited accessibility in the villages of the Pauri district [7,8].

4.2. Livelihood Skill and Social Network

The limited livelihood opportunities in the district act as a major driver for migration. With limited income-generating avenues and few prospects for sustainable employment, individuals and families are compelled to seek better opportunities elsewhere. This migration, driven by the quest for improved livelihoods, can have significant social and economic implications for both the migrants and the district, including changes in demographics, strains on infrastructure and services, and the potential loss of local workforce and skills. Thus, year-round diversified livelihood opportunities are required in all zones. Livelihood opportunities for unskilled households is required in Zones 'A' to 'C', while livelihood opportunities for skilled households is required in Zone 'B'. Migration in Uttarakhand from hilly district to plains is the reason for structural transformation. The limited livelihood opportunities or income-generation activities at a local level resulted in significant outmigration. The diversified livelihood opportunity could reduce migration and strengthen the decision capability of the household in Zone 'C'. Livelihood diversification, particularly engaging in non-farm sectors, has been an important adaptation strategy, and is evident in north-central Peru [62], Tibet, China [63] and Mustang (Nepal) [64].

Moreover, adaptation is strengthened by access to information, credit [17,25], and social networking [65]; these are of great importance in adaptation planning. The social network in all three selected zones is good and should be appropriately mobilized through an awareness program. Livelihood generation with a higher participation of local people and the optimum utilization of social networks could also be an opportunity for adaptation. The collective measures will maximize benefits and minimize losses. The approach would be more effective with the involvement of the local government as a stakeholder.

4.3. Sensitization on Governance

The capacity building or sensitization of households in attaining government assistance, along with the efficient implementation of programs and schemes of the state and central government, should be initiated in the least-possible time throughout the district. The support of the government in the rural development program for adaptation has been widely discussed by the scientific community [40]. It is an important adaptation option under changing climatic scenarios [66]. Better access to the above-mentioned site-specific facilities in the district will certainly reduce migration, which arises from limited livelihood opportunities and access to facilities.

4.4. Agricultural Transition

Adaptation opportunities for the agricultural sector are diverse: improvements in the existing production system with better access to facilities; a change in sowing and planting time; updated extension services; innovative technological intervention (irrigation system, intercultural operation, etc.), and the enhancement of agrobiodiversity and agroforestry/shelterbelt. The next opportunity is shifting the production system according to climate suitability.

It includes cultivating new climate-adapted crops and varieties, genetically modified crops and protected cultivation. However, it is practically tough to identify and analyze agricultural adaptation opportunities because of the site-specificity and climate suitability of agricultural crops [67]. A study undertaken in Malawi highlighted that the majority of farmers (85%) undertook adaptation measures because of the exposure to climate risk [68]. Landholdings in the study zones were small and scattered. Optimizing land utilization through technological development was required in Zones 'B' and 'C', and the introduction of farm equipment was pertinent for Zone 'A'. Similarly, technologies and farm assets are important components of the adaptation to climate change in Africa [27]. Furthermore, the agricultural land in the district was highly vulnerable to climate change. Thus, economically feasible and socially accepted technological interventions are required to reduce the loss of agricultural land and provide compensation for losses, which are prioritized adaptation opportunities in the study area.

The households also need technical knowledge on land and crop management, the enhancement of production systems, and support with re-cultivation after the loss of crops (especially in Zone 'C'). Better knowledge of maintaining soil fertility and enhancing production through crop diversification, rotation, and specific climate advice is needed in Zones 'A' and 'B'. Farmers need to be trained for site-specific integrated nutrient management; interventions for improving nutrient-use efficiency; green manuring; and the adoption of legumes in a cropping system, and/or legumes with other main crops in alternate rows or mixed. This practice improves nitrogen supply, soil quality, and overall health [69]. The overall activities and strategic agricultural planning under the local climate will enhance agricultural production, which is required in Zones 'A' and 'B'.

Moreover, access to agricultural inputs must be enhanced in Zone 'C' through the improved distribution of information from the district's agricultural department and other agencies, including subsidies for seed-fertilizer shops and improved extension services. Access to farm support and extension services are important tools for adaptation in Kenya [21]. Strategies for the availability of irrigation are required in Zone 'A' together with irrigation accessibility for Zones 'B' and 'C'. Improved access to irrigation through technological interventions for efficient water utilization is pertinent in Zones 'B' and 'C', and natural-spring renovation or rejuvenation is required in Zone 'A'. Moreover, rainwater harvesting, optimum water utilization through applying water directly to the root zone (drip irrigation), and uniform agricultural land leveling for even water distribution should also be ensured for climate adaptation [21].

Climate change has a significant impact on livestock, and studies [70] have reported that it could increase the prevalence of diseases and reduce livestock production in mountainous regions. Its impacts on indigenous breeds are slightly lower compared to other breeds. In households, indigenous livestock are kept primarily for economic needs [71], while the possession and management of high-yield livestock are limited at higher altitudes. The high-yield livestock could be introduced initially as a pilot program, and, further to this, the tested and learned model could be replicated throughout Zones 'B' and 'C'. High-yielding livestock fulfills the requirement of nutritious food and contributes to the household's income significantly. This will be a potential livelihood opportunity, strengthening economic status and reducing the pressure on forests. Possessing livelihood assets or facilities and their appropriate and efficient utilization is important to adaptation [72].

The proposed adaptation action will promote agriculture as an engine for pro-poor economic growth in the long run. Improvements in the agricultural calendar, agrobiodiversity, and traditionally adapted and new climate-resilient crops will strengthen production and agricultural insurance, minimizing losses. A socially accepted and scientifically proven reactionary adaptation is adjustments to crops and cropping patterns. Furthermore, the adoption of drought-resistant crops such as buckwheat (Nepal), climate resilient agriculture in Bihar (India), and the cultivation of vegetables in Sikkim (India) and Mustang (Nepal) [62] are proven strategies for adaptation.

The farmers should be sensitized to scientific agricultural practice by integrating horticulture, forestry, animal husbandry, the silvi-pastoral system, etc. It will further contribute towards a surplus of agriculture from subsistence. Additionally, rationalized extension services aiming to support farmers with innovative interventions (scientific and technical), the exchange of experiences (farmers, Krishi Vigyan Kendra, research institutions, etc.), and strong market services will enhance agricultural productivity, food security, and investments in agriculture.

4.5. Water Wealth and Reserve

The impacts of climate change on water resources are expected to worsen [73]. More extreme precipitation events will lead to more surface runoff and less groundwater recharge, resulting in more floods [74]. The rise in temperature causes more water loss with higher demand [75]. This shrinking monsoon and a temperature rise, resulting in the drying up of natural springs and the declining base flow of streams, has been recently reported in the western Himalaya [76] Darjeeling hills (India) [77]. Most water sources in the district dried during summer, and households were forced to travel more than 500 m to collect drinking water in Zone ‘A’. Sufficient water availability, especially for summer, should be improved, and the developmental policies must prioritize the regular maintenance of water sources. Strategies for water availability are required in Zone ‘A’, and accessibility should be prioritized for Zones ‘B’ and ‘C’. Tambe et al. [78] emphasized that catchment degradation has been the prominent cause for the drying up of the springs, which restricts water availability, especially during summer.

The socially accepted technological advancement of ancient sources with efficient water-saving technologies, rainwater harvesting, water storage tanks, and the rejuvenation of traditional water sources was vital for adaptations to climate change in Zone ‘A’. Rebuilding and re-using ancient water sources with a wider geographical distribution and better future dynamics, even with high investment, could be capital-intensive.

Additionally, the doorstep water supply system should be strengthened, and government officials in the selected zones should ensure special provisions for movable tankers. Supporting the water-supply systems by different means, such as an increased water supply by greater water extraction from rivers, springs, and the storage of excess seasonal water in large reservoirs with the minimum utilization of groundwater, will enhance long-term water availability and its sustainability in Zones ‘B’ and ‘C’. The drying of springs was also reported by others [79]. Climate change, along with forest degradation and unplanned infrastructural development, causes deterioration in water quality, and the above challenges lead to more time spent on water collection. The perennial water sources were less accessible in Zone ‘C’, and households did not get sufficient water throughout the year. Moreover, a variation in water quality was reported in Zone ‘C’, and deterioration was reported in Zones ‘A’ and ‘B’. Thus, the qualitative monitoring of the public water supply system, awareness of water quality, development of a low-cost water purification system, development of a cadre of trained personnel in water management (qualitative and quantitative), and a mechanism for inspection need to be developed in Zones ‘A’ and ‘B’ with the involvement of administration, academia, NGOs and local communities.

Innovative approaches with technical modernization and the facilitation of site-specific adaptation options are vital for water resource management in the Pauri district. Water supply and distribution systems require high capital investment and regular maintenance in Zones ‘B’ and ‘C’. Additionally, an innovative and sustainable decision support system related to climate-change adaptation measures, for a secure supply of drinking water, is vital in the district. Additionally, there is a huge potential for nature-based local-level water conservation measures such as watershed or spring-shed management [80,81] and the rejuvenation of water sources with a technologically sound approach.

4.6. Natural Resources

Forests are highly sensitive ecosystems and indispensable repositories of flora and fauna. The ecosystem is vital for the uninterrupted supply of ecological services. It is socially and economically associated with people and is considered one of the major determinants of the socioeconomic structure. A large section of mountainous populations heavily depend on forests for daily necessities, and this causes substantial anthropogenic pressure. This is similar to previous studies that have stated that adaptation in the forestry sector is crucial since local communities heavily rely on forests for their livelihood [36].

The households did not get sufficient fodder and fuelwood even after devoting more time to it. Additionally, households need more alternatives to fodder and fuelwood. Thus, the recent drivers of deforestation must be identified, and sustainable forest-management practices should be applied. A community-centered afforestation program with site-specific and climate-adapted multi-species needs to be initiated, with protective measures for species-rich ecosystems. It will not only restore forests but also support the requirement of fodder and fuelwood. To reduce the dependency on the forest, establishing a fodder bank and upgrading energy consumption patterns (improved smokeless chulha, solar cookers, pine bricks, etc.) in Zones 'A' and 'B' should be supported. Agroforestry practices emphasizing fast-growing demand-oriented local tree species in Zone 'A' also have a high potential for reducing the gap between demand and supply. Upgraded fodder storage techniques (hay and silage) are required in the selected zones, especially in Zone 'C'.

Pauri is among the most fire-affected districts, and approximately 38% of forest fires in the state are reported in the district. The highest incidence of forest fires, i.e., 712, were recorded in the Kotdwar block of Garhwal Himalaya [82]. The majority were human-induced, especially to promote fodder collection. The introduction of management techniques, such as thinning, selective cutting, prescribed burning, fire lining, the collection of pine needles and the production of pine briskets, collective measures such as the formulation of a forest protection committee, and MMD/YMD for forest conservation, is required. Moreover, introducing innovative approaches for fire monitoring and warning, effective tools and techniques to deal with forest fires, and awareness programs for villagers and frontline forest staff could reduce the incidence and losses due to forest fires. This adaptation strategy should be devised using an adequate monitoring system with site-specific indicators. The zonation of forests as per their susceptibility to fire must be carried out, and anthropogenic activities such collection of saplings, barks, branches, leaves, etc., and other related resources should be banned in the highly susceptible forests during fire season.

The unsustainable harvest of NTFPs (especially MAPs) was reported in Zone 'C'. Thus, an orientation on sustainable NTFP harvesting (parts, collection time and quantity); technical and infrastructural support for the cultivation of MAPs; the strengthening of local institutions (Van Panchayat, BMC, etc.); and an improved market value chain would promote a sustainable harvest and facilitate the cultivation of MAPs. Furthermore, programs need to be initiated with an improved PoP and awareness of subsidized SMPB, CAP, HDRI, etc. A sustainable harvest reduces anthropogenic pressure, maintains the health of forests, and strengthens the households' income basket.

This study attempted to analyze adaptation opportunities in the mountains and provide a strong tool to assist decision-makers in identifying the need to cope with climate-change impacts. The adaptation opportunity must be learned through a vulnerability-assessment process with detailed explanations on capturing and quantifying the multiple dimensions [83]. Furthermore, the sectoral contribution to vulnerability must be quantified with site-specificity. Finally, the ability or capability of natural systems to accept changes and adjust to the changing climate must be studied for successful adaptation planning.

5. Conclusions

Climate change is real, and its impact on natural support systems is high. Contrastingly, the pace of adaptation is much lower. Thus, planned or anticipatory adaptation is pertinent to minimize the negative impacts of climate change. The development of adaptation strategies must be identified after extensive vulnerability-assessment exercises, including sectoral challenges. Sectors should be selected after consultation with local people and government officials, and grass-root-level learning. Due to differences in research objectives, perceptions of researchers, and site-specificity, the literature can only be used to select indicators to a certain extent.

The exposure to climate change is very similar for all three zones but varies with sector, and it caused several direct and indirect impacts. Zone 'C's households feel a slightly higher exposure; this might be attributed to fragility, instability, and proximity to natural resources. Diversified livelihood opportunity is required in the district, and more opportunities for skilled households is needed to reduce migration. Infrastructural development for education and improved health facilities is required in all zones.

The mountainous agriculture system needs to be strengthened with innovative, socially acceptable, and economically viable approaches, such as climate-resilient agricultural systems with technological interventions for reducing loss, and access to irrigation. Additionally, efficient land utilization, capacity building for strategic cultivation, and the exploration of the market value chain are needed for sustainable agricultural development. Sustainable water management, especially rainwater harvesting, the rejuvenation of traditional water sources, the qualitative monitoring of public water-supply system, the development of low-cost water purification systems, constant doorstep water supply, a cadre of personnel trained in water management (qualitative and quantitative), and mechanisms for inspection, must be developed with the involvement of administration, academia, NGOs and local communities. There is an urgent need to identify the drivers of deforestation along the altitudinal gradient. The community-centered multi-species afforestation and fire monitoring program, agro-forestry and the concept of fodder banks could be important climate change mitigation strategies and should be introduced rapidly. This will not only maintain the health of the forest but also strengthen household income in the long run.

Sectoral adaptation planning along the altitudinal gradient is pertinent in the mountain because they contribute to vulnerability reduction differently. The research is applicable to mountainous settings having a similar socio-ecological system or settings with a higher dependence on a system. A few short-term adaptation strategies must be implemented in the least possible time to respond to climate change and long-term sectoral strategies will be devised carefully. Mainstreaming adaptation strategies with national development measures is better than formulating a climate-specific adaptation program. In coordination with regional and national institutions, the local institutions need to step up their efforts to enable people to benefit from adaptation opportunities and access planting material and knowledge. Finally, cross-sectoral planning is also required for resource management that combines users, planners, scientists, and policymakers. This will strengthen local people's capacity to withstand climate-change impacts.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/world4030025/s1, Table S1: Components of socio-ecological system, dimension of vulnerability with respective indices, indicators, explanations and indicator value (sector and altitude specific prioritized indicators for vulnerability is highlighted).

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